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Short Communication

Effect of Tillage and Herbicides on Weeds and Yield of Maize (*Zea mays* L.)

Dinesh Choudhary[1], Rajender Singh Chhokar[1], Subhash Chander Gill[1], Shiv Ram Samota[1*], Nitesh Kumar[1] and Girdhari Lal Yadav[2]

[1]*ICAR-Indian Institute of Wheat & Barley Research, Karnal – 132001 (India)*
[2]*Department of Agronomy, MJRP, Jaipur*

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****Corresponding author:*** *E-mail: shivram10051995@gmail.com*

Maize (*Zea mays* L.) is an important widely adapted food, feed and industrial utilities crop. Although, numerous factors are responsible for limiting the productivity and production of maize crop but among them, weed infestation is major one. The wider row spacing and slow initial growth of maize crop make it more vulnerable to weed competition. Further, during *Kharif* season, frequent rains provide the conducive environment for emergence and growth of diverse weed flora comprising of grasses, broad-leaved and sedges leading to severe yield reductions. Yield reductions of as high as, 90% have been reported depending upon the type and intensity of weed flora (Massinga *et al.,* 2003). For achieving optimum maize yield, effective weed control measures are absolutely needed. Moreover, intensive tillage practices contribute greatly to high energy and labour costs, resulting in low economic returns. These issues can be tackled with adoption of resource conservation technologies (RCTs) such as zero tillage and conservation tillage (Sharma *et al.,* 2005). However, tillage and residue management can influence the weeds abundance because of change in microclimate. A very few studies have been done in respect of effect of different tillage and herbicide options for maize crop. Therefore, it is of immense importance to determine the influence of these changing agronomic practices on weed dynamics, so as to develop the efficient weed management strategies.

A field study consisting of three tillage options as main plot (Zero tillage, zero tillage + residue retention of 6 t ha^{-1}, conventional tillage) and six weed control treatments in sub-plots (Pre-emergence atrazine at 1000 g ha^{-1}, tembotrione at 110 g ha^{-1}, atrazine + tembotrione at 800 + 90 g ha^{-1}, atrazine + tembotrione +bentazone at 800 + 90 + 960 g ha^{-1}, atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1} and weedy check) was conducted during *Kharif* 2019 at the Resource Management Research Farm, of ICAR-Indian Institute of Wheat and Barley Research (IIWBR), Karnal, Haryana. The soil was sandy loam in texture, slightly alkaline (pH 8.5, EC 0.12 dS m^{-1}), low in available N (173.4 kg/ha) and medium in available P_2O_5 (14.82 kg/ha) and K_2O (140.09 kg/ha). Maize hybrid S7750 was sown at 60 cm x 20 cm spacing using Turbo Happy Seeder at seed rate of 20-25 kg/ha. Except tillage and weed control treatments, all other agronomic practices such as fertilizer application, irrigation management and plant protection measures were taken as per standard recommendations. The observations on crop biomass, cob weight, grain yield and stover yield were taken. The data on weed density and dry matter were taken at 45 and 75 days after sowing (DAS) by using quadrate of size 50 cm × 50 cm at two places in each plot and then the observed values were multiplied by 2 to convert into per square metre. The data on weed density and dry matter accumulation of weeds were subjected to square root transformation {√(x+1)} before statistical analysis. Weed control efficiency (WCE) was calculated by subtracting dry weight of treatment plot from dry weight of weeds in unweeded control and by dividing it with dry weight of unweeded control. Differences among treatment means were determined using ANOVA and when the F test was significant, means were compared with LSD test at 5 per cent level of significance.

Effect on weeds

Results revealed that among grass weeds, the crop establishment methods significantly affected the dry weights of *Echinochloa colonum, Dactyloctenium aegypticum* and *Digitaria sanguinalis* (Table 1). The dry weights of these weeds were less with zero tillage + residue (ZT + R) treatment compared to two other crop establishment methods (CT and ZT). At 45 DAS, the dry weights of *E. colonum, D. aegypticum* and *D. sanguinalis* were 0.4, 27.6 and 2.5 g/m^2 in ZT, 0.7, 9.0 and 0.4 g/m^2 in ZT+R and 2.9, 21.9 and 11.3 g/m^2 in CT, respectively. Weed control treatments also had significant effect on all the major grass weeds. In comparison to untreated control, all the herbicide treatments caused significant reductions in dry weight of all the grass weeds at 45 DAS except atrazine for *D. aegypticum and D. sanguinalis* dry weights. All the three tank-mix herbicide treatments were at par among themselves. Between two solo herbicide treatments *i.e.,* atrazine and tembotrione, the latter was significantly superior for control of *D. aegypticum* and *Digitaria sanguinalis.* However, for control of *Echinochloa* spp. both the treatments were statistically similar. The significant effect of crop establishment methods was observed on dry weight of *Digera arvensis, Trianthema portulacastrum,* and *Cyperus rotundus.* In general, the lowest weed dry weights were found in ZT with residue retention. This conservation agriculture treatment was significantly superior to CT method for reducing the dry weight of *D. arvensis, T. portulacastrum* and *C. rotundus.* The dry weight of major broad-leaved weed, *T. portulacastrum* recorded under ZT, ZT+R and CT was 23.9, 5.2 and 14.2 g/m^2, respectively. Whereas, *C. rotundus* dry weight under ZT, ZT+R and CT were 17.2, 4.4 and 46.3 g/m^2, respectively. Also, in comparison to untreated control, the various herbicide treatments significantly reduced the dry weight of major broad-leaved weeds namely *D. arvensis, and T. portulacastrum* (Table 1). Application of atrazine alone at 1000 g ha^{-1} was very effective in controlling *D. arvensis.* Tembotrione alone at 110 g ha^{-1} was also effective in controlling *D. arvensis. D. arvensis* and *P. niruri* dry weight did not significantly differ among various herbicide treatments. *T. portulacastrum* and *C. rotundus* control with the tank-mix combinations was better than solo application of either atrazine or tembotrione. Application of atrazine + tembotrione + halosulfuron caused maximum reduction in dry weight of *C. rotundus* (6.3 g/m^2) and was significantly superior to all other weed control treatments. However, atrazine + tembotrione + bentazone (21.3 g/m^2) tank-mix treatment was statistically at par with the application of atrazine + tembotrione + halosulfuron tank mixture. The total weed dry weight was also significantly less with the treatment having ZT with residue retention of 6 t ha^{-1} compared to ZT and CT crop establishment method. The total weeds dry weight recorded under ZT, ZT+R and CT was 79.0, 29.5 and 146.1 g/m^2. The ZT without residue retention was also superior to CT in reducing the total weed dry weight. Among weed control treatments, all the herbicidal treatments significantly lowered the weed dry weight than weedy check treatment. However, the two and three herbicides tank mixture treatments were better than the alone application of either atrazine or tembotrione. Among three herbicides tank mixture treatments, the maximum reduction in weed dry weight was observed with the combination of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1}. The weed control efficiency at 45 DAS was the highest with application of tank mixture of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1} followed by atrazine + tembotrione at 800 + 90 g ha^{-1} and atrazine + tembotrione + bentazone at 800 + 90 + 960 g ha^{-1}. The effective weed control with application of atrazine (Sahoo *et al.,* 2016) and tembotrione (Rana *et al.,* 2017) in maize has also been earlier reported.

At 75 DAS also, ZT + R had lower grass weed dry weight except *Commelina benghalensis.* Statistically, it was significantly superior to CT in reducing the dry weight of *E. colona* and *D. sanguinalis*. Among grass weeds, *D. aegypticum* dry weight recorded in ZT, ZT+R and CT treatments was 9.1, 5.6 and 6.9 g/m^2, respectively. The dry weights of *D. sanguinalis* in ZT+R, ZT and CT were 2.1, 1.2 and 12.9 g/m^2, respectively (Table 2). Weed

Table 1. Effect of crop establishment methods and weed control treatments on weed dry weight in maize at 45 DAS

Treatment	*E. crus-galli*	*E. colonum*	*D. aegypticum*	*Digitaria sanguinalis*	Commelina benghalensis	*D. arvensis*	*T. portulacastrum*	*C. rotundus*	Other weeds	Total weeds	Weed control efficiency (%)
Tillage options											
Zero tillage (ZT)	1.5 (2.0)	1.1 (0.4)	3.8 (27.6)	1.6 (2.5)	1.6 (3.4)	1.6 (4.1)	4.7 (23.9)	4.0 (17.2)	1.5 (2.3)	7.6 (79.0)	6.6
Zero tillage (ZT) + residue 6 t ha^{-1}	1.1 (0.5)	1.2 (0.7)	2.5 (9.0)	1.1 (0.4)	1.7 (4.1)	1.2 (1.0)	2.1 (5.2)	2.1 (4.4)	1.5 (4.0)	4.4 (29.5)	6.7
Conventional tillage (CT)	1.4 (2.2)	1.5 (2.9)	3.0 (21.9)	2.8 (11.3)	1.6 (3.9)	2.4 (12.6)	3.5 (14.2)	6.5 (46.3)	4.3 (27.3)	11.2 (146.1)	6.9
LSD at 5%	NS	0.262	0.490	0.408	NS	0.607	1.750	1.143	NS	1.842	-
Weed control											
Atrazine at 1000 g ha^{-1}	1.1 (0.5)	1.3 (0.9)	7.0 (50.7)	3.1 (12.5)	1.0 (0.0)	1.0 (0.2)	3.1 (12.9)	5.4 (33.3)	2.8 (16.0)	10.3 (118.4)	5.6
Tembotrione at 110 g ha^{-1}	1.1 (0.3)	1.2 (0.5)	1.7 (2.9)	1.6 (3.0)	1.0 (0.1)	1.2 (0.6)	2.7 (8.2)	6.1 (43.9)	2.8 (13.1)	7.8 (68.2)	7.0
Atrazine + tembotrione at 800+90 g ha^{-1}	1.0 (0.0)	1.0 (0.0)	1.0 (0.1)	1.0 (0.0)	1.1 (0.5)	1.1 (0.3)	2.6 (7.1)	3.8 (18.7)	1.9 (6.9)	4.9 (32.1)	9.0
Atrazine + tembotrione + bentazone at 800+90+960 g ha^{-1}	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.2)	1.0 (0.1)	3.3 (12.2)	3.2 (12.3)	1.7 (4.5)	4.4 (25.2)	9.9
Atrazine + tembotrione + halosulfuron at 800+90+67.5 g ha^{-1}	1.1 (0.2)	1.0 (0.1)	1.1 (0.3)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	3.1 (10.4)	2.4 (6.3)	2.3 (12.1)	4.0 (22.6)	9.0
Weedy Check	2.8 (8.1)	2.4 (6.6)	7.7 (63.2)	3.3 (12.8)	4.7 (21.9)	5.2 (34.3)	5.8 (35.8)	4.2 (21.3)	3.2 (14.8)	15.0 (242.8)	0.0
LSD at 5%	0.355	0.366	0.703	0.496	0.42	0.682	0.926	0.839	NS	1.142	-

Data were subjected to square root transformation ($\sqrt{x+1}$) for statistical analysis and original values are in parentheses

Table 2. Effect of crop establishment methods and weed control treatments on weed dry weight in maize at 75 DAS

Treatment	*E. crus-galli*	*E. colonum*	*D. aegypticum*	*Digitaria sanguinalis*	*Commelina benghalensis*	*D. arvensis*	*T. portulacastrum*	*C. rotundus*	*Physalis minima*	Other weeds	Total weeds	Weed control efficiency (%)
Tillage options												
Zero tillage (ZT)	1.7 (3.0)	1.3 (1.2)	2.5 (9.1)	1.5 (2.1)	1.9 (8.1)	1.4 (2.3)	1.8 (2.8)	1.8 (2.9)	2.0 (7.5)	1.3 (1.8)	5.3 (40.8)	74.8
Zero tillage (ZT) + residue 6 t ha^{-1}	1.1 (0.6)	1.1 (0.4)	2.1 (5.6)	1.3 (1.2)	2.0 (6.8)	1.1 (0.7)	1.1 (0.5)	1.1 (0.5)	1.6 (3.6)	1.0 (0.2)	3.4 (20.0)	78.6
Conventional tillage (CT)	1.6 (3.5)	1.6 (3.3)	2.2 (6.9)	2.8 (12.9)	1.9 (7.5)	1.7 (4.6)	2.1 (4.9)	2.9 (9.2)	2.2 (8.4)	2.2 (6.2)	7.1 (67.4)	72.0
LSD at 5%	NS	0.353	0.302	0.342	NS	NS	NS	1.151	NS	NS	1.053	-
Weed control												
Atrazine at 1000 g ha^{-1}	1.1 (0.3)	1.37 (1.0)	4.5 (19.9)	3.6 (16.8)	1.0 (0.0)	1.0 (0.0)	1.3 (1.1)	2.03 (4.0)	1.1 (0.3)	1.5 (2.6)	6.6 (46.1)	73.4
Tembotrione at 110 g ha^{-1}	1.1 (0.5)	1.27 (0.9)	1.4 (1.5)	1.1 (0.5)	1.0 (0.2)	1.0 (0.0)	1.4 (1.4)	2.9 (10.8)	1.0 (0.2)	1.9 (4.3)	4.1 (20.3)	89.7
Atrazine + tembotrione at 800+90 g ha^{-1}	1.0 (0.0)	1.0 (0.0)	1.0 (0.1)	1.0 (0.2)	1.1 (0.5)	1.0 (0.0)	1.6 (2.3)	2.0 (4.6)	1.2 (0.6)	1.4 (2.2)	2.9 (10.5)	95.0
Atrazine + tembotrione + bentazone at 800+90+960 g ha^{-1}	1.1 (0.5)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.1 (0.3)	1.0 (0.0)	1.7 (2.7)	1.4 (1.4)	1.2 (0.8)	1.3 (1.8)	2.6 (7.4)	96.3
Atrazine + tembotrione + halosulfuron at 800+90+67.5 g ha^{-1}	1.3 (0.9)	1.0 (0.0)	1.0 (0.1)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	1.4 (1.3)	1.5 (1.5)	1.3 (1.0)	1.4 (1.9)	2.5 (6.7)	96.4
Weedy Check	3.3 (11.9)	2.6 (8.0)	4.6 (21.5)	3.4 (15.0)	6.5 (43.8)	3.7 (15.2)	2.5 (7.4)	1.7 (2.9)	5.8 (36.1)	1.7 (3.6)	12.6 (165.4)	0.0
LSD at 5%	0.457	0.406	0.489	0.559	0.588	0.386	0.613	0.609	0.685	NS	0.844	-

Data were subjected to square root transformation ($\sqrt{x+1}$) for statistical analysis and original values are in parentheses control treatments had significant effect on all the major grass weeds. In comparison to untreated control, all the herbicide treatments caused significant reductions in the dry weight of all the grass weeds except *D. aegypticum* and *D. sanguinalis* dry weight with atrazine application at 1000 g/ha. Tank mix combination of atrazine + tembotrione + bentazone or atrazine + tembotrione + halosulfuron caused complete kill of all the grass weeds except *E. crus-galli.* The significant effect of crop establishment methods was observed on *C. rotundus* dry weight. In general, the lowest weed dry weights were found in ZT with residue retention. The dry weight of *C. rotundus* recorded under ZT, ZT+R and CT were 2.9, 0.5 and 9.2 g/m^2, respectively. Also, the various herbicide treatments in comparison to untreated control significantly reduced the dry weights of four major broad-leaved weeds namely *D. arvensis, P. niruri, T portulacastrum,* and *P. minima* as well as sedge weed *C. rotundus*. Application of atrazine at 1000 g ha^{-1} was very effective in controlling *D. arvensis.* Tembotrione alone at 110 g ha^{-1} was also effective in controlling *D. arvensis and P. minima.* However, tank mix combination of atrazine + tembotrione was at par with three-way combinations of atrazine + tembotrione + bentazone 800 + 90 + 960 g ha^{-1} as well as atrazine + tembotrione + halosulfuron 800 + 90 + 67.5 g ha^{-1}. The tank mixture of atrazine + tembotrione + bentazone and atrazine + tembotrione + halosulfuron were significantly superior to other herbicide treatments in reducing the *C. rotundus* dry weight. The total weed dry weight at 75 DAS was also significantly less with the ZT +R treatment compared to ZT and CT crop establishment method. The total weeds dry weight recorded under ZT, ZT+R and CT was 40.8, 20.0 and 67.4 g/m^2. Zero tillage without residue retention was also superior to CT in reducing the total weed dry weight. Among weed control treatments, all the herbicidal treatments significantly reduced the weed dry weight over weedy check treatment. However, the two and three herbicides tank mixture treatments were better than the alone application of either atrazine or tembotrione. Among three herbicide tank mixture treatments, the maximum reduction in weed dry weight was observed with the combination of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1}. Among tillage practices, ZT+R recorded highest WCE (78.6 %) followed by ZT and CT. The weed control efficiency was the highest with application of tank mixture of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1} followed by atrazine + tembotrione + bentazone at 800 + 90 + 960 g ha^{-1} as compared to alone application of either atrazine or tembotrione. Our results showed the positive effect of straw mulch for controlling different weed species in maize as compared to no mulch treatment. Similarly, various research workers (Sarwar *et al.,* 2013; Shah *et al.,* 2014; Dutta *et al.,* 2016; Chhokar *et al.*, 2020) also observed that straw mulch recorded lesser weed infestation in comparison to no mulch.

Table 3: Effect of tillage options and weed control treatments on plant height, biomass, cob weight, grain yield, stover yield, net returns and B C ratio of maize.

Treatment	Biomass (q/ha)	Grains/ cob (no.)	Grain yield (q/ha)	Stover yield (q/ha)	Net returns (Rs ha^{-1})	B C ratio
Tillage options						
Zero tillage (ZT)	293.7	454	82.5	159.4	114341	2.4
Zero tillage (ZT) + residue 6 t ha^{-1}	311.5	471	85.3	173.7	119851	2.5
Conventional tillage (CT)	262.9	451	78.4	134.4	104086	2.1
LSD at 5%	16.5	15.33	3.5	12.7	6609	0.1
Weed control						
Atrazine at 1000 g ha^{-1}	287.2	448	79.6	153.9	110310	2.4
Tembotrione at 110 g ha^{-1}	297.9	470	82.7	160.2	113870	2.4
Atrazine + tembotrione at 800+90 g ha^{-1}	298.9	479	85.7	160.5	119453	2.5
Atrazine + tembotrione + bentazone at 800+90+960 g ha^{-1}	302.1	479	86.6	164.8	119824	2.4
Atrazine + tembotrione + halosulfuron at 800+90+67.5 g ha^{-1}	300.5	481	87.1	162.88	118954	2.3
Weedy Check	249.4	397	70.7	132.86	94143	2.1
LSD at 5%	10.05	12.83	3.60	8.09	6599	0.14

Effect on crop performance

The effect of tillage options and herbicide treatments on crop performance is shown in Table 3. Out of three tillage options, ZT + residue 6 t ha^{-1} recorded the maximum crop biomass (310.96 q/ha) and was followed by ZT (293.72 q/ha) and CT (262.93 q/ha). The crop grown using conventional tillage practice recorded minimum biomass. The differences were significant only between ZT+R and CT treatments and the crop biomass accumulated under ZT without residue was statistically at par with ZT with residue. This may be attributed to the fact that mulch helped in controlling the weeds and changed the microclimatic conditions near plant base leading to better growth of roots and more availability of nutrients leading to higher dry matter accumulation. Among weed control treatments, the maximum crop biomass (302.16 q/ha) was found in tank mix application of atrazine + tembotrione + bentazone at 800 + 90 + 960 g ha^{-1} and was followed by atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1} with biomass accumulation of 300.58 q/ha. In comparison to untreated control (249.47 q/ha), all the herbicide treatments showed significant superiority in biomass accumulation. Among herbicide treatments, only application of atrazine 1000 g ha^{-1} registered significantly lesser biomass compared to rest of herbicide application treatments.

Among three tillage practices, significantly higher number of grains/cob observed in ZT + R. Better grains per cob recorded under ZT + R system compared to that of CT method might be due to fewer weed infestation as well as the better soil physio-chemical properties. Similarly, the improved maize yield with conservation tillage practices has been reported by various workers (Memon *et al.,* 2013). Among various weed control treatments, the highest number of grains/cob (481) were recorded with the application of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1}, which was found to be at par with all chemicals except atrazine at 1000 g ha^{-1}. The better yield attributes under herbicide treated plots were due to significant reduction in weed competition as evident from weed dry weights data leading to better growth and development of maize plants. Similar results were reported by Chhokar *et al.*, (2020).

The maximum (173.75 q/ha) and minimum (134.43 q/ha) stover yields were recorded with ZT + R and CT, respectively. Zero tillage with and without residue had significantly higher stover yield compared to CT. The maximum and minimum maize grain yields were also recorded with the ZT +R (85.32 q/ha) and CT (78.45 q/ha) treatment, respectively. The ZT with and without residue produced significantly more maize grain yield than produced with CT treatment. Statistically ZT+R and ZT were not different for the grain yield. Earlier researchers (Shah *et al.,* 2014; Dutta *et al.*, 2016) also reported higher grain and stover yield in mulch treatments as compared to no mulch.

Among various weed control treatments, untreated weedy check produced the lowest stover yield (132.86 q ha^{-1}) and it was significantly inferior to all the herbicide treatments. The application of tank mix combination of atrazine + tembotrione + bentazone 800 + 90 + 960 g ha^{-1} resulted in the highest stover yield of 164.89 q ha^{-1} followed by 162.88 q/ha obtained with application of atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1}. Weedy check treatment recorded significantly the lowest grain yield of 70.73 q ha^{-1} and it was due to higher weed infestation. Walia *et al.* (2005) also observed significant reduction in grain yield of maize due to weed competition. While, Rana *et al.* (2017) also found significant increase in grain yield with application of tembotrione. Among herbicide treatments, tank mix combinations treatments *i.e.* atrazine + tembotrione, atrazine + tembotrione + bentazone and atrazine + tembotrione + halosulfuron were statistically at par among themselves but significantly better to standard treatment of atrazine alone application. The three groups of herbicide combinations were significantly better yielder compared to alone application of either atrazine or tembotrione. Higher grain yield in these treatment combinations could be attributed to drastic decrease in weed population and dry matter accumulation by weeds, thereby better crop growth and yield attributes. These findings were in accordance with the findings of Swetha *et al.* (2015), Sarwar *et al.* (2013) and Chhokar *et al.* (2019).

Economics

Net returns and benefit cost ratio differed significantly due to different tillage and weed control treatments (Table 3). Among tillage options, zero tillage with residue recorded the maximum net returns (RS 119851). The highest B C ratio was obtained with ZT+R (2.57) followed by ZT (2.47). The CT had the lowest net returns and benefit cost ratio. The higher net returns under ZT+R mulch treatment was attributed to higher grain and stover yield as well as lower cost of cultivation compared to CT system. Shah *et al.* (2014) also reported that straw mulch treatments recorded significantly higher net returns than no mulch treatment. Thus, improved profitability was recorded with the adoption of no-till system.

Among the weed control treatments, maximum net returns (Rs 119824/ha) and benefit cost ratio (2.53) were under atrazine + tembotrione + bentazone and atrazine + tembotrione, treatments, respectively. The higher net return under these weed control treatments was attributed to better weed control efficiency and higher grain and stover yield of maize as compared to unweeded check. Rana *et al*. (2017) also reported that maximum benefit cost ratio was obtained with application of tembotrione.

Based on this study, it can be concluded that for achieving effective weed control, and higher maize yield and profitability, combinations of conservation tillage (zero tillage + 6 t ha^{-1} residue) with tank mixture of either atrazine + tembotrione + halosulfuron at 800 + 90 + 67.5 g ha^{-1} or atrazine + tembotrione + bentazone at 900 + 90 + 960 g ha^{-1} as post-emergence can be adopted.

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Author's contribution

Conceptualization of research (DC and RSC); Designing of the experiments (DC, RSC and SRS); Contribution of experimental materials (RSC, SCG and NK); Execution of field/lab experiments and data collection (DC, SRS and GLY); Analysis of data and interpretation (RSC and SCG); Preparation of the manuscript (DC, RSC and SRS).

Conflicts of Interest

The authors declare no conflict of interest.

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