



Integrated effect of rice straw mulch and sequential herbicide application in *kharif* maize (*Zea mays*)

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Maize (*Zea mays* L.), one of the major cereal crops in India, has a versatile usage including food consumption, livestock feed, poultry industry and starch production (ICAR-IIMR 2021). The national average productivity of maize is, however, nearly half of the world average productivity (5.8 t/ha) (Radheshyam *et al.* 2021). Weeds are one of the major biotic stresses faced by maize that hinders in achieving higher yield since it is majorly cultivated in the rainy season in India. Weeds proliferate in this season which is characterised by heavy rainfall and high relative humidity. Due to slow initial growth and wider row spacing, weeds get ample space to flourish and compete for resources such as sunlight, nutrients and moisture with the crop, which can cause yield reduction from 28% to even 100% (Dass *et al.* 2012). Manual removal of weeds is effective, but labour intensive, time consuming and expensive, hence the use of herbicides is more economical. Atrazine, for instance is a widely recommended and economical herbicide for maize, but has been observed to be less effective against sedges (Singh *et al.* 2015). Suitable broad-spectrum herbicides, therefore, are needed for effective control of weeds and obtaining higher economic produce. But the use of herbicides alone may not remain feasible for long run sustainability. The use of rice straw mulch as cultural weed control method can be considered as a viable option to suppress weeds as well as minimise the adverse effect of agrochemicals on environment. Keeping all the issues in consideration, a field study was carried out to explore the integrated impact of varying rates of rice straw mulch and new generation herbicides on the dynamics of weeds and growth, productivity and profitability of maize.

The field experiment was conducted during the rainy (*kharif*) season of 2022–23 at ICAR-National Institute of

Biotic Stress Management, Raipur (21.3746°N, 81.8306°E; at an elevation of 292 m amsl), Chhattisgarh which falls under Eastern Plateau and Hills agro-climatic zone with a sub-humid climate. Total rainfall received during the cropping season was 1,013 mm with maximum and minimum temperature ranging from 29.7–33.4°C and 13.8–25.7°C, respectively. The experimental site had clayey textured soil and was neutral in chemical reaction (pH 7.4), having medium organic carbon content (0.62%). Available nitrogen content of the soil was low (188 kg/ha), while available phosphorus and potassium contents were found to be medium (13.4 kg/ha and 210 kg/ha, respectively). The study was laid out in split-plot design (SPD) comprising 15 treatment combinations, including three rice straw mulch levels in main plot (8 t/ha, 5 t/ha and no mulch) and five chemical weed management options in sub plots [atrazine PE (pre-emergence), atrazine PE + tembotrione PoE (post-emergence), atrazine PE + topramezone PoE, weed-free check and un-weeded check], replicated thrice. The hybrid maize variety Super 459 Gold was grown in the experiment at inter-row and intra-row spacing of 0.60 m and 0.25 m, respectively. The crop was fertilised with 120, 26.2 and 33.3 kg N, P and K per hectare where one third of total N dose and total dose of P and K were applied as basal. The rest amount of N was applied at knee high and tasseling stages in two equal splits. The inter row space in maize was covered with air-dried rice straw mulch as per the treatment 2 days after pre-emergence herbicide spray. Herbicide application was done using a knapsack sprayer with a flat fan nozzle at a spray volume of 500 L/ha as per the dosage at 2 days after sowing (DAS) in case of pre-emergence application (atrazine 1,000 g/ha) and at 25 DAS for post-emergence application (tembotrione 120 g/ha, topramezone 30 g/ha). Weed density and biomass accumulation per unit area were recorded at 45 DAS from the experimental field. Weed control efficiency (WCE) and weed control index (WCI) was calculated as suggested by Das (2008). Growth parameters and relevant yield attributing characters were recorded and finally, grain and stover yield

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were determined. The yield was adjusted at 15% moisture content and reported as t/ha. For microbial biomass carbon, dehydrogenase activity and fluorescein diacetate analysis (FDA), soil samples were collected at flowering stage (0–15 cm). Statistical analysis of the collected data was executed as per Gomez and Gomez (1984) for split plot design using OPSTAT software. The interaction between rice straw mulch (main plot) and chemical weed management (sub-plot) was tested using ANOVA with F test at 5% level of significance. Square root transformation ($\sqrt{x + 0.5}$) of the observed data related to weeds was carried out for normalisation before their statistical analysis.

Weed density and dry matter were significantly influenced by rice straw mulch and chemical weed management options. No mulch plots recorded the highest total weed density (57.9/m²) with grasses (23.5/m²), sedges (18.6/m²) and broad-leaves (15.8/m²) (Table 1). *Echinochloa colona* and *Cynodon dactylon* were dominant among grassy weeds, *Commelina benghalensis*, *Ludwigia parviflora*, *Alternanthera sessilis* and *Physalis minima* among broadleaved weeds and *Cyperus rotundus* among sedges. The application of 8 t/ha and 5 t/ha straw mulch reduced the total weed density by 42.8% and 31.8% over no mulch, respectively. The suppressive effect of mulch was more evident on grasses and sedges, where 8 t/ha mulch reduced

grass and sedge density by 43.8% and 53.2%, respectively as compared to no mulch. Among chemical weed management options, atrazine PE + tembotrione PoE recorded the lowest weed density (23.1/m²) which was statistically similar to atrazine PE + topramezone PoE (25.8/m²). Significantly higher number of weeds per unit area (39.1/m²) was recorded with atrazine PE which can be attributed to absence of post-emergence weed control measures against subsequent weed flushes (Table 1). Interaction effect of straw mulch and chemical weed management options was also significant. The maximum weed density (129.3/m²) was noted in unweeded check. A similar trend was observed for dry matter accumulation of weeds. The application of 8 t/ha and 5 t/ha rice straw mulch significantly reduced total weed dry matter by 36.4% and 20.6% respectively, over no mulch treatment. Broad-leaved weeds contributed the highest dry matter accumulation in no mulch plots (21.7 g/m²). The 8 t/ha mulch effectively suppressed sedge dry matter (3.7 g/m²) over no mulch (8.2 g/m²). Among herbicide treatments, higher weed dry matter was recorded with atrazine PE (49.8 g/m²) where broad-leaves contributed 52.0% of the total dry matter (23.9 g/m²). Atrazine PE + tembotrione PoE recorded the lowest amount of grass, sedge, broadleaf as well as total weed dry matter (28.0 g/m²) followed by atrazine PE + topramezone PoE (30.5 g/m²). This can be

Table 1 Effect of rice straw mulch and chemical weed management treatments on total weed density, dry matter accumulation, weed control efficiency and weed control index at 45 days after sowing

Treatments	Weed density (Nos./m ²)				Weed dry matter accumulation (g/m ²)				Weed control efficiency (%)	Weed control index (%)
	Grass	Sedge	Broad-leaf	Total	Grass	Sedge	Broad-leaf	Total		
Rice straw mulch										
8 t/ha	2.7 (13.2)c*	2.2 (8.7)b	2.5 (11.2)c	4.9 (33.1)c	3.4 (15.6)b	1.6 (3.7)c	3.2 (16.2)b	5.3 (35.5)c	-	-
5 t/ha	3.4 (16.7)b	2.4 (9.3)b	2.8 (13.5)b	5.5 (39.5)b	3.7 (21.1)b	1.7 (4.4)b	3.7 (18.8)b	5.9 (44.3)b	-	-
No mulch	3.8 (23.5)a	3.3 (18.6)a	3.6 (15.8)a	6.5 (57.9)a	4.8 (25.9)a	2.2 (8.2)a	4.3 (21.7)a	6.4 (55.8)a	-	-
Chemical weed management										
Atrazine PE	3.7 (17.2)c	2.7 (10.6)d	2.7 (11.3)c	6.3 (39.1)c	3.9 (20.5)c	2.1 (5.4)c	4.1 (23.9)c	7.1 (49.8)c	69.8	58.1
Atrazine PE + tembotrione PoE	2.3 (10.1)b	2.3 (5.3)b	2.6 (7.7)b	4.8 (23.1)b	3.1 (13.8)b	1.6 (2.9)b	2.5 (11.6)b	5.3 (28.0)b	82.1	76.4
Atrazine PE + topramezone PoE	2.6 (11.8)b	2.7 (6.1)c	2.7 (7.9)b	5.1 (25.8)b	3.3 (15.4)b	1.7 (3.3)b	2.6 (11.8)b	5.5 (30.5)b	80.0	74.3
Weed-free check	0.7 (0.0)d	0.7 (0.0)d	0.7 (0.0)d	0.7 (0.0)d	0.7 (0.0)d	0.7 (0.0)e	0.7 (0.0)d	0.7 (0.0)d	100.0	100.0
Un-weeded check	6.8 (58.3)a	4.9 (28.4)e	5.7 (42.6)a	11.3 (129.3)a	6.6 (49.7)a	2.8 (11.9)d	6.7 (57.2)a	10.8 (118.8)a	0.0	0.0
Interaction	S	S	S	S	S	S	S	S	-	-

Data were subjected to square root transformation ($\sqrt{x + 0.5}$) before statistical analysis; Original values are given in the parentheses. Means within a factor sharing common letter are non-significant at $p < 0.05$ and vice-versa.

PE, Pre-emergence application; PoE, Post-emergence application; S, Significant.

attributed to the disruption in chlorophyll biosynthesis and membrane structure (HPPD inhibition) ultimately causing death of weeds (Sivamurugan *et al.* 2024). The maximum dry matter accumulation by weeds was observed in unweeded check (118.8 g/m²). The application of tembotrione and topamezone at 25 DAS as post-emergence were able to manage the weeds effectively due to their bleaching action on weeds decreasing their density and dry matter. Atrazine PE + tembotrione PoE offered the highest weed control efficiency (82.1%) and weed control index (76.4%) among the chemical weed management options, followed by atrazine PE + topamezone (80.0% and 74.3%, respectively) (Table 1). Atrazine PE provided comparatively lower WCE (69.8%) and WCI (58.1%). This highlights the importance of sequential use of herbicides having distinct modes and mechanisms of action targeting broader spectrum of weeds and enhanced extent of weed control (Chinyo *et al.* 2024). No phytotoxicity was observed in the crop.

Weed control measures had great influence on growth of maize and its yield attributing parameters (Table 2). The maximum plant height (203.2 cm) was obtained with 8 t/ha rice straw mulch use and was significantly superior to no mulch (192.4 cm). Atrazine PE + tembotrione PoE resulted in the maximum plant height (202.8 cm), which remained statistically at par with atrazine PE + topamezone PoE (201.3 cm). Likewise, significantly higher dry matter accumulation/plant was noted with use of straw mulch at 8 t/ha (190.84 g/plant) which was statistically higher than 5 t/ha straw mulch and no mulch treatment. Atrazine PE

+ tembotrione PoE recorded higher dry matter of crop (185.72 g/plant) among the herbicidal weed control measures that was closely followed by atrazine PE + topamezone PoE (184.17 g/plant) (Table 2). The minimum plant dry matter was recorded from weedy plots because of severe competition for resources among crop and weeds. The 8 t/ha straw mulch application resulted in numerically longer cob (16.5 cm) and significantly higher cob girth (15.0 cm). Number of grain rows/cob and grains/row were not significantly affected by mulch levels and registered numerically higher values (12.5 and 35.2, respectively) with 8 t/ha mulch application. Atrazine PE + tembotrione PoE recorded significantly higher cob length (15.4 cm), grain rows/cob (12.7) and grains/row (34.0), compared to atrazine PE. Weed-free check recorded the highest yield attributes and the maximum grain yield was obtained from the 8 t/ha rice straw mulch application (5.68 t/ha) followed by 5 t/ha mulch (5.34 t/ha) (Table 2). Atrazine PE + tembotrione PoE recorded the highest grain yield among the chemical weed management options (5.69 t/ha) which was statistically superior to atrazine PE + topamezone PoE (5.44 t/ha) and atrazine PE (5.04 t/ha). The straw mulch × herbicide interaction was found significant for grain yield where 8 t/ha straw mulch in combination with atrazine PE + tembotrione PoE recorded higher yield than all other straw mulch and herbicide treatment combinations (Fig. 1). A similar trend was observed for stover yield, with 8 t/ha straw mulch treatment (6.96 t/ha) and atrazine PE + tembotrione PoE (7.01 t/ha). However, the interaction of mulch and herbicide

Table 2 Effect of rice straw mulch and chemical weed management treatments on growth, yield and economics of maize

Treatments	Plant height (cm)	Dry matter accumulation (g/plant)	Cob length (cm)	Cob girth (cm)	Grain rows/cob	Grains/row	Grain yield (t/ha)	Stover yield (t/ha)	Net return (₹ × 10 ³ /ha)	Net return per ₹ invested
Rice straw mulch										
8 t/ha	203.2a	190.84a	16.5	15.0a	12.5	35.2	5.68a	6.96a	80.10a	2.04a
5 t/ha	200.0a	184.50b	13.8	13.4b	12.1	33.7	5.34b	6.77b	73.23b	1.95b
No mulch	192.4b	177.53c	12.4	13.1b	11.2	31.9	4.63c	6.43c	60.98c	1.72c
Chemical weed management										
Atrazine PE	196.5c	178.40c	14.0b	13.6b	11.4c	31.3c	5.04c	6.57c	69.02c	1.78c
Atrazine PE + tembotrione PoE	202.8b	185.72b	15.4ab	14.4a	12.7b	34.0b	5.69a	7.01b	76.61b	1.96a
Atrazine PE + topamezone PoE	201.3b	184.17b	14.4b	13.6b	12.1b	33.3b	5.44b	6.84b	75.95b	1.93b
Weed free check	206.4a	202.86a	16.3a	14.8a	13.9a	38.9a	6.18a	7.76a	87.58a	1.71d
Un-weeded check	185.6d	170.31d	11.0c	12.8c	9.7d	30.6d	3.73d	5.44d	48.03d	1.49e
Interaction	NS	NS	NS	NS	NS	NS	S	NS	NS	NS

Economic analysis was based on minimum support price of maize grain in 2022–23 and prevailing market rate of stover. Base cost of cultivation included cost of seed, fertiliser, irrigation (Urea, DAP, MOP), insecticide and cultural operations. Additional costs included labour costs (₹350 person/day) for all operations, cost of herbicide products at prevailing market rates, spraying charges and hand weeding charges wherever applicable. Means within a factor sharing common letter are non-significant at $p < 0.05$ and vice-versa.

PE, Pre-emergence application; PoE, Post-emergence application; NS, Non significant; S, Significant.

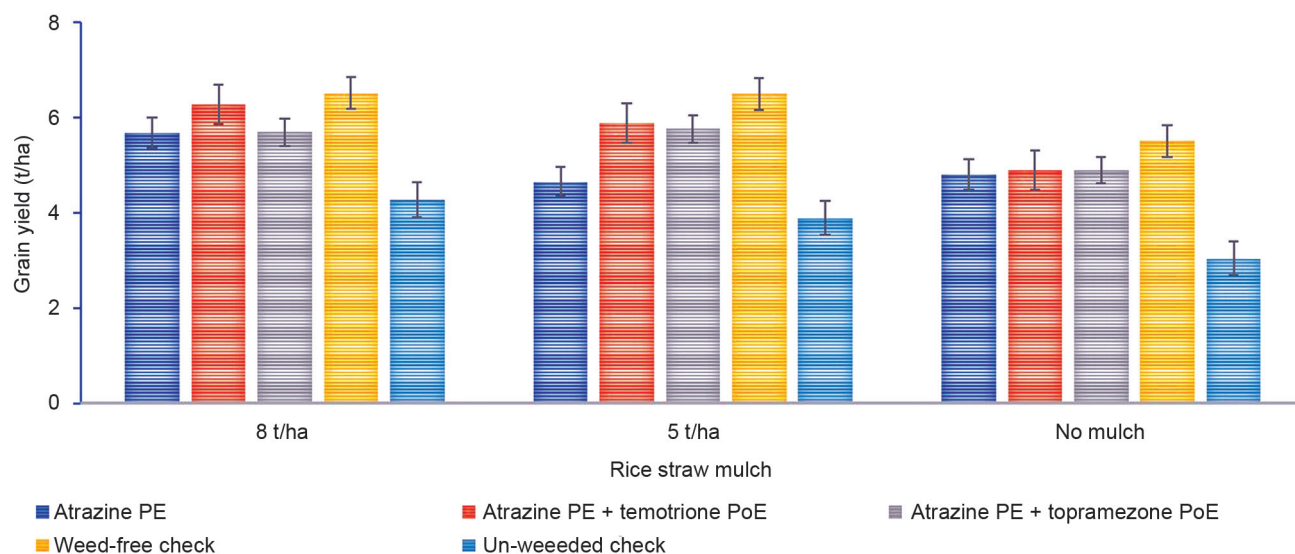


Fig. 1 Interaction effect of rice straw mulch and chemical weed management on grain yield of maize.

PE, Pre-emergence application; PoE, Post-emergence application.

was not significant for stover yield.

Soil microbial activity at flowering stage (0–15 cm) was significantly influenced by rice straw mulch application (Fig. 2). The 8 t/ha mulch recorded higher microbial biomass carbon (MBC) (284.1 $\mu\text{g C/g soil}$), dehydrogenase activity (DHA) (158.7 $\mu\text{g TPF/g soil/day}$) and fluorescein diacetate activity (FDA) (125.8 $\mu\text{g fluorescein/g soil/h}$) over no mulch treatment attributable to the release of substrates from rice straw, resultant microbial growth stimulation and enzymatic activity. However, chemical weed management treatments did not significantly influence microbial activity at flowering stage.

The 8 t/ha straw mulch application recorded the highest net return ($\text{₹}80.10 \times 10^3/\text{ha}$) and net return/ ₹ invested (2.04) among the straw mulch treatments. Among the chemical

weed management options, atrazine PE + tembotrione PoE fetched the highest net return ($\text{₹}76.61 \times 10^3/\text{ha}$) with the highest net return/ ₹ invested (1.96), closely followed by atrazine PE + topramezone PoE ($\text{₹}75.95 \times 10^3/\text{ha}$; 1.93) (Table 2). Although weed-free check recorded the highest net return ($\text{₹}87.58 \times 10^3/\text{ha}$), its net return/ ₹ invested was lower (1.71) due to high cost of hand weeding, making it economically less viable than herbicide treatments (Kaul *et al.* 2023). Un-weeded check registered the lowest net monetary return due to minimum grain and stover yield.

It can be concluded that addition of mulch could effectively reduce weed density and dry matter, contributing to more yield, net economic return and improved soil microbial activity. Also, the application of atrazine PE + tembotrione PoE achieved higher weed control efficiency

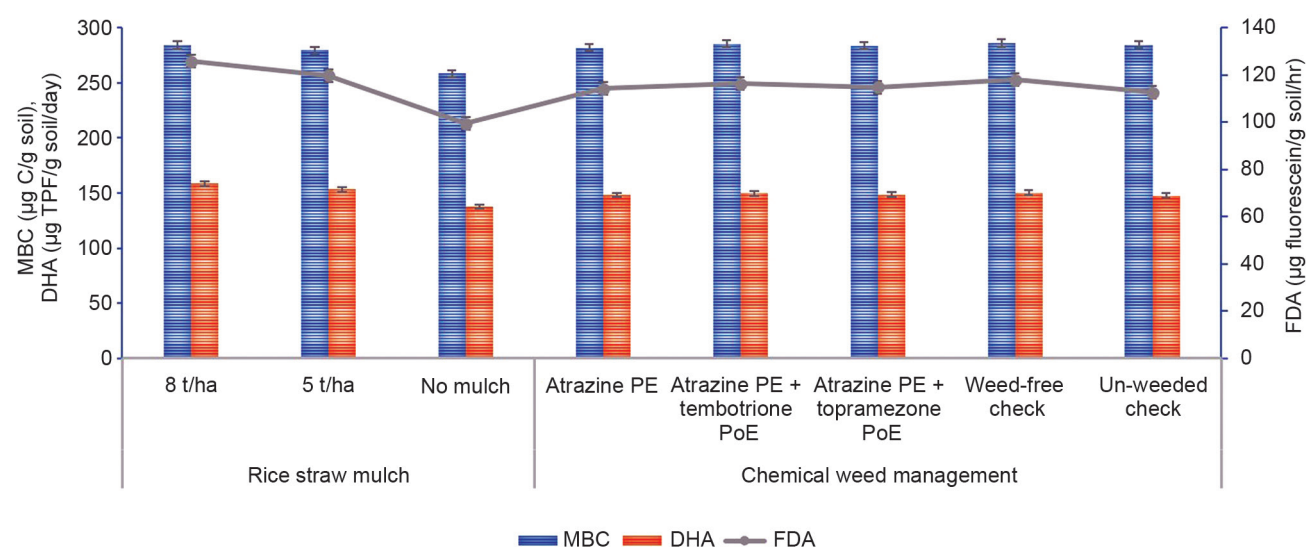


Fig. 2 Effect of rice straw mulch and chemical weed management on soil microbial activity parameters (0–15 cm soil) at flowering stage of maize.

MBC, Microbial biomass carbon ($\mu\text{g C/g soil}$); DHA, Dehydrogenase activity ($\mu\text{g TPF/g soil/day}$); FDA, Fluorescein diacetate hydrolysis ($\mu\text{g fluorescein/g soil/h}$); PE, Pre-emergence application; PoE, Post-emergence application.

and weed control index with better growth, yield and net return/₹ invested. The 8 t/ha straw mulch in combination with atrazine PE + tembotrione PoE can bring about higher yield of *kharif* maize in the sub-humid conditions of Chhattisgarh. However, the findings are based on a single season study needing verification across seasons and locations for wider scale recommendation.

SUMMARY

A field experiment was conducted at ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh during *kharif* 2022–23 to evaluate the effect of rice straw mulch and chemical weed management on weed dynamics, productivity and profitability of maize through a split-plot design with three replications. A significant reduction in total weed density and dry matter was observed with the application of 8 t/ha straw mulch and atrazine PE + tembotrione PoE, which also recorded higher grain yield and net returns/₹ invested without any adverse effect on soil microbial activity. Integration of 8 t/ha straw mulch with atrazine PE + tembotrione PoE recorded better weed control, higher yield and economic return in *kharif* maize under sub-humid conditions.

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