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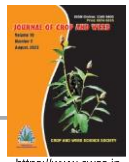

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Efficacy of new herbicide formulation on the growth and yield of maize (*Zea mays* L.)

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ABSTRACT

A field experiment was carried out at a farmer's field in the Perambalur District of Tamil Nadu, India, during the kharif season of 2021 to ascertain the effects of various weed management methods on the growth and yield of maize. The study comprised ten treatments (Pre application of Atrazine was fb post emergence application were 2,4-D, Halosulfuron methyl, Tembotrine, Tembotrine+ Atrazine, Mesotrione + Atrazine) and was set up in a randomised block design. Hand weeding on 15 and 30 DAS ranked first and resulted in the lowest weed count on 45 DAS (Grasses – 2.73, Sedges – 3.12, BLW's – 6.34), weed biomass on 30 and 45 DAS (10.89, 6.09 g), weed index (0 %) and highest weed control efficiency (93.71 %) among all the treatments examined. Among the herbicides sprayed, pre-emergence herbicide atrazine followed by post-emergence herbicide tembotrine had the lowest weed count on 45 DAS (Grasses – 2.90, Sedges – 3.44, BLW's – 6.68), weed biomass (12.10, 12.55 6.77 g m^2), weed index (0.29 %) and highest weed control efficiency (93.28 %) and resulted in tallest height (204.12 cm), Leaf Area Index (6.04), Dry matter production (8.92 t ha^{-1}), cob length (22.4 cm), grain yield (4.47 t ha^{-1}) and stover production (5.71 t ha^{-1}).

***Keywords*:** Grain yield, tembotrine, weed biomass and weed control efficiency

After rice and wheat, maize (*Zea mays* L.) is the third-most significant crop in India. Among the world's maize-growing nations, India ranks fourth in terms of area and seventh in terms of output. India produces 4% of the world's maize and occupies 2% of the total land area. Maize has adapted to a variety of temperatures in India, from tropical to temperate. In a frost-free season, it may be grown at a low temperature of 10°C, but the ideal temperature for excellent production is 20°C to 27°C. Due to its greater soil and climate adaptability, there is a lot of room to boost productivity. One of the main causes of decreased maize productivity is weed infestation, which is encouraged by wider row spacing and crop cooperation with the rainy season. (Oerke and Dehne 2004).

Depending on the kind of weed flora, intensity, stage, nature, and length of agricultural weed competition, yield losses in maize range from 28 to 93 per cent (Pandey *et al*., 2001). One to six weeks after planting is when crop weed competition in maize is at its most critical (Dass *et al*., 2012). Weed control is crucial at this time in order to maximise maize output potential. Atrazine is extensively used in maize due to its inexpensive cost, broad-spectrum weed control, flexibility in administration (pre-emergence or post-emergence), and compatibility with a range of herbicide combinations (Walsh *et al*., 2012). Herbicides are the most straightforward and cost-effective method for weed control in agriculture, hastening their widespread use. Although herbicide-dependent agricultural production benefited farmers in many ways, it also resulted in a slew of challenges such as herbicide-resistant weeds, a shifting weed flora, and pollution in the environment (Kumar *et al*., 2017). On the other hand, atrazine usage over an extended period of time alters the weed flora and results in the emergence of plant resistance. 45 weed species have demonstrated resistance to photosystem II (PSII) inhibitor herbicides like atrazine in a number of corn-growing regions across the world (Heap, 2019). Farmers still have difficulties in keeping grasses, broad-leaved weeds (BLWs) and sedges under control, particularly when labour shortages during peak weeding seasons combine with excessive or insufficient soil moisture (Swetha *et al*., 2015). Weeding by hand takes a lot of time and is expensive. Farmers in irrigated regions use pre-emergence (PE) herbicides to decrease weeds in the absence of human weeding, despite the fact that it is commonly proven ineffective at the farm level due to a variety of limitations (Rana *et al*., 2017). In these conditions, herbicides administered 40–45 days after sowing (DAS) appear to be a workable substitute for minimising weed pressure during the latter phases of crop growth (Kumar and Angadi, 2014). As a result, the current study made use of pre-emergence Atrazine

Short communication

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as well as post-emergence herbicides such 2, 4-D, Halosulfuron methyl, and Tembotrine.

During the *kharif* season of 2021, the current field experiment was conducted in a farmer's field in Kurmalur village, Perambalur District, Tamil Nadu, India. The experimental field is located at 11°14' North latitude and 78°47' East longitude, with a height of 143 metres above sea level. The soil texture is sandy loam, with a pH of 8.32 and a conductivity of 0.15 dSm^{-1} at the experimental site. Nitrogen, phosphorus, and potassium availability were low, medium and high, respectively, at the experimental site. During the crop season, 644 mm of rainfall received over 54 days, with average maximum temperatures ranged from 24.4^{0}C to 36.6^{0}C and minimum temperatures ranged from 20.3^{0}C to 24.6^{0}C.

The weed management options were separated into 10 treatments and were laid in a randomised block design with three replications, namely control, Hand weeding on 15 and 30 DAS, Pre-emergence application of Atrazine of 0.5 kg per hectare on 3 DAS, Pre-emergence application of Tembotrine of 105 g per hectare on 20 DAS, Pre-emergence application of 2,4-D of 1 kg per hectare on 20 DAS, Pre-emergence application of Atrazine of 0.5 kg per hectare on 3 DAS, Pre-emergence application of Halosulfuron methyl of 75% WDG (3rd Leaf stage of weeds), Tembotrine 105 g per hectare as a Post emergence application (3rd Leaf stage of weeds), Tembotrine 105 g per hectare as a Post emergence treatment (3rd Leaf stage of weeds) fb. Tembotrine 105 g per hectare + Atrazine 0.5 kg a.i per hectare Hand weeding on 30 DAS, Halo sulfuron methyl at 75% WDG at 90 g per hectare on 20 DAS, and Mesotrione + Atrazine at 3.5 l per hectare on weeds in the third leaf stage. According to the treatment plan, herbicide spraying was done using a knapsack sprayer with a flat fan nozzle and 500 litres of water per hectare. Atrazine, a pre-emergence herbicide, was administered as instructed on three DAS and 2,4-D, Halosulfuron methyl, Tembotrine, and Mesotrione + Atrazine, post-emergence herbicides, were treated as instructed. Weeding was done by hand on 15 and 30 DAS in accordance with treatments. Weed dry weight was assessed at sampling time (30 and 60 DAS) by randomly placed 0.25 m^2 quadrats at each plot, where the weeds were uprooted, cleaned, and dried at 70°C for 48 hours. The crop observation were taken in crop on 30, 60 DAS and harvest. On weeds, the observation was done on 15, 30 and 45 DAS. Need-based plant protection measures were adopted on the basis of the economic threshold level of pests and diseases. The maize hybrid NK 6240 was selected for this experiment and sown at a 60 x 20 cm spacing. Using urea, single super phosphate, and potash murate, a fertilizer dose of 60:30:30 NPK kg ha^{-1} was applied. The full doses of P_2O_5 and K_2O, as well as half of the authorised N, were given at the start. The rest of the N was used as a top dressing. The formula was used to perform square root transformations on weed density and weed biomass. Mishra and Mishra (1997) provided equations for calculating the weed index (WI). Biometric data, analytical data from soil and plant samples, and calculated data were all statistically scrutinised using Gomez and Gomez's technique (1984). Where the treatment difference was found to be significant using the F test, the crucial difference was calculated at a 5% probability level.

Effect on weeds

In the experimental field, broad-leaved weeds such as *Cleome viscosa, Trianthema portulacastrum,* and *Euphorbia hirta* were discovered amid the grasses *Cynodon dactylon, Dactyloctenium aegyptium, Panicum repens* and *Cyperus rotundus.* All weed-management methods reduced weed population and dry weight in comparison to the unweeded control (Table 1). On 15, 30 and 45 DAS, respectively, control plots contained 47.6%, 45.4 per cent, and 46.3 per cent of broad-leaved weeds. In comparison to pre-emergence herbicide atrazine @ 0.5 kg a.i ha^{-1} and post-emergence herbicide tembotrine @ 105 g ha^{-1} on 3 DAS and 30 DAS, hand weeding reduced grasses, sedges, and broad-leaved weeds on 15 and 30 DAS. Pre-emergence and post-emergence herbicide applications in a certain order reduced biotic stress and weed density in maize plants. Atrazine plus tembotrine fared much better in weed elimination than other combinations due to its effectiveness against wide leaf and grassy annual weeds, leading to a noticeably reduced total weed count. This might be as a result of the timely and effective efficacy of herbicidal treatments, both individually (greater dosage) and in combination. Singh *et al.* (2015) noted comparable results.

The lowest overall weed biomass and weed index were obtained by hand-weeding twice on 15 and 30 DAS. This could be because the experimental field was kept free of weeds until the crucial weed competition phase was achieved mechanically. The lowest weed index was produced by pre-emergence atrazine @ 0.5 kg a.i ha^{-1} on 3 DAS and post-emergence tembotrine @ 105 g ha^{-1} on 20 DAS, which together reduced total weed biomass and were equivalent to physically weeding twice. The total weed biomass was 12.1, 12.55, and 6.77 g m^2 on 15, 30, and 45 DAS, respectively, following the pre-emergence application of atrazine @ 0.5 kg a.i ha^{-1} on 3 DAS and the post-emergence treatment with tembotrine @ 105 g ha^{-1} on 20 DAS.

Table 1: Efficacy of newer herbicide formulation on weed count, weed biomass and weed index

Treatments	Weed count (m^2) on 45 DAS			Weed biomass (g m^2)			Weed control Efficiency (%)	Weed Index (%)
	Grass	Sedges	BLW	15 DAS	30 DAS	45 DAS		
T_1	42.50 (6.56)	61.54 (7.88)	89.72 (9.50)	272.16 (16.51)	224.35 (15.00)	294.52 (17.18)	0.00	69.08
T_2	2.73 (1.80)	3.12 (1.90)	6.34 (2.62)	244.56 (15.65)	10.89 (3.37)	6.09 (2.57)	93.71	0.00
T_3	2.90 (1.84)	3.44 (1.98)	6.68 (2.68)	12.10 (3.55)	12.55 (3.61)	6.77 (2.70)	93.28	0.29
T_4	4.58 (2.25)	6.11 (2.57)	8.23 (2.95)	13.45 (3.73)	25.02 (5.05)	16.08 (4.07)	90.24	11.62
T_5	7.24 (2.78)	10.44 (3.31)	15.09 (3.95)	15.29 (3.97)	28.98 (5.43)	32.44 (5.74)	83.09	12.05
T_6	4.78 (2.30)	6.23 (2.59)	8.45 (2.99)	259.31 (16.12)	36.15 (6.05)	17.32 (4.22)	89.96	17.63
T_7	4.14 (2.15)	5.39 (2.43)	7.84 (2.89)	250.14 (15.83)	23.99 (4.95)	14.42 (3.86)	91.04	6.78
T_8	4.10 (2.14)	5.36 (2.42)	7.79 (2.88)	16.21 (4.09)	29.48 (5.48)	13.63 (3.76)	91.10	5.91
T_9	7.34 (2.80)	10.54 (3.32)	15.22 (3.96)	268.08 (16.39)	38.24 (6.22)	33.77 (5.85)	91.10	17.94
T_{10}	4.64 (2.27)	6.18 (2.58)	8.28 (2.96)	255.12 (15.99)	26.48 (5.19)	16.81 (4.16)	82.91	12.83
SEm(±)	**0.06**	**0.06**	**0.07**	**0.42**	**0.19**	**0.17**		
LSD(0.05)	**0.18**	**0.18**	**0.19**	**1.20**	**0.55**	**0.48**		

The figures in parenthesis are the original values; the data underwent square root modification. T_1 - Control, T_2 - Hand weeding on 15 and 30 DAS, T_3 - Atrazine 0.5 kg a.i ha^{-1} as a PE on 3 DAS *fb* Tembotrine 105 g ha^{-1} as a PoE application on 20 DAS, T_4 - Atrazine 0.5 kg a.i ha^{-1} as a PE application on 3 DAS *fb* 2,4-D @ 1 k g ha^{-1} as a PoE application on 20 DAS, T_5 - Atrazine 0.5 kg a.i ha^{-1} as a PE application on 3 DAS *fb* Halosulfuron methyl 75% WDG @ 90 g ha^{-1} PoE application on 20 DAS, T_6 - Tembotrine 105 g ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds), T_7 - Tembotrine 105 g ha^{-1} + Atrazine 0.5 kg a.i ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds), T_8 - Tembotrine 105 g ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds) *fb* Hand weeding on 30 DAS, T_9 - Halo sulfuron methyl 75% WDG @ 90 g ha^{-1} on PoE application 20 DAS, T_{10} - Mesotrione + Atrazine 3.5 l ha^{-1} on 3^{rd} leaf stage of weeds.

The various treatments applied caused the efficiency of weed control to vary from 82.91 to 93.71 per cent. Using the pre-emergence herbicide atrazine at 0.5 kg a.i ha^{-1} and the post-emergence herbicide tembotrine at 105 g ha^{-1}, weed control effectiveness was comparable to hand weeding twice on 15 and 30 DAS. Hand weeding twice had the lowest weed index percentage, at 0%. T_7, T_8, and T_9 treatments all had similar weed control efficacy. The T_1 group had the lowest weed control effectiveness. In unweed control, the greatest weed index was found. This could be due to atrazine has an 8-day half-life and a high solubility, making it widely available in the solution and allowing for a better sorption/ adsorption balance. As a result, the herbicide was able to operate more effectively on weed seeds that were germinating. Further, tembotrine is a post-emergence herbicide that can control late-emerging weeds due to its increased solubility. Tembotrine is a triketone herbicide that operates by stopping the enzyme 4-hydroxyphenylpyruvate dioxygenase from doing its job (HPPPD). Carotenoid formation is disrupted as a result of this. Chlorophyll oxidation occurs when carotenoids are reduced, protecting photosynthetic sites from overexposure to light. Sensitive weeds and plants that are bleached gradually become white, demonstrating the molecular chain of events. The newest aerial plant tissues are bleached first. Before surrendering to death, bleached plants droop and suffer acute necrosis. The pesticide takes action in a few days, so this is a simple procedure. Similar result was found by Santel 2009. Control plot recorded the highest weed index with 69.08 per cent and also Weed control efficiency is zero per cent.

Table 2: Efficacy of newer herbicide formulation on growth and yield parameters

Treatments	Plant height (cm)	LAI	DMP ($t\ ha^{-1}$)	Cob length (cm)	Yield of grain ($t\ ha^{-1}$)	Yield of stover ($t\ ha^{-1}$)
T_1	70.12	3.17	3.10	12.7	1.39	2.97
T_2	207.12	6.12	8.93	22.5	4.48	5.72
T_3	204.12	6.04	8.92	22.4	4.47	5.71
T_4	182.01	5.47	8.08	20.1	3.96	5.16
T_5	181.83	5.41	8.01	19.8	3.94	5.13
T_6	170.01	5.12	7.52	18.5	3.69	4.82
T_7	193.29	5.71	8.48	21.1	4.18	5.43
T_8	193.99	5.81	8.50	21.5	4.22	5.45
T_9	169.89	5.04	7.50	18.2	3.68	4.80
T_{10}	180.56	5.39	7.98	19.4	3.91	5.11
SEm(±)	**3.71**	**0.1**	**0.16**	**0.4**	**0.08**	**0.10**
LSD(0.05)	**7.81**	**0.23**	**0.34**	**0.84**	**0.17**	**0.21**

The figures in parenthesis are the original values; the data underwent square root modification. T_1 - Control, T_2 - Hand weeding on 15 and 30 DAS, T_3 - Atrazine 0.5 kg a.i ha^{-1} as a PE on 3 DAS *fb* Tembotrine 105 g ha^{-1} as a PoE application on 20 DAS, T_4 - Atrazine 0.5 kg a.i ha^{-1} as a PE application on 3 DAS *fb* 2,4-D @ 1 k g ha^{-1} as a PoE application on 20 DAS, T_5 - Atrazine 0.5 kg a.i ha^{-1} as a PE application on 3 DAS *fb* Halosulfuron methyl 75% WDG @ 90 g ha^{-1} PoE application on 20 DAS, T_6 - Tembotrine 105 g ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds), T_7 - Tembotrine 105 g ha^{-1} + Atrazine 0.5 kg a.i ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds), T_8 - Tembotrine 105 g ha^{-1} as a PoE application (3^{rd} Leaf stage of weeds) *fb* Hand weeding on 30 DAS, T_9 - Halo sulfuron methyl 75% WDG @ 90 g ha^{-1} on PoE application 20 DAS, T_{10} - Mesotrione + Atrazine 3.5 l ha^{-1} on 3^{rd} leaf stage of weeds.

Effect on crops

Different weed management strategies have a big impact on the height of the plants at harvest. Hand weeding twice on 15 and 30 DAS (T_2) resulted in higher plant height of 207.12 cm, which was equivalent to T_3 (204.12 cm). Due to various treatments, the leaf area index was increased from 1.87 to 2.95. T_2 had the highest Leaf Area Index (6.12) at 60 DAS, Dry matter production at harvest (8934 kg ha^{-1}), grain, and stover yields of 4.48 t ha^{-1}, and 5.72 t ha^{-1}, respectively (Table 2). This was followed by T_8 and T_7. Twice hand weeding increased the dry matter production upto 5.83 t ha^{-1} compared to control. The combined application of Mesotrione + Atrazine 3.5 l ha^{-1} on 3^{rd} leaf stage of weeds increased the dry matter production upto 4.88 t ha^{-1}. Pre application of atrazine *fb* post emergence application of tembotrine or 2, 4 – D or halosulfuron methyl on 20 DAS increased the grain yield upto 3.08, 2.57 and 2.55 t ha^{-1} compared to unweed control. Crop-weed competition was decreased throughout the crop development cycle in order to produce the greatest grain under weed-free conditions. This allowed the crop to maximise space, moisture, light and nutrients, all of which are beneficial to growth and yield components. The control had the least amount of grain output (1.38 t ha^{-1}) of all the treatments. The manual weeding method yielded the longest cob, measuring 22.5 cm. The control treatment had the shortest cob length (12.7 cm). In comparison to the control, the length of the cob rose by 9.8 cm. Weed management at a crucial time period resulted in an increase in cob length and proper source to sink conversion. The findings are similar to those of Hatti *et al.* (2014) and Shantveerayyahawaldar and Agasimani (2012). This was equivalent to using 0.5 kg a.i ha^{-1} of atrazine on 3 DAS *fb*. Tembotrine 105 g ha^{-1} post-emergence treatment on 20 DAS (25.96 g, 4.46 t ha^{-1} and 5.70 t ha^{-1}). Grain yields were equivalent after post-emergence applications of Tembotrine 105 g ha^{-1} (3^{rd} Leaf stage of weeds) or Halo sulfuron methyl 75 percent WDG @ 90 g ha^{-1} on 20 DAS. Tembotrine or Mesotrione application with atrazine on third leaf stage. The post emergence of tembotrine was found to be better and increase the grain yield upto 2.79 t ha^{-1} comparable with control. This might be due to less rivalry between crop plants and weeds for available resources during the crop development phase, allowing crop plants to make better use of resources, as seen by increased kernel production. Using weedy check resulted in lower yields. This was confirmed by Mahto *et al.* (2020).

According to the results of this experiment, when labour is scarce during the crop growing period, Pre-emergence on 3 DAS, atrazine @ 0.5 kg a.i The greatest approach for enhancing maize productivity by controlling weeds is using post-emergence tembotrine

@ 105 g ha^{-1} on 20 DAS. After pre-emergence treatment, Tembotrine performed better than the other post-emergence herbicides in terms of weed control and grain yield.

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