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Efficacy of Pre and Post Emergent Herbicides for Weed Management in Maize (*Zea mays* L.)

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Authors Contribution

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Abstract

A field experiment was carried out at College of Agriculture, V.C. Farm, Mandya during *kharif* 2021 to study the efficacy of pre and post emergent herbicides for weed management in maize (*Zea mays* L.). The experiment was laid out in Randomized Complete Block Design (RCBD) with fourteen treatments and replicated thrice. The treatments comprised of sole and combined application of pre-emergence herbicides (atrazine and pendimethalin) at 3 days after sowing and post emergence herbicides (2,4-D, topramezone and tembotrione) at 3-4 weed leaf stages were compared with two hand weedings (at 20 and 40 DAS), weed free check and unweeded check. Among chemical weed management practices, application of atrazine (50% WP) @ 1 kg a.i. ha^{-1} as pre-emergence at 3 DAS followed by topramezone (33.6% SC) @ 50 g a.i. ha^{-1} as post emergence application at 3-4 weed leaf stages recorded significantly lower total weed density (2.61, 2.34 and 4.26 no. 0.25 m-2 at 20, 40 DAS and at harvest, respectively) and lower total weed dry weight (0.90, 1.31 and 1.49 g. 0.25 m-2 at 20, 40 DAS and at harvest, respectively) with weed control efficiency of 70.4 per cent and weed index of 1.5 per cent at harvest. The same treatment recorded higher kernel yield (11469 kg ha^{-1}), stover yield (13542 kg ha^{-1}), net monetary returns (Rs.132141 ha^{-1}) and B:C ratio (3.47). Hence, it was found to be suitable and economical for effective control of weeds in maize.

Keywords : Pre and post emergent herbicides, Chemical weed management, Weed density and weed dry weight

Maize (*Zea mays* L.) is the third most important cereal crop in the world, both by area and production after rice and wheat. It gives an average kernel yield of 4.1 tons ha^{-1} compared to other major cereals such as rice (3.7 tons ha^{-1}), wheat (2.5 tons ha^{-1}) and millets (1.2 tons ha^{-1}) (Panda, 2010). Further, it is a staple food for the poor in most of the developing countries and provides about 30 per cent of food calories for more than 4.5 billion people.

Globally it is cultivated extensively in an area of about 201 m-ha with a production of 1162 mt and productivity of 5.75 t ha^{-1} (Anonymous, 2020). Among different countries, USA stands first in terms of area and production followed by China whereas, India stands fourth position cultivated in an area of 9.89 m ha and seventh position in production (31.64 mt) with an average productivity of 3.20 t ha^{-1} (Anonymous, 2021). In Karnataka, it is cultivated in an area of 1.72 m ha with a production and productivity of 5.36 mt and 3.11 t ha^{-1}, respectively (Anonymous, 2021). Karnataka ranks first among all other maize growing states of India.

Even though kernel yield has been increased in maize crop with the help of new improved varieties and hybrids, there are number of constraints for its growth and development. Weed menace is one among them which is affecting maize production. Maize is highly vulnerable for weed competition, mainly because of higher amount of fertilizer application, wider spacing and initial slow growth.

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The critical period of weed competition is more during initial 2 to 6 weeks after sowing. This shows the importance of maintaining the fields in weed free condition during this critical period of weed competition. The extent of reduction in kernel yield of maize has been reported to be in the range of 33 to 50 per cent depending on the intensity and persistence of weed density in standing crop (Sharma *et al*., 2000). Therefore, to ensure optimum kernel yield of maize, weed management is an important practice

Management of weeds during the critical period is of greater importance for realizing higher yield. Though hand weeding is effective, it is expensive and heavy demand for labour during peak period and its scarcity necessitates the use of herbicides as a method of control for suppressing the weeds in the early stages of crop growth.

Maize, which is a widely spaced crop, is infested with a wide variety of weeds and subject to intense weed competition, often causing huge yield losses of 28 to 100 per cent (Patel *et al*., 2006). There are very few herbicide options available for weed management in maize crop in India. Currently, herbicides used for weed management in maize includes atrazine, simazine, pendimethalin, alachlor and post-emergence use of 2, 4-D. Most of these herbicides provide only a narrow spectrum of weed control in maize (Patel *et al*., 2006).

Non-availability and higher wages of manual labour also comes in the way of timely weed management in maize. Weed management by mechanical means is feasible only when crop grows up to certain stage and crop needs to contend with weeds until such period. But herbicides play a significant role in managing weeds in such a situation. The most common and effective pre-emergence herbicide used in maize is atrazine but it is not effective for controlling broad leaved weeds. Hence, in order to manage this composite and vigorous weed flora during later stages of crop growth, sequential application of pre and post emergence herbicides needs to be assessed.

Material and Methods

The field experiment was conducted at College of Agriculture, V. C. Farm, Mandya. The site was coming under the region III and Agro Climatic Zone-6, Southern Dry Zone of Karnataka. It is situated between 12º 45' and 30º 57' North latitude and 76º 45' and 78º 24' East longitude with 695 metre above mean sea level. Experimental site soil belongs to red sandy loam class in texture with 65.6 per cent sand, 27.20 per cent silt and 7.20 per cent clay. The soil is neutral in reaction (pH: 7.27) and low in soluble salts (0.16 dSm^{-1}). The soil is having medium available organic carbon (0.52%), P_2O_5 (39.91 kg ha^{-1}), K_2O (202.57 kg ha^{-1}) and low in available nitrogen (237.52 kg ha^{-1}). The field experiment was laid out with fourteen treatments and replicated thrice in Randomized Complete Block Design (RCBD). The treatments *viz.,* T_1: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE application at 3 DAS, T_2: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as Pre Emergence (PE) application at 3 DAS, T_3: 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as Post Emergence (PoE) application at 3-4 leaf stages, T_4: Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_5: Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_6: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_7: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_8: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_9: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_{10}: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_{11}: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_{12}: Handweeding at 20 DAS and 40 DAS, T_{13}: Weed free check, T_{14}: Unweeded check. The recommended package of practices was followed for the establishment of crops. The manual hand weeding was done twice at 20 and 40 DAS in

the respective treatment of hand weeding. Weed free check was maintained in weed free condition upto 60 DAS. Chemical weed management was carried out with pre and post emergence herbicides as per the treatments. The inter-cultivation was carried out @ 45 DAS which is common for all treatments. At the time of 30 DAS and at harvesting plant height and dry matter production were recorded by keeping in thermo statically controlled oven at 65 $\pm$ 5°C temperature and dried till it attains constant dry weight. The species wise weed count was taken randomly at two points in each plot in 0.25 m^2 area at different crop growth stages and average was done and classified into grasses, sedges and broad-leaved weeds.

Results and Discussion

Growth Parameters

The data on the growth parameters like plant height, leaf area and dry matter accumulation in maize as influenced by chemical weed management are presented in the Table 1.

Plant Height (cm)

At harvest, weed free check recorded significantly higher plant height (196.9 cm). Among chemical weed management treatments atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly higher plant height (195.2 cm), which was on par with

Table 1

Plant height, leaf area and dry matter accumulation of maize as influenced by chemical weed management practices at harvest

	Treatment	Plant height (cm)	Leaf area (cm^2 $plant^{-1}$)	Dry matter accumulation (g $plant^{-1}$)
T_1	: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE application at 3 DAS	172.3	3373.05	260.32
T_2	: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE application at 3 DAS	172.5	3868.57	257.08
T_3	: 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	169.3	3826.46	248.75
T_4	: Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	174.0	3828.71	258.21
T_5	: Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	169.3	3664.23	253.64
T_6	: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE	190.1	4463.75	288.32
T_7	: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE	195.2	4607.71	309.82
T_8	: Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE	193.1	4424.30	308.42
T_9	: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE	183.1	4569.47	285.99
T_{10}	: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE	178.9	4086.38	286.08
T_{11}	: Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE	181.0	4020.50	292.58
T_{12}	: Handweeding at 20 DAS and 40 DAS	180.3	4369.79	296.69
T_{13}	: Weed free check	196.9	4864.10	313.75
T_{14}	: Unweeded check	150.1	2827.03	233.17
	S.Em ±	8.05	253.20	14.76
	CD (p = 0.05)	23.40	736.03	42.90

atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (193.1 cm) and atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (190.1 cm) and superior over rest of the treatments (150.1 cm to 183.1 cm) as in Table 1. This is due to lower weed population and weed dry weight in early stages of crop growth which resulted in greater availability of nutrients, which led to better growth of plants. The results are in conformity with findings of Arunkumar *et al*. (2020).

Leaf Area (cm^2 plant^{-1})

At harvest also, atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly higher leaf area (4607.71 cm^2 plant^{-1}), which was on par with all other combination of different herbicides (4020.50 to 4569.47 cm^2 plant^{-1}) and significantly superior over application of single herbicide alone (3373.05 to 3868.57 cm^2 plant^{-1}). Weed free check recorded significantly higher leaf area (4864.10 cm^2 plant^{-1}) over all other treatments as expressed in Table 1. This is due to successful weed control during the initial stages of maize crop growth, which reduced weed competition and ultimately resulted in noticeably more leaf area per plant. The similar results were also observed by Khan *et al*. (2002) and Akhtar *et al*. (1984).

Dry Matter Accumulation in Plant (g plant^{-1})

At harvest, treatment having atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly higher dry matter production (309.8 g plant^{-1}), which was on par with all other combination of different herbicides (286.0 to 308.4 g plant^{-1}) and significantly superior over application of single herbicide alone (248.8 to 260.3 g plant^{-1}). Weed free check recorded significantly higher dry matter production (313.8 g plant^{-1}) over all other treatments as seen in Table 1. The increased production of dry matter is due to better weed management, which would increase leaf area and improve photosynthesis. These results are in conformity with Shinde *et al*. (2001).

Weed Density (No. 0.25 m^{-2})

At 20, 40 DAS and at Harvest

Sedge, grass, broad leaf and total weed density recorded at 20, 40 DAS and at harvest were significantly influenced by chemical weed management practices (Table 2).

TABLE 2

Weed density (No. 0.25 m^{-2}) as influenced by chemical weed management in maize recorded at 20, 40 DAS and at harvest

Treatment	Total weed density		
	20 DAS	40 DAS	At Harvest
T_1 : Atrazine	2.79 (7.33)	6.27 (39.00)	7.23 (52.00)
T_2 : Pendimethalin	2.91 (8.00)	5.30 (27.67)	7.63 (57.67)
T_3 : 2,4-D	5.39 (28.67)	7.36 (54.00)	7.56 (56.67)
T_4 : Topramezone	5.18 (26.33)	5.42 (29.00)	6.83 (46.33)
T_5 : Tembotrione	5.33 (28.00)	5.90 (34.33)	6.26 (39.00)
T_6 : Atrazine fb 2,4-D	2.79 (7.33)	4.78 (22.33)	5.25 (27.33)
T_7 : Atrazine fb Topramezone	2.61 (6.33)	2.34 (5.00)	4.26 (17.67)
T_8 : Atrazine fb Tembotrione	2.86 (8.00)	2.89 (8.33)	4.55 (20.33)
T_9 : Pendimethalin fb 2,4-D	2.91 (8.00)	3.17 (9.67)	5.04 (25.00)
T_{10} : Pendimethalin fb Topramezone	3.31 (10.67)	3.28 (10.33)	5.22 (27.00)

Table 2 Contd....

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Treatment	Total weed density		
	20 DAS	40 DAS	At Harvest
T_{11} : Pendimethalin fb Tembotrione	3.47 (11.67)	2.96 (8.33)	4.98 (24.67)
T_{12} : Handweeding at 20 and 40 DAS	3.39 (11.00)	5.18 (26.67)	5.10 (25.67)
T_{13} : Weed free check	3.12 (9.33)	2.04 (4.00)	3.91 (15.00)
T_{14} : Unweeded check	5.37 (28.33)	10.27 (105.0)	9.26 (87.33)
S.Em±	0.20	0.29	0.33
CD (p=0.05)	0.59	0.83	0.96

* Square root (X + 0.5) transformed values. Values in the parenthesis are original values. fb - followed by

Note : T_1 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE application at 3 DAS, T_2 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE application at 3 DAS, T_3 : 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_4 : Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_5 : Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_6 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_7 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fbTopramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_8 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_9 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_{10} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_{11} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_{12}: Handweeding at 20 DAS and 40 DAS, T_{13}: Weed free check, T_{14}: Unweeded check.

At 20 DAS, weed free check recorded significantly lower total weed population (3.12 No. 0.25 m^{-2}). Among chemical weed management treatments significantly lower total weed density (2.61 No. 0.25 m^{-2}) was recorded in atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE compared to all other treatments (2.79 to 5.39 No. 0.25 m^{-2}).

At 40 DAS, weed free check recorded significantly lower total weed population (2.04 No. 0.25 m^{-2}). Among chemical weed management treatments atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly lower total weed density (2.34 No. 0.25 m^{-2}) compared to all other treatments (3.28 to 7.36 No. 0.25 m^{-2}) and it was on par with atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (2.89 No. 0.25 m^{-2}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (2.96 No. 0.25 m^{-2}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (3.17 No. 0.25 m^{-2}). Unweeded check recorded significantly higher sedges, broad leaf, grass and total weed density (10.27 No. 0.25 m^{-2}).

At harvest, significantly lower total weed population (3.91 No. 0.25 m^{-2}) was recorded in weed free check. Among chemical weed management treatments, atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly lower total weed density (4.26 No. 0.25 m^{-2}) compared to other treatments (5.25 to 7.63 No. 0.25 m^{-2}) and it was at par with atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (4.55 No. 0.25 m^{-2}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (5.04 No. 0.25 m^{-2}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (5.22 No. 0.25 m^{-2}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (4.98 No. 0.25 m^{-2}) and handweeding at 20 DAS and 40 DAS (5.10 No. 0.25 m^{-2}). Lower density of weeds in the treatments involving atrazine followed by topromezone which was also at par with atrazine followed by tembotrione was due to the better and longer-lasting effects of pre

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and post emergence herbicides as these chemicals applied are broad-spectrum herbicides (herbicide inhibits 4-Hydroxyphenylpyruvate dioxygenase) in the early and middle stages resulting in reducing weed growth, rapidly degrading the carbohydrate synthesis of weeds, bleaching of white chlorophyll pigment, reduce leaf area and reduce photosynthesis. Similar findings were also observed earlier by Sanodiya *et al*. (2013), Walia *et al*. (2007), Patel *et al*. (2006), Deshmukh *et al*. (2009), Madhavi *et al*. (2014), Harish *et al.* (2022) and Ramachandra Prasad *et al.* (1990) reported that important weeds observed in maize field were *Cynodondactylon*, *Digitaria marginata*, *Dactyloctenium aegyptium, Eragrostis pilosa*, *Eragrostis riparia* and *Panicum* spp. (among grasses), *Cyperus rotundus* (sedge), *Ageratum conyzoides, Amaranthus viridis, Acanthospermum hispidum, Mimosa pudica, Phyllanthus niruri, Portulaca oleracea* and *Cleome monophylla* (among broad leaved weeds)

Yield Parameters and Yield of Maize

The yield and yield parameters of maize varied due to chemical weed management practices are presented in Table 3.

TABLE 3

Influence of chemical weed management on yield parameters of maize

Treatment	Cob length (cm)	Cob girth (cm)	Cob weight (g)	Kernel weight (g cob^{-1})	Kernel yield (kg ha^{-1})
T_1 : Atrazine	16.92	16.44	280.89	226.78	8668
T_2 : Pendimethalin	16.90	16.66	283.44	227.22	8546
T_3 : 2,4-D	15.70	16.42	264.22	196.55	7803
T_4 : Topramezone	16.77	16.51	286.11	196.78	9570
T_5 : Tembotrione	17.31	16.61	299.67	211.44	9199
T_6 : Atrazine fb 2,4-D	18.08	16.38	318.44	200.89	9856
T_7 : Atrazine fb Topramezone	18.86	17.28	331.67	249.66	11469
T_8 : Atrazine fb Tembotrione	18.79	17.08	329.33	237.44	11446
T_9 : Pendimethalin fb 2,4-D	18.18	17.08	312.22	232.89	10309
T_{10} : Pendimethalin fb Topramezone	18.04	17.03	326.00	228.22	10308
T_{11} : Pendimethalin fb Tembotrione	18.28	17.10	313.11	220.77	10454
T_{12} : Handweeding at 20 and 40 DAS	18.27	17.14	323.67	213.89	10292
T_{13} : Weed free check	18.91	17.30	347.89	230.44	11649
T_{14} : Unweeded check	15.31	14.16	213.00	188.66	6156
S.Em ±	0.78	0.39	23.22	15.58	835.6
CD (p=0.05)	2.27	1.14	67.49	45.30	2428.9

Note : T_1 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE application at 3 DAS, T_2 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE application at 3 DAS, T_3 : 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_4 : Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_5 : Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages, T_6 : Atrazine (50% WP) @ 1 kg *a.i.*ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_7 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fbTopramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_8 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fbTembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_9 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE, T_{10} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fbTopramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE, T_{11} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fbTembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE, T_{12}: Handweeding at 20 DAS and 40 DAS, T_{13}: Weed free check, T_{14}: Unweeded check.

Cob Length (cm)

Weed free check recorded significantly higher cob length (18.91cm). Chemical weed management treatments had significant influence on cob length. The significantly higher cob length (18.86 cm) was recorded with application of atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE and it was statistically at par with rest of the treatments (16.77 cm to 18.79 cm) except 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (15.70 cm). Significantly lower cob length was recorded with unweeded check (15.31 cm).

Cob Girth (cm)

The Cob girth was differed significantly with herbicidal treatments. Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE has recorded significantly higher cob girth (17.28 cm) and was statistically at par with remaining treatments (16.38 cm to 17.14 cm). Unweeded check recorded significantly lower cob girth (14.16 cm).

Cob Weight (g)

The chemical weed management had significant influence on cob weight. Application of atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE has resulted in a significantly higher cob weight (331.67 cm), which was statistically on par to the other treatments (264.22 g to 329.33 g). With unweeded check, the cob length was significantly less (213.00 g).

Kernel Weight Per Cob (g cob^{-1})

The weight of kernels per cob was significantly impacted by weed management treatments. Considering herbicidal treatments, atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded significantly higher kernel weight per cob (249.66 g cob^{-1}) which was statistically at par with rest of all other treatments (211.44 to 237.44 g cob^{-1}) except 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (196.55 g cob^{-1}), topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (196.78 g cob^{-1}) and atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (200.89 g cob^{-1}). Unweeded check (188.66 g cob^{-1}) was noticed with lower kernel weight per cob.

Kernel Yield (kg ha^{-1})

Weed free check (T_{13}) recorded significantly higher kernel yield (11649 kg ha^{-1}). Among chemical weed management practices, atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (T_7) has recorded significantly higher kernal yield (11469 kg ha^{-1}) which was on par with topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (T_4) (9570 kg ha^{-1}), tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (T_5) (9199 kg ha^{-1}), atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (T_6) (9856 kg ha^{-1}), atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (T_8) (11446 kg ha^{-1}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by 2,4- D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (T_9) (10309 kg ha^{-1}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (T_{10}) (10308 kg ha^{-1}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (T_{11}) (10454 kg ha^{-1}) and hand weeding @ 20 DAS and @ 40 DAS (T_{12}) (10292 kg ha^{-1}) but it is superior over atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE (T_1) (8668 kg ha^{-1}), pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE(T_2) (8546 kg ha^{-1}), 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE (T_3) (7803 kg ha^{-1}) and unweeded check (T_{14}) (6156 kg ha^{-1}) as expressed in Table 3.

The higher yield recorded in the present investigation with atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE (8994 kg ha^{-1}) was due to higher growth parameters (Table 1) and yield parameters (Table 3). As a result of using both pre and post emergent herbicides in maize it has showed maximum utilization of nutrients, moisture, light and space during initial days of crop growth which had influenced the growth and yield components. The total dry matter production in maize at harvest showed highly positive significant correlation with yield (Table 3).

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TABLE 4

Economics of maize cultivation as influenced by chemical weed management

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{1})	B:C ratio
T_1 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE application at 3 DAS	53194	139821	86626	2.63
T_2 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE application at 3 DAS	53379	137758	84378	2.58
T_3 : 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	53546	124413	70867	2.32
T_4 : Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	52792	151455	98663	2.87
T_5 : Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE application at 3-4 leaf stages	58806	145532	86726	2.47
T_6 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ as PoE 2.5 kg *a.i.* ha^{-1}	54186	158380	104194	2.92
T_7 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE	53432	185573	132141	3.47
T_8 : Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE	59446	184132	124685	3.10
T_9 : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb 2,4-D (58% SL) @ 2.5 kg *a.i.* ha^{-1} as PoE	53954	166071	112116	3.08
T_{10} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE	53617	165602	111985	3.09
T_{11} : Pendimethalin (30% EC) @ 0.75 kg *a.i.* ha^{-1} as PE fb Tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE	59631	167891	108259	2.82
T_{12} : Handweeding at 20 DAS and 40 DAS	53114	165637	112522	3.12
T_{13} : Weed free check	55514	189531	134017	3.41
T_{14} : Unweeded check	51994	97023	45028	1.87

The improvement in yield components was in turn due to improved growth attributes such as higher total dry matter production, leaf area index, better nutrient uptake by crop as quoted by Sreenivas and Satyanarayana (1994), Saini and Angiras (1998), Kamble *et al.* (2005) and Patel *et al.* (2006) and also due to greater availability of nutrients under lower weed competition, which might have promoted higher production and better translocation and partitioning of photosynthates from source to sink. Similar results were also reported by Ahmed and Susheela (2012), Dharmendra *et al.* (2017), Sivamurugan *et al.* (2017) and Hargilas (2017).

Economics

Atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded higher gross and net returns (185573 and 132141 Rs.ha^{-1}, respectively) among the weed control treatments followed by atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (184132 Rs. ha^{-1}) as compared to the rest (124413 Rs ha^{-1} to 167891 Rs ha^{-1}) and lowest was found in unweeded check (97023 and 45028 Rs. ha^{-1}).

The higher gross and net returns with pre and post emergence application of atrazine and topramezone

repectively was recorded due to better control of weeds which when resulted in higher gowth and yield parameters inturn increases the kernel yield apart from lower cost of cultivation. The results obtained are in accordance with Pandey *et al.* (2002) and Sanjay *et al.* (2012).

Among weed control treatments, atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as PoE recorded higher B:C ratio (3.47), followed by atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as PE followed by tembotrione (34.4% SC) @ 150 g *a.i.* ha^{-1} as PoE (3.10) as compared to the rest of the treatments (2.32 to 3.12) and lower B: C ratio (1.87) was noticed in unweeded check.

The treatments having combination of pre and post emergence herbicides and treatments having application of only post emergence herbicides recorded significantly higher B:C ratio and the reason might be due higher economic yield, gross returns, net returns and lower cost of cultivation. Whereas, significantly lower B:C ratio (1.87) was recorded in unweeded control as compared to all other treatments (Table 4).

Based on the results it can be inferred that, sequential application of atrazine (50% WP) @ 1 kg *a.i.* ha^{-1} as pre-emergence at 3 DAS followed by topramezone (33.6% SC) @ 50 g *a.i.* ha^{-1} as post emergence application at 3-4 weed leaf stages found suitable and economical for effective control of weeds in maize which recorded higher plant height (195.2 cm), higher leaf area (4607.71 cm^2 $plant^{-1}$), higher dry matter production (309.8 g $plant^{-1}$), higher kernel yield (11469 kg ha^{-1}), net monetary returns (132141 Rs. ha^{-1}) and B:C ratio (3.47).

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