Maize Journal (October 2026) 15(2): 101-104

RESEARCH PAPER

Effect of herbicides on weed flora, productivity and soil enzymatic activities in *kharif* maize

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Abstract: A field experiment was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, during the 2022 rainy season to study the effects of herbicidal on weed flora, productivity and soil enzymatic activities in *kharif* maize. The trial was conducted in the Randomized Complete Block Design having nine treatments replicated thrice. Atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha reduced the weed density and dry weight, with higher weed control efficiency (90.40%), and a lower weed index (9.09%) compared to atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha. This treatment also recorded significantly higher grain yield (5.2 t/ha) than atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha (4.8 t/ha). At harvest, atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha showed significantly greater dehydrogenase activity (13.61 µg TPF/g soil/24h) and alkaline phosphatase activity (106.88 µg PNP/g soil/h) than atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha. However, soil microbial biomass carbon was lower under atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha compared to atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha.

Keywords: Halosulfuron • Tembotrione • Topramezone • Weed-control efficiency • Weed index

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Received: 28 September 2026/ Accepted: 14 October 2026

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Introduction

Maize (*Zea mays* L.) is the third most important crop in India after rice and wheat, with cultivated area of approximately 10.36 million hectares and a record production of about 55.09 million tonnes (Ministry of Agriculture and Farmers Welfare, 2026). It is highly valued for its versatility and wide range of uses, including as food, fodder, and raw material for various industrial products (Bamboriya *et al*., 2023). Weed infestation is a major factor responsible for reduced maize production and significant grain yield losses due to the crop's delayed initial growth, broad row spacing, and frequent rains during the rainy season. Crop yield loss wasrecorded up to 90%, depending on weed flora and density, when weed species reached above the critical population threshold (Lavanya *et al*. 2021). The critical period for crop weed competition in maize is between 15 - 45 days after sowing. During that period, weeds are required to be controlled effectively in order to realize the maximum production and return from the crop (Mishra *et al*., 2020).

Broad-leaved weeds reduce maize productivity through intense competition for essential growth resources. Therefore, timely and effective weed management is crucial for successful maize production (Kumar *et al*., 2023).

Currently, a variety of selective post-emergence herbicides with distinct modes of action are available for controlling weeds in maize, including topramezone, tembotrione, and halosulfuron methyl. ALS (Acetolactate synthase) inhibiting herbicides are most effective for weed control by inhibiting amino acid synthesis (Singh *et al*., 2015). HPPD (4-hydroxyphenylpyruvate dioxygenase) inhibiting herbicide, topramezone [3-(4, 5-Dihydro- 3-isoxazolyl)-2-methyl-4-(methylsulfonyl) phenyl] (5-

hydroxy- 1-methyl-1H- yrazol-4-yl) methanone] inhibits the hydroxylphenyl pyruvate dioxygenase enzyme of carotenoid biosynthesis (pigment). It is selective to maize by rapidly metabolizing the herbicide into non-active substances and used primarily to manage broad- and narrow-leaved weeds (Bhusal and Sanodiya, 2025).

Soil enzyme activity serves as a key indicator of biological processes, playing a vital role in productivity and ecological balance. As protein-based catalysts, enzymes are essential for driving a wide range of biochemical reactions within the soil (Sepat *et al*., 2023).

The soil environment supports a rich diversity of enzymes that influence and are influenced by its physical, chemical, microbiological, and biochemical characteristics. These enzymes are central to critical soil functions such as nutrient cycling and energy flow, as they facilitate numerous chemical, physiological, and biological processes (Pan *et al*., 2020).

Therefore, the present study was undertaken to identify the most effective herbicide combinations for effective weed management in rainy season maize.

Materials and methods

The experimental trial was conducted during *kharif* season of 2022 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The soil of the experimental field was sandy clay loam in texture and alkaline in nature (pH 7.2), 0.17 dS/m EC, low in organic carbon (0.341%) and available nitrogen (188.1 kg/ha), and medium in available phosphorus (20.45 kg/ha) and potash (122.52 kg/ha). The experiment was laid-out in a Randomized Complete Block Design (RCBD) comprising nine treatments replicated thrice. These treatments were atrazine PE 1.0 kg/ha *fb* one hand weeding at 20 DAS, atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha, Atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha, Atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha, Atrazine PE 0.5 kg/ha *fb* topramezone PoE 25.2 g/ha, Atrazine PE 0.5 kg/ha *fb* halosulfuron PoE 67.5 g/ha, Atrazine PE 0.5 kg/ha *fb* tembotrione PoE 120 g/ha, weed-free check and weedy check. Maize variety 'C.P. 858' having duration of 130 days and a yield potentiality of 10 t/ha was sown manually during the second fortnight of June. Maize was sown at 60 × 20 cm row-row and plant-plant spacing using a seed rate of 25 kg/ha. The herbicides were sprayed using 400 L/ha of water with a knapsack sprayer equipped with a flat-fan nozzle. The recommended dose of nutrients @ 150-60-40 kg N-P_2O_5-K_2O/ha was applied. Nitrogen was applied in two equal splits at knee high and tasseling stages. After the harvest of maize, soil samples were collected and analyzed for enzyme activities *viz*., dehydrogenase, microbial biomass carbon, and phosphatase. The method involved in determination of dehydrogenase activity in the soil was spectrophotometry of Tri Phenyl Formazon (TPF) produced when soil is treated with Triphenyl Tetrazolium Chloride (TTC), given by (Cassida *et al*., 1964). Likewise the acid and alkaline phosphatase activity was assayed by quantifying the amount of p-nitrophenol released and expressed as µg of p-nitrophenol released/g soil/h as described by (Tabatabai and Bremner, 1972). Observations on weed flora, including narrow-leaved, broad-leaved weeds, and sedges, were recorded at 60 days after sowing (DAS) by randomly placing a 0.50 m² quadrat at two locations within each plot. Weed control efficiency (WCE) and weed index (WI) were calculated based on weed dry weight and grain yield (Das *et al.*, 2019).

$$WCE\ (\%) = (WPc - WPt)/WPc \times 100$$

Where, WPc and WPt are the weed density (no./m²) in WC and treatment plots, respectively.

$$WI\ (\%) = (Ywf - Yt)/Ywf \times 100$$

Where, Ywf and Yt are the maize yields in WFC and treatments, respectively.

To ensure homogeneity of variances for analysis of variance (ANOVA), the data on weed density and dry weight were subjected to square root transformation.

Results and discussion

Effects of herbicides on weed density and biomass

The field was infested with the narrow-leaf weeds (NLW) weeds *Echinochloa colona* (L.) Link*, Digitaria sanguinalis* (L.) Scop., and *Dactyloctenium aegyptium* (L.) Willd.; broad-leaf weeds (BLW) such as *Trianthema portulacastrum* L., *Commelina benghalensis* L. and *Cyperus esculentus* L. during experimentation (Table 1). At 60 DAS, among weed management treatments, atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha, exhibited significantly lower weed density and dry weight compared to atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha

Table 1. Effect of weed management treatments on weed density, weed dry weight and weed control efficiency at 60 DAS in maize

Treatments	Weed density (No./m^2)					Weed dry weight (g/m^2)					Weed control efficiency (%)
	E. colona	*D. sanguinalis*	*C. esculentus*	*T. portulacastrum*	*C. benghalensis*	*E. colona*	*D. sanguinalis*	*C. esculentus*	*T. portulacastrum*	*C. benghalensis*	
Atrazine *fb* hand weeding	3.02(8.67)	1.30(1.33)	3.20(10.00)	2.41(5.30)	1.86(3.00)	2.41(5.43)	0.75(0.06)	1.08(0.67)	1.75(2.55)	0.72(0.02)	94.38
Atrazine *fb* topramezone	3.79 (14.00)	5.80(33.30)	1.47(1.67)	3.24(10.00)	7.10(53.00)	4.10(16.5)	0.80(0.14)	1.17(0.87)	3.81(14.05)	0.76(0.08)	90.40
Atrazine *fb* halosulfuron	5.29(27.67)	2.20(4.33)	1.40(1.47)	3.48(11.67)	3.50(12.00)	3.10(9.41)	0.77(0.10)	0.87(0.26)	2.73(7.00)	0.81(0.16)	87.95
Atrazine *fb* tembotrione	4.91 (23.67)	1.70(2.33)	3.90(15.00)	2.79(7.33)	3.16(9.67)	2.84(7.60)	0.74(0.05)	1.25(1.06)	2.02(3.59)	0.74(0.05)	88.82
Atrazine *fb* topramezone	4.15(17.00)	2.00(3.33)	4.50(20.00)	3.48(11.67)	2.16(4.33)	2.77(72.00)	0.79(0.12)	1.40(1.47)	2.36(5.10)	0.74(0.05)	82.92
Atrazine *fb* halosulfuron	6.56(42.67)	3.10(9.00)	3.20(10.00)	4.14(16.67)	4.90(24.00)	3.47(11.67)	0.83(0.19)	1.01(0.52)	3.70(13.27)	0.82(0.17)	75.85
Atrazine *fb* tembotrione	4.58(20.67)	2.30(4.67)	5.50(30.00)	3.89(14.67)	4.06(16.00)	3.31(10.50)	0.76(0.08)	1.64(2.33)	2.54(5.99)	0.76(0.08)	79.68
Weed-free check	2.73(7.00)	1.50(1.67)	0.70(0.00)	1.46(1.67)	1.43(1.67)	1.99(3.63)	0.74(0.05)	0.71(0.00)	1.58(2.00)	0.80(0.14)	97.62
Weedy check	9.03(81.33)	11.10(122.33)	9.90(97.67)	6.44(41.00)	12.73(161.30)	9.55(90.73)	6.20(38.00)	10.01(99.60)	7.80(60.55)	5.11(25.67)	0.00
SEm±	0.24	0.10	0.20	0.12	0.43	0.26	0.03	0.09	0.15	0.04	-
CD (P=0.05)	0.72	0.30	0.59	0.36	1.31	0.78	0.10	0.28	0.44	0.12	-

The values in parentheses are the original values, which were transformed to $\sqrt{(x+0.5)}$.

and atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha except *Cyperus esculentus*. However, density and dry weight of *Commelina benghalensis* were reported to be lower in atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha. Atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha, showed higher weed control efficacy compared to atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha. Atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha had lesser weed index as compared to atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha. The sequential application of pre- and post-emergence herbicides effectively suppressed weed germination and establishment throughout the crop growth period, resulting in improved weed control (Sepat and Singh, 2024).

Effect on soil enzymes

At harvest, dehydrogenase activity and alkaline phosphatase values were observed significantly higher in atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha in comparison to atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha. However, soil microbial biomass carbon was noted to be lower in atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha. Higher values were recorded in atrazine PE 1.0 kg/ha *fb* halosulfuron PoE and atrazine PE 0.5 kg/ha *fb* halosulfuron PoE 67.5 g/ha. This exhibited the residual activity of herbicides on soil properties. In atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha treated plots, the activity of these enzymes increased at harvest due to higher dissipation of these herbicides after application. In context to soil enzymes, dehydrogenase activity and alkaline phosphatase values were recorded superior in atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha while soil microbial biomass carbon in atrazine PE 0.5 kg/ha *fb* halosulfuron PoE 67.5 g/ha.

Effect on maize

Grain and stover yields were significantly higher (5.2 and 8.2 t/ha, respectively) in atrazine PE 1.0 kg/ha *fb* topramezone PoE as compared to atrazine PE 1.0 kg/ha *fb* halosulfuron PoE (4.8 and 6.4 t/ha) and atrazine PE 0.5 kg/ha *fb* tembotrione PoE (4.6 and 6.71 t/ha, respectively). Harvest index was recorded lowest with atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha (38.80) than atrazine PE 1.0 kg/ha *fb* tembotrione PoE 120 g/ha (40.67) and atrazine PE 1.0 kg/ha *fb* halosulfuron

Table 2. Effect of weed management practices on yield and soil enzymatic activities at harvest

Treatments	Weed index (%)	Test weight (g)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Dehydro-genase activity (µg of TPF released/g soil/24h)	Alkaline phosph-atase (µg PNP released /g soil/h)	Soil microbial biomass carbon (SMBC µg /g)
Atrazine PE 1.0 kg/ha *fb* one hand weeding at 20 DAS	3.85	30.9	5.50	8.80	38.5	13.5	96.3	178.7
Atrazine PE 1.0 kg/ha *fb* topramezone PoE 25.2 g/ha	9.09	36.4	5.20	8.20	38.8	13.6	106.9	105.1
Atrazine PE 1.0 kg/ha *fb* halosulfuron PoE 67.5 g/ha	17.8	35.2	4.80	6.40	42.8	13.5	105.8	231.0
Atrazine PE 1.0 kg/ha PE *fb* tembotrione PoE 120 g/ha	24.8	34.6	4.60	6.71	40.7	13.5	98.9	180.4
Atrazine PE 0.5 kg/ha *fb* topramezone PoE 25.2 g/ha	22.7	33.6	5.00	7.70	39.4	13.50	103.4	212.3
Atrazine PE 0.5 kg/ha *fb* halosulfuron PoE 67.5 g/ha	26.6	34.7	4.70	6.50	42.0	13.4	95.1	260.7
Atrazine PE 0.5 kg/ha *fb* tembotrione PoE 120 g/ha	28.3	35.0	4.50	6.60	40.54	13.5	99.9	203.6
Weed-free check	0.0	37.7	5.72	6.70	46.05	13.4	94.2	104.0
Weedy check	44.4	21.0	3.18	5.0	38.87	13.8	112	366.9
SEm±	0.07	0.36	0.16	0.15	0.05	NS	0.23	0.29
CD (P=0.05)	0.21	1.11	0.49	0.47	0.15	NS	0.69	0.87

NS–Non significant

PoE 67.5 g/ha (42.85) (Table 2). Similarly, a reduction in weed competition due to weed control by pre- as well as post-emergence herbicides resulted in significant grain and stover yields in these treatments (Bhusal and Sanodiya, 2025). Compared with the weed-free plots (5.72 t/ha), the weedy check lost 2.54 t/ha, or 44.4%. The herbicide treatments lost between 3.9% and 21.3%.

Conclusion

Based on the study, it can be concluded that the sequential application of atrazine PE 1.0 kg/ha *fb* topramezone PoE (25.2 g/ha) proved to be the most effective weed management strategy for improving weed control, grain yield, and soil enzymatic activity in *kharif* maize.

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