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RESEARCH ARTICLE

Weed management and yield of *Kharif* hybrid maize as affected by post-emergence herbicides and plant growth promoters

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ABSTRACT

A field experiment was conducted during two consecutive *Kharif* seasons (2022 and 2023) at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur Uttar Pradesh, India, to study the effect of post-emergence herbicides and plant growth promoters in managing weeds and improve productivity of *Kharif* maize (*Zea mays* L.). On the pooled data basis, the application of Amino acid + Humic acid + Sea weed extract 2ml/liter of water recorded significantly highest values of maize growth attributes, *viz.* plant height, dry weight and leaf area index at 90 days after seeding (DAS) and yield attributes, *viz.* number of cob/plants, number of grain rows/cob, number of grains/row and seed index along with maize grain yield and harvest index. Among herbicidal treatments, tembotrione at 120 g/ha significantly reduced total weed density, fresh weight and dry weed biomass, and recorded the highest weed control efficiency (85.92%). It also recorded maximum growth attributes, improved yield attributes and higher grain yield, harvest index and benefit-cost ratio. There was no substantial interaction between herbicide treatments and plant growth regulators.

Keywords: Amino acid, Humic acid, Maize, Tembotrione, Weed management and Sea weed extract

INTRODUCTION

Maize (*Zea mays* L.) is the veritably most important cereal crop in the world with enormous yield potential. It occupies a central place in global agriculture, ranking third after rice and wheat in total production, but surpassing both in productivity potential. Globally, during 2022-23 around 200.53 million hectares area is under maize along with 1157.53 million tonnes production and 5.7 t/ha productivity (USDA 2024). In India around 11.24 million hectares area is under maize with 37.66 million tonnes production and 3.35 t/ha productivity in 2023-24 (DA&FW 2025). A major source of food for people, feed for fish and cattle, and a vital raw material for a variety of businesses, maize is an important cereal on a global scale. In addition to significant levels of vitamin A, nicotinic acid, phosphorus, riboflavin, and vitamin E, its grains have around 10% protein, 4% oil, 70% carbs, 2.3% crude fibre, 10.4% albuminoids and 1.4% ash. Additionally, maize offers cattle a plenty of green forage. Because of its versatility, it is widely grown in a variety of agro-ecological zones and is a crucial industrial feedstock for the production of ethanol and a number of value-added goods, including corn oil, flour, syrups, flakes, cosmetics, wax and tanning agents.

Maize cultivation often suffers from weak early growth, inadequate root development, low nutrient uptake and reduced photosynthesis, while drought, heat, salinity and nutrient deficiencies intensify stress, weaken crop vigor and significantly reduce yield potential. According to Etesami and Maheshwari (2018), the use of plant growth boosters has demonstrated encouraging results in increasing maize growth metrics like shoot length, root development, leaf area, and eventually yield. It has been demonstrated that plant growth promoters greatly increase the efficiency of nutrient uptake, especially for nitrogen, phosphorus, and potassium, all of which are critical for the growth of maize. Additionally, they strengthen maize's resistance to harsh climatic circumstances by making it more resilient to abiotic stresses such salinity, drought, and high temperatures (Iqbal *et al.* 2023).

Rainy-season maize experiences intense weed competition depending on weed density, type, growth stage and duration, causing yield losses of 28–100% (Patel *et al.* 2006). Wider spacing and slow initial

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growth during the *Kharif* season further aggravate infestation. Weeds also deplete 30–40% of available nutrients and utilize a major portion of applied fertilizers, thereby reducing nutrient-use efficiency and limiting crop access to essential growth factors. Consequently, maize growth and productivity decline severely if weeds remain unchecked (Ramesh *et al.* 2017). Herbicides play a crucial role in weed suppression by targeting specific weed species while minimizing adverse effects on maize plants (Abbas *et al.* 2018). Halosulfuron-methyl is a selective, systemic post-emergence herbicide effective against *Cyperus rotundus* in maize (Chand *et al.* 2014). Topramezone controls broad-leaved and narrow-leaved weeds, while atrazine, a triazine herbicide, is widely used as pre- and early post-emergence, absorbed through roots and foliage (Singh 2018). The premix mesotrione + atrazine provides long-lasting control of grasses and broad-leaved weeds (Singh *et al.* 2024). Thus, the combined use of herbicides for effective weed control and foliar application of plant growth promoters enhances crop physiology, supports better plant growth, and ultimately improves maize productivity and yield potential. This study was conducted to assess the effect of post-emergence herbicides and plant growth promoters in managing weeds and improve productivity of *Kharif* maize.

MATERIALS AND METHODS

The field experiment was conducted during the *Kharif* seasons of 2022 and 2023 at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India, which is situated 26.4148^0 North latitude, 80.2321^0 East longitude and at the 125.9 meters above sea level in the alluvial tract of Indo - Gangetic Plain zone of central part of Uttar Pradesh. The farm was well equipped with adequate and reliable irrigation facilities. The experiment was laid out in a Split Plot Design, with plant growth promoters allocated to the main plots and herbicides to the subplots. Eighteen treatment combinations were replicated three times. The experimental setup included three plant growth promoters, *viz.* gibberellic acid at 2 ml/liter of water (P_1), cytokinin + enzymes at 2ml/liter of water (P_2) and amino acid + humic acid + sea weed extract at 2 ml /liter of water (P_3) along with six herbicides, *viz.* weedy check, tembotrione 42% SC (tembotrione) at 120 g/ha, halosulfuron-methyl 75% WG (halosulfuron-methyl) at 72 g/ha, topramezone 33.6 SC (topramezone) at 25.2 g/ha, atrazine 50%WP (atrazine) at 1.0 kg /ha and mesotrione + atrazine (pre-mix) at 750 g/ha. The seeds of maize variety DKC-9144 were sown at the depth of 5 cm, at the rate of 25 kg/ha, with 50 × 20 cm spacing using seed drill. The crop was sown on 7th July during 2022 and 17th July during 2023. The experimental field had silty loam soil with 0.37% and 0.34% organic carbon, 179.5 and 152.2/ kg/ha available N, 12.5 and 13/ kg/ ha available P, 142.0 and 139.0/ kg/ha available K and pH 7.7 and 7.7 in 2022 and 2023, respectively. The recommended dose of nutrients was 120 kg N, 60 kg P, 40 kg K and 25 kg zinc sulphate per hectare through urea, di-ammonium phosphate, muriate of potash and heptahydrate zinc sulphate. One third dose of nitrogen, entire amount of phosphorus, potassium and zinc sulphate were applied below the seeds at the time of sowing. Remaining nitrogen was applied in two equal splits at knee height and tasselling stage. Plant growth promoters (2 ml/liter of water) were applied in two equal splits at knee-height and silking stages. As per the treatments, all herbicides were applied as post-emergence sprays at 25 DAS in aqueous solution using 400 liters of water/hectare. The required quantities of herbicides and water were calculated carefully according to the gross plot area and were sprayed uniformly using a knapsack sprayer fitted with a flat-fan nozzle. The crop was harvested at full maturity stage on October 25th in 2022 and November 2nd in 2023.

At 25, 50, 75 and 90 DAS the number of individual weeds was recorded by using a quadrat of 0.5 × 0.5 m from the area marked for observations. Weed species present within three randomly selected 0.5 × 0.5 m quadrat in each net plot area were counted separately, converted into number of weeds / m^2. For dry weight of weed the samples were dried under shade for 24 hours, followed by oven dried at ± 70 p C till constant weight was achieved. Then dried weed samples weighed done on pan balance and the weight was expressed as weed biomass (g/m^2) before subjecting to statistical analysis. The data on density of weed species and their fresh and dry biomass were analyzed after square root transformation ($r = \sqrt{(x+1)}$). The treatment comparisons were made at 5% level of significance.

Weed control efficiency (WCE) is usually determined by calculating weed dry biomass recorded from each treatment by utilizing the formula-

$$\text{W.C.E}\,(\%) = \frac{\text{Wo} - \text{Wt}}{\text{Wo}} \times 100$$

where,

W_0 = weed dry biomass of weedy check plot (g/m^2)

W_t = weed dry biomass of treated plot (g/m^2)

The plant height of selected plants was measured with the help of meter scale from ground level to the tip of the newly emerged leaf before tasselling while after tasselling it was measured from ground level up to the ligule of the upper most fully opened leaf. Average plant height was worked out in cm. For dry weight the samples were dried in sun for few days and then in electric oven for constant drying at 65 p C temperature for 24-48 hours. After drying weight of this sample was done on physical balance and figures obtained were used for computing dry weight per plant.

Five plants were selected randomly and the leaves were detached and categorized into small, medium and large size group. The total leaf area of the sample was calculated by multiplying the mean leaf area value by total number of leaves in each category and summing them up. Leaf area index was computed taking into account, the area occupied by each plant as per the following formula (Watson 1952).

Leaf area = K × length of leaf × width of leaf

where,

K = constant or factor (0.75).

$$\text{LAI} = \frac{\text{Total leaf area of plant}}{\text{Ground area}}$$

Harvest index was calculated by the formula (Donald and Hamblin, 1976).

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

where,

Economic yield = Grain yield (kg/ha)

Biological yield = Grain yield + Stover yield (kg/ha)

Recorded data was analysed using appropriate method of 'Analysis of Variance (ANOVA)' given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with several weed species, *viz. Echinochloa colona* (16.10%), *Digitaria sanguinalis* (8.41%), *Dactyloctenium aegyptium* (8.63%). and *Eleusine indica* (3.08%) were among grassy weeds. Broad-leaved weeds, *viz. Trianthema portulacastrum* (15.38%), *Digera muricata* (9.11%), *Commelina benghalensis* (9.94%), *Phyllanthus niruri* (2.41%), *Cucumis melo* (2.48%) and *Convolvulus arvensis* (1.76%) were dominant. *Cyperus rotundus* (22.66%). was the only sedge.

Analysis of the pooled data revealed that the application of plant growth promoters did not show any significant variation in the weed parameters.

The weed density (no./m^2) was significantly influenced by the application of herbicides in *kharif* maize (**Table 1**). The density of *Cyperus rotundus* was significantly reduced by halosulfuron-methyl 72 g/ha as compared to other treatments. It inhibits the acetolactate synthase (ALS) enzyme, crucial for the synthesis of branched-chain amino acids, leading to the cessation of cell division and effectively translocate to underground tubers of sedges and suppresses reserve food and regrowth plant growth, ultimately killed the weed (Dey *et al.* 2018, Kumar 2018 and Patil *et al.* 2017). Among herbicidal treatments, tembotrione 120g/ha has significantly reduced the density of grassy weeds (*Echinochloa colona, Digitaria sanguinalis* and *Dactyloctenium aegyptium*) and broad-leaved weeds (*Trianthema portulacastrum, Digera muricata* and *Commelina benghalensis*) and other weeds over other treatments. However, mesotrione + atrazine 750 g/ha was found at par with tembotrione 120 g/ha. Similarly, in case of total weed density, fresh and dry weed biomass were significantly reduced by tembotrione 120 g/ha, while the maximum fresh and dry weed biomass were recorded under weedy check (**Table 2**). Tembotrione, a selective post-emergence herbicide, targets broad-leaved and grassy weeds by inhibiting the 4-hydroxyphenylpyruvate dioxygenase (HPPD) enzyme, disrupting carotenoid biosynthesis and leading to chlorosis and eventual weed death (Balaji *et al.* 2023, Kumar and Chawla 2019 and Mali *et al.* 2019). Mesotrione + atrazine 750 g/ha effectively checked early emerging broad-leaved and grassy weeds by inhibiting carotenoid formation and photosynthesis, resulting in reduced weed density and improved crop growth throughout the critical period (Chhokar *et al.* 2019). Among herbicidal treatment, tembotrione 120 g/ha recorded significantly higher weed control efficiency (85.92% at 90 DAS) in maize due to its strong post-emergence activity against dominant grassy and broad-leaved weeds (Singh 2024 and Kaur *et al.* 2018).

Effect on maize

The pooled data clearly indicate that different plant growth promoters and herbicides had significant influence on the growth characteristics of maize (**Table 2**). Amino acid + humic acid + sea weed extract 2 ml/liter of water recorded significantly maximum maize plant height and dry weight at 90 DAS. Amino acids enhance nutrient uptake by chelating nutrients, making them more available, while humic acid releases essential nutrients, reduces transpiration, improves stomatal conductance and promotes plant growth (Maurya *et al.* 2025 and Wang *et al.* 2021).

In herbicidal treatments, tembotrione 120g/ha in *Kharif* maize recorded significantly maximum maize plant height, dry weight and leaf area index at 90 DAS (**Table 2**) due to its superior weed control, which reduces competition for space, light, moisture and nutrients. Better root development, effective nutrient uptake, enhanced photosynthesis and increased assimilate accumulation are all facilitated by this favourable environment, which raises plant height, increases biomass production and improved maize growth performance (Mhlanga *et al.* 2016).

Table 1. Effect of plant growth promoters and herbicides on weed density at 90 DAS in *Kharif* maize (pooled data of two years)

Treatment	Weed density (no./m^2) at 90 DAS							
	Cyperus rotundus	*Digitaria sanguinalis*	*Echinochloa colona*	*Dactyloctenium aegyptium*	*Digera muricata*	*Commelina bengalensis*	*Trianthema portulacastrum*	Other weeds
Plant growth promoters (a)								
Gibberellic acid 2 ml /liter of water	3.41(11.12)	1.76(2.31)	2.40(5.24)	1.85(2.65)	1.88(2.74)	1.83(2.64)	2.29(4.59)	1.81(2.60)
Cytokinin + enzymes 2 ml /liter of water	3.41(11.08)	1.77(2.37)	2.41(5.27)	1.81(2.47)	1.89(2.77)	1.84(2.69)	2.30(4.67)	1.84(2.60)
Amino acid + humic acid + sea weed extract 2 ml /liter of water	3.39(10.96)	1.75(2.28)	2.39(5.25)	1.83(2.57)	1.88(2.72)	1.82(2.65)	2.26(4.50)	1.82(2.62)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Herbicide (b)								
Weedy check	4.02(15.14)	2.57(5.62)	3.43(10.76)	2.60(5.77)	2.66(6.09)	2.76(6.64)	3.36(10.28)	2.74(6.50)
Tembotrione 120 g/ha	3.37(10.35)	1.36(0.85)	1.73(1.99)	1.37(0.88)	1.50(1.26)	1.37(0.89)	1.50(1.26)	1.38(0.90)
Halosulfuron-methyl 72 g/ha	2.14(3.59)	2.25(4.05)	3.29(9.81)	2.32(4.40)	2.34(4.45)	2.46(5.05)	2.68(6.18)	2.43(4.90)
Topramezone 33.6 25.2 g/ha	4.01(15.07)	1.45(1.09)	2.05(3.19)	1.56(1.43)	1.58(1.51)	1.44(1.07)	1.74(2.02)	1.45(1.09)
Atrazine 1.0 kg/ha	3.98(14.81)	1.53(1.34)	2.13(3.52)	1.67(1.78)	1.66(1.76)	1.51(1.29)	2.10(3.41)	1.53(1.34)
Mesotrione + atrazine 750 g/ha	2.89(7.38)	1.41(0.97)	1.79(2.22)	1.45(1.11)	1.55(1.40)	1.42(1.02)	2.31(4.37)	1.43(1.05)
LSD (p=0.05)	0.115	0.050	0.083	0.054	0.055	0.048	0.089	0.059
Interaction (A × B)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Note: LSD, least significant difference at the 5% level of significance; the values in parentheses represent the original data, while the values without parentheses are the transformed data, DAS=Days after sowing.

Table 2. Effect of plant growth promoters and herbicides on total weed density, fresh and dry weed biomass, weed control efficiency, maize plant height, dry weight per plant and leaf area index in *Kharif* maize (pooled data of two years)

Treatment	Total weed density (no./m^2) at 90 DAS	Fresh weed biomass (g/m^2) at 90 DAS	Dry weed biomass (g/m^2) at 90 DAS	Weed control efficiency (%) at 90 DAS	Maize plant height (cm) at 90 DAS	Dry weight of plant maize (g) at 90 DAS	Maize leaf area index at 90 DAS
Plant growth promoters (a)							
Gibberellic acid 2 ml/liter of water	5.76(33.9)	11.56(154.0)	7.04(55.6)	58.18	193.15	264.24	4.90
Cytokinin + enzymes 2 ml/liter of water	5.77(34.0)	11.52(152.8)	7.09(56.3)	57.26	198.05	269.91	5.01
Amino acid + humic acid + sea weed extract 2 ml/liter of water	5.72(33.6)	11.51(153.4)	6.97(54.5)	58.28	200.04	276.97	5.06
LSD (p=0.05)	NS	NS	NS	NS	4.90	9.27	NS
Herbicide (b)							
Weedy check	8.23(66.8)	19.40(375.8)	11.53(132.0)	0.00	168.56	240.53	4.51
Tembotrione 120 g/ha	4.40(18.4)	7.11(49.6)	4.42(18.5)	85.92	208.74	287.01	5.23
Halosulfuron-methyl 72 g/ha	6.59(42.4)	16.27(264.0)	9.72(93.5)	28.94	192.75	260.51	4.91
Topramezone 25.2 g/ha	5.24(26.5)	8.69(74.7)	5.38(28.0)	78.73	203.49	277.44	5.10
Atrazine 1.0 kg/ha	5.50(29.2)	9.71(93.3)	6.15(36.8)	72.01	201.97	273.72	5.04
Mesotrione + atrazine 750 g/ha	4.53(19.5)	7.99(62.9)	4.99(23.9)	81.83	206.95	283.01	5.16
LSD (p=0.05)	0.112	0.416	0.236	2.64	7.50	15.62	0.28
Interaction (A × B)							
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS

Note: LSD, least significant difference at the 5% level of significance; the values in parentheses represent the original data, while the values without parentheses are the transformed data, DAS=Days after sowing.

Table 3. Effect of plant growth promoters and herbicides on maize yield attribute, yield and B:C ratio in *Kharif* maize (pooled data of two years)

Treatment	No. of cobs/ plant	No. of grain rows/cob	No. of grains/ row	Seed index 100 seed weight (g)	Grain yield (kg/ha)	Stover yield (kg/ha)	Harvest index (%)	B:C ratio
Plant growth promoters (A)								
Gibberellic acid 2ml /liter of water	1.10	13.06	37.27	26.33	6493	12502	33.95	2.96
Cytokinin + enzymes 2 ml /liter of water	1.15	14.01	38.73	26.62	6680	12727	34.20	2.97
Amino acid + humic acid + sea weed extract 2 ml/liter of water	1.21	14.42	39.57	26.83	6836	12995	34.26	3.14
LSD (p=0.05)	NS	0.96	1.73	NS	167	NS	NS	0.05
Herbicide (B)								
Weedy check	1.02	11.49	31.52	24.98	4065	9103	30.90	2.00
Tembotrione 120 g/ha	1.26	15.14	41.56	27.47	7600	13959	35.27	3.40
Halosulfuron-methyl 72 g/ha	1.10	12.51	35.33	25.93	6113	11931	33.86	2.71
Topramezone 25.2 g/ha	1.18	14.67	40.94	27.07	7412	13811	34.94	3.30
Atrazine 1.0 kg/ha	1.14	14.39	40.71	26.86	7343	13748	34.82	3.38
Mesotrione + atrazine 750 g/ha	1.21	14.77	41.09	27.26	7483	13895	35.02	3.33
LSD (p=0.05)	0.14	1.10	1.64	0.74	262	657	0.93	0.10
Interaction (A × B)								
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Note: LSD= least significant difference at the 5% level of significance, B-C ratio= Benefit-cost ratio

Amino acid + humic acid + sea weed extract 2 ml/liter of water was enhanced number of cob/plant, number of grain rows/cob, number of grains/row and seed index. This treatment has also recorded 5.28%, 3.94% and 0.91% higher grain yield, stover yield and harvest index, respectively when compared to gibberellic acid (**Table 3**). Improving maize yield attributes is achieved through integrating amino acids, humic acids, and seaweed extracts, which enhance protein synthesis, promote growth, improve nutrient uptake, boost enzymes and increase stress tolerance. (Eryigit and Husamalddin 2023 and Ebrahimi *et al.* 2020). Seaweed extracts enhance the source-sink relationship and the translocation of photo assimilates, improving plant's photosynthetic ability, which significantly improved in growth and yield attributing characters were ultimately reflected in higher yield (Aalipour *et al.* 2023, Mahmood *et al.* 2020 and Hegab *et al.* 2020).

Tembotrione 120g/ha recorded significantly better yield attribute, *viz.* number of cob/plant, number of grain rows/cob, number of grains/row and seed index. Tembotrione 120g/ha has recorded an increase of 86.96%, 53.34% and 14.14% increase in grain yield, stover yield, and harvest index, respectively compared to weedy check (**Table 3**). Tembotrione targets broad-leaved and grassy weeds, which compete with maize for essential nutrients, water and light (Singh *et al.* 2025). By controlling these weeds, the maize plants grew more robustly and access resources more efficiently. For optimal results, application of herbicide during the early post-emergence stage of the maize crop, when weeds are actively growing but before they become established found successful. This strategy helps in minimizing competition and maximizing the maize crop yield potential (Sahoo *et al.* 2024, Gupta *et al.*2023 and Kaur *et al.* 2018). The interaction effect between plant growth promoters and herbicides did not show statistical significance.

The combined application of amino acid + humic acid + sea weed extract recorded the highest B:C ratio. Tembotrione 120 g/ha recorded higher B:C ratio, which was 70% higher compared to the weedy check. The improvement in B:C ratio was mainly attributed to higher grain yield and better weed control efficiency in the maize crop (Sundari *et al.* 2019).

Conclusion

It can be concluded that the combined application of Amino acid + humic acid + sea weed extract 2 ml/liter of water resulted in better growth, yield attributes and higher grain yield. Among the herbicidal treatments, tembotrione 120 g /ha recorded the highest weed control efficiency (85.92%) and significantly improved maize growth and yield attributes with maximum *Kharif* maize grain yield, harvest index and benefit–cost ratio.

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