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RESEARCH PAPER

Performance evaluation of quality protein hybrid maize under different planting and weed control methods

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Abstract: A field experiment was conducted at Agronomy research farm, CCS Haryana Agricultural University, Hisar, Haryana during *kharif* 2012. Three main plot treatments and six sub plot treatments were tested using a split plot design with four replications. In main plots, three planting methods namely Conventional Tillage (CT), Zero Tillage (ZT) and Furrow Irrigated Raised Bed System (FIRBS) were evaluated. In the sub-plots, the evaluation encompassed three pre-emergence herbicides atrazine @ 750 g/ha, atrazine @ 500 g/ha + hand weeding at 35 DAS and pendimethalin @ 1000 g/ha. Additionally post-emergence herbicides., tembotrione (Laudis 42% SC) @ 120 g /ha + S 1000 ml/ha (10-15 DAS/2-4 leaf stage) were compared with weed free and weedy check conditions. Important weed species observed in the experimental plots were *Cyperus rotundus*, *Echinochloa colona*, *Trianthema portulacastrum* and *Digera arvensis.* Application of atrazine (750 g/ha) recorded significantly reduced weed population and weed dry weight. This treatment also exhibited higher weed control efficiency and resulted in improved crop growth and higher crop yields. Whereas, in planting methods, zero tillage recorded lowest weed population, dry weight of weeds and higher weed control efficiency with higher crop growth and crop yield. Pre-emergence application of atrazine (750 g/ha) under zero tillage was found effective for controlling weeds with higher crop yield in *kharif* maize.

Keywords: Atrazine · Hybrid maize · Planting methods · Tembotrione · Weed control efficiency

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Introduction

Cereals play a vital role as a primary source of nutrition for a significant portion of the global population, particularly in regions such as Southeast Asia and Sub-Saharan Africa. Among these cereals, wheat, rice, and maize stand out as the predominant staples, serving as essential dietary components for millions of people in these areas. Maize is known as the Queen of cereals due to its high yield potential and wider utilization for diverse purposes (Sethi *et al*., 2021). The global consumption pattern of maize is: feed-61 per cent, food-17 per cent, and industry-22 per cent. Currently, about 1151.7 million MT of maize is being produced together by over 170 countries from an area of 200.96 m ha with average productivity of 5.73 t/ha (Anonymous, 2023). India produced 36 million MT of maize in an area of 10.1 m ha during 2022-23 with average productivity of 3.56 t/ ha (Anonymous, 2023). The primary maize-producing states in India, including Karnataka, Madhya Pradesh, Maharashtra, Tamil Nadu, West Bengal, Rajasthan, Bihar, Andhra Pradesh, Uttar Pradesh, Telangana, Gujarat, Punjab, Haryana, and Odisha, collectively contribute to more than 95 per cent of the country's total maize production. Haryana state has an ample scope to further increase acreage and productivity of maize as it can be a strong candidate in the drive of crop diversification to displace puddled transplanted rice.

The maize cultivation occurred throughout the year in all states of the country for various purposes including grain, fodder, green cobs, sweet corn, baby corn and pop corn in peri-urban areas. Maize is renowned for its broad adaptability and its versatility in being used for food, animal feed, and various industrial applications (Murdia *et al*., 2016). Maize is an important source of vitamins and minerals like Ca, P, S and small amounts of Na. Its flour is considered to be a good diet for heart patients due to its low gluten (protein) content (Rasool and Khan, 2016). The productivity of maize in India is relatively very low compared to developed countries of world and the yield can be increased with many agronomic practices. Among the various agronomic practices that can impact maize productivity, weed management is widely recognized as a crucial factor in achieving higher maize yields (Gharde *et al*., 2018).

Weeds are serious problem in *kharif* maize since its sowing time coincides with the commencement of monsoon rains and congenial growing conditions i.e., high temperature and humidity. Addition of farm yard manure (FYM) during *kharif* season also encourages weed growth in this crop. Initial slow growth and wider row spacing coupled with congenial environmental conditions allows luxuriant weed growth, with yield reduction from 28-100 per cent (Dass *et al*., 2012). Weed infestation is supreme importance among the biotic factors that are responsible for low maize grain yield. Weed control practices in maize resulted in 77 to 96.7 per cent higher grain yield than the weedy check (Rani *et al*., 2020). Weeds can exert a detrimental influence on maize growth and yield by competing for essential resources like nutrients, light, and water. In this context, it becomes imperative to implement effective weed management strategies to mitigate these adverse effects and optimize maize production. Achieving this goal typically involves a comprehensive approach that combines mechanical, chemical, and cultural methods of weed control (Alptekin *et al*., 2023). Manual weeding is most popular among the farmers but it is expensive, laborious and time-consuming. Herbicides usage for weed control is an important alternative to manual weeding because they are cheaper, faster and gives better weed control (Rani *et al*., 2020).

Maize crop management involves decision making on several cultural practices aimed to maximize grain yields like planting methods, improved varieties and proper nutrient management. Interventions in the form of new resource conservation technologies (RCTs) like zero-tillage and furrow irrigated raised bed system (FIRBS) coupled with crop diversification by including maize in place of rice may be a viable solution (Hossain *et al*., 2020). The mean grain yield of hybrid genotypes grown on FIRBS yielded 44 per cent more than conventional practice and 12 per cent with no-till practices (Jat *et al*., 2007). Higher maize yield on bed planting as compared to conventional tillage was also reported by Basavanneppa *et al*. (2017). The total water use in maize under FIRBS and no-tillage were remarkably reduced by 84.3 and 62.8 per cent, respectively compared to conventional tillage practice. Weeds are accountable for causing a substantial global loss of approximately 37 per cent in total maize production. In the contemporary agricultural landscape, chemical methods have gained prominence and are now considered the predominant approach for weed management in maize cultivation (Sharma and Rayamajhi, 2022). Efficacy of different herbicides may also vary with different planting methods in any crop including maize. Most of the pre-emergence (PRE) herbicides (most commonly and widely used herbicides atrazine or pendimethalin) provide only narrow spectrum weed control in maize (Tetarwal *et al*., 2022), and therefore, an attempt was done to find out an effective and economical method for weed control in maize using post emergence (POST) herbicides.

Materials and methods

A field experiment was conducted at Agronomy research farm, CCS Haryana Agricultural University, Hisar, Haryana during *kharif* 2012. The experimental site is located at 29°16'N latitude and 75°7'E longitude at the mean sea elevation of 215.2 m in north-west part of India. The climate of the area is semiarid type, with very hot summers (40-46 °C) and relatively cool winters (1.5-4 °C) and main characteristics of climate in Hisar are dryness, extremes of temperature, and scanty rainfall (around 450 mm).

Figure 1 show that temperature ranged between 16.2 to 37.8 ºC, average relative humidity fluctuated between 53.5 to 88.5 per cent, bright sunshine hours ranged from 1.4 to 10.1 hrs/day and crop received 393.6 mm of rainfall during the entire crop growing season.

The texture of the surface soil of the experimental field was sandy loam, that was low in organic carbon and nitrogen (230 kg/ha), medium in available phosphorus (19 kg/ha), high in potassium (310 kg/ha) and slightly alkaline (pH 7.9) in reaction. Hybrid maize HQPM-1 was planted on July 19, 2012, using the dibbling method. The spacing between rows was set at 70 cm, and the distance between individual plants within the row was 22.5 cm. The seeds were sown at a depth of 5-6 cm. Harvesting of the maize crop was completed on October 23, 2012.

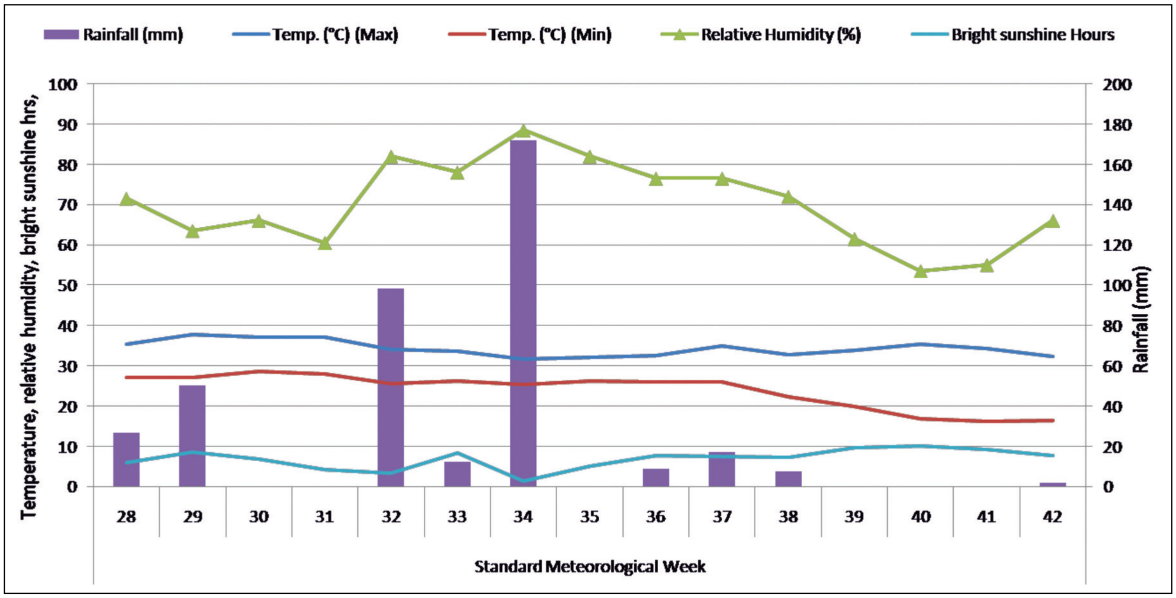

Figure 1. Weekly meteorological observatory data during experimental year

Three main plot treatments [planting methods including CT, ZT and FIRBS] and six sub plot treatments [three pre emergence herbicides *viz.*, atrazine 750 g/ha, atrazine 500 g/ha + hand weeding at 35 DAS and pendimethalin 1000 g/ha and one post-emergence herbicides *viz.*, tembotrione (Laudis 42% SC) 120 g/ha + S 1000 ml/ha (10-15 DAS/2-4 leaf stage) along with weed free and weedy check] were tested using a split plot design with four replications. Herbicide atrazine and pendimethalin were applied as pre-emergence (PRE) spray to the soil surface as per treatment on the day of sowing and tembotrione was applied as post emergence (POST) spray to the foliage as per treatment at 15 DAS. Herbicides were applied through knapsack sprayer fitted with flat fan nozzles delivering 700 L water/ha (for PRE and 325 L water/ha for POST application) and sufficient moisture was maintained in the soil at the time of application.

Observations for total weed density were recorded by randomly placing quadrate (0.25 m^2) in each plot at maturity. Important weed species observed in the experimental plots were *Cyperus rotundus*, *Echinochloa colona*, *Trianthema portulacastrum* and *Digera arvensis.* For calculating dry matter accumulation (g/m^2) of weeds, the weeds taken with a quadrate were dried in oven at 65 ± 5 ºC. The dried samples were weighed and expressed as g/m^2. Weed control efficiency was calculated with the help of formula:

$$\text{WCE (\%)} = \frac{W_2 - W_1}{W_2} \times 100$$

Where, W_2 = Dry weight of weeds in weedy check plot
W_1 = Dry weight of weeds in treatment plot

The plant height was measured from the base of the plant to collar of the flag leaf and expressed in cm. Three plants were randomly selected from each plot and carefully uprooted to take dry matter accumulation. These samples were dried at 70 ºC in oven to achieve a constant weight. The number of cobs per meter row length was recorded in each plot at physiological maturity. Grain number per cob was calculated from the grain weight per cob and the corresponding 100 grain weight as follows:

$$\text{Grain number per cob} = \frac{\text{Grain weight per cob (g)}}{\text{Weight of 100 grains (g)}} \times 100$$

After harvesting the net area of individual plot, the bundles were sun dried for 4-5 days and weight was taken from each plot before threshing. After sun drying, the biomass, representing the biological yield, was threshed and subsequently weighed to determine the grain yield (kg/ha). The grain yield so obtained was deducted from the biomass of the harvested crop to compute the stover yield. Harvest index, which is the ratio of economic yield to biological yield (expressed in per cent), was worked out by the following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

The experimental data were statistically analyzed by the methods of analysis of variance (ANOVA) as described by Panse and Sukhatme (1978).

Results and discussion

Effect on weed density

There was significant variation in weeds density in maize due to different planting and weed control methods. ZT recorded the lowest number of total weeds density compared to FIRBS and CT (Table 1). This might be due to lower weed population due to crop residue of previous crop which acted as mulch resulting into lower crop-weed competition in ZT than other treatments. These results are in line with Khedwal *et al.* (2017) where they observed lower grassy weeds in zero tillage as compared to raised bed planting method. Dahal and Karki (2014) have also reported that zero tillage had significantly lowered density and dry weight of grassy weeds and broad leaf weeds as compared to conventional tillage in maize crop. Ghosh *et al.* (2023) also reported that zero tillage reduced weed densities compared with conventional tillage in maize-wheat-mungbean system. In the present study, significantly lower density of weeds was also observed in raised seed bed as compared to conventional tillage. Gaurav *et al.* (2018) also reported lesser weeds in raised beds as compared to the conventional system.

Maximum weed density was observed in weedy check while in weed free plots, which received hand weeding at regular intervals, indicated that complete weed control was possible only by local control methods. These results align with the research conducted by Alptekin *et al.* (2023). The lowest weed density was observed in plots treated with atrazine at a rate of 750 g/ha compared to other herbicide treatments. Conversely, among the various herbicidal treatments, the highest weed density was recorded in plots treated with atrazine at a rate of 500 g/ha along with hand weeding at 35 days after sowing (1HW 35 DAS). This weed density was comparable to the weed densities observed in plots treated with tembotrione at 120 g/ha along with S at 1000 ml/ha and pendimethalin at 1000 g/ha. Importantly, these herbicide treatments exhibited a significant difference in weed density compared to the weedy check plots. These results are supported by Kaur *et al.* (2020) who observed that significantly less density of weeds, including *C. rotundus*, was recorded under atrazine at dose of 0.8 and 1.0 kg/ha with or without residue in Punjab. Barla *et al.* (2016) also reported lower weed density (including sedges) with application of atrazine 1.0 kg/ha as pre-emergence in maize crop. Similarly, Kakade *et al.* (2016) and Iqbal *et*

Table 1. Effect of different planting methods and weed control treatments on density of weeds in maize

Treatments	Density of weeds (No./m^2) at maturity			
	C. rotundus	*E. colona*	*T. portulacastrum*	*D. arvensis*
Planting methods				
Conventional tillage (CT)	4.08 (15.62)	3.41 (10.66)	3.15 (8.91)	2.37 (4.62)
Zero tillage (ZT)	3.79 (13.37)	3.15 (8.95)	2.87 (7.25)	1.85 (2.41)
Furrow irrigated raised bed system (FIRBS)	4.06 (15.50)	3.29 (9.83)	3.07 (8.45)	2.25 (4.08)
SEm$\pm$	0.10	0.08	0.07	0.07
CD (p=0.05)	0.26	0.25	0.18	0.19
Weed control treatment				
Atrazine 750 g/ha (PRE)	3.87 (14.00)	3.11 (8.66)	2.71 (6.33)	1.89 (2.58)
Atrazine 500 g/ha (PRE)+ 1 HW 35 DAS	4.10 (15.83)	3.38 (10.42)	3.11 (8.66)	2.10 (3.41)
Pendimethalin 1000 g/ha (PRE)	4.07 (15.58)	3.41 (10.66)	3.17 (9.08)	2.14 (3.58)
Tembotrione 120 g/ha + S 1000 ml/ha (POST)	4.07 (15.58)	3.44 (10.83)	3.17 (9.08)	2.61 (5.83)
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Weedy check	5.39 (28.00)	4.40 (18.33)	4.13 (16.08)	2.80 (6.83)
SEm$\pm$	0.07	0.08	0.10	0.07
CD (p=0.05)	0.19	0.24	0.29	0.20

Original data given in parenthesis were subjected to square root ($\sqrt{x+1}$) transformation before analysis *al.* (2020) reported decreased weed concentration and dry weight of the weed with pre-emergence application of atrazine @ 1.0 to 1.2 kg/ha.

Effect on weed dry weight and WCE

Weed dry weight also differed significantly due to various planting and weed control methods and significantly lower dry weight of weeds along with higher WCE was recorded under the ZT compared to CT and FIRBS (Table 2). This might be due to the fact that ZT recorded the lowest number of total weeds density compared to FIRBS and CT. This aligns with the findings of Gaurav *et al.* (2018), where researchers observed a tillage operation resulted in significant reduction in dry weight of weeds at all the growth stages in maize. Dahal and Karki (2014) have also reported that zero tillage had significantly lowered dry weight of grassy weeds and broad leaf weeds as compared to conventional tillage in maize crop.

Among weed control treatments, significantly higher weed dry weight was recorded under weedy check compared to other methods. In the present study, this was mainly due to higher and uninterrupted growth of weeds which made best use of the growth resources. Among weed control methods, atrazine @ 750 g/ha attained lowest weed dry weight as compared to other treatments. Weed free treatment attained highest WCE**,** while, lowest was in weedy check. Maximum WCE was recorded under atrazine @ 750 g/ha compared to rest of the treatments. The higher WCE with these treatments could be attributed to the lower weed population and total weed dry weight. These results are also in consensus with Barla *et al.* (2016) who reported lower weed dry weight with application of atrazine 1.0 kg/ha as pre-emergence in maize crop. Another report by Kaur *et al.* (2020) also observed significantly less dry weight of weeds with application of atrazine 0.8 to 1.0 kg/ha as pre-emergence in maize crop. Kakade *et al.* (2016) also reported that, among all the herbicidal treatments, application of 50 per cent WP atrazine at 1.0 kg/ha as pre-emergence demonstrated the highest weed control efficiency with a range of values extending from 75.52 per cent to 83.10 per cent except for *Cyperus* spp., which showed only 2.84 per cent efficiency. Iqbal *et al.* (2020) reported that the maximum weed control efficiency, along with remarkably decreased weed concentration and dry weight of the weed, was registered in the pre-emergence application of atrazine at 1.2 kg/ha.

Effect on crop growth and yield attributes

Among planting methods, maximum plant height was attained in ZT which was at par with FIRBS but significantly higher than CT at maturity (Table 3). The

Table 2. Effect of different planting methods and weed control treatments on dry weight of weeds and WCE in maize

Treatments	Dry weight of weeds (g/m^2) at maturity				WCE (%)
	C. rotundus	*E. colona*	*T. portulacastrum*	*D. arvensis*	at maturity
Planting methods					
Conventional tillage (CT)	4.42 (18.55)	3.25 (9.56)	2.79 (6.79)	2.07 (3.29)	42.66
Zero tillage (ZT)	4.20 (16.66)	3.01 (8.06)	2.50 (5.26)	1.69 (1.87)	52.18
Furrow irrigated raised bed system (FIRBS)	4.39 (18.31)	3.13 (8.82)	2.69 (6.22)	1.99 (2.98)	45.45
SEm±	0.06	0.05	0.05	0.04	–
CD (p=0.05)	0.16	0.16	0.14	0.12	–
Weed control treatment					
Atrazine 750 g/ha (PRE)	4.26 (17.17)	2.97 (7.81)	2.41 (4.80)	1.73 (2.01)	52.27
Atrazine 500 g/ha (PRE)+ 1 HW 35 DAS	4.47 (18.94)	3.22 (9.35)	2.74 (6.49)	1.87 (2.50)	44.02
Pendimethalin 1000 g/ha (PRE)	4.48 (19.05)	3.24 (9.52)	2.76 (6.64)	1.89 (2.56)	43.29
Tembotrione 120 g/ha + S 1000 ml/ha (POST)	4.44 (18.70)	3.28 (9.74)	2.75 (6.58)	2.30 (4.30)	40.96
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100.00
Weedy check	5.85 (33.19)	4.18 (16.47)	3.61 (12.04)	2.43 (4.90)	0.00
SEm±	0.07	0.08	0.08	0.07	–
CD (p=0.05)	0.17	0.22	0.24	0.19	–

Original data given in parenthesis were subjected to square root ($\sqrt{x+1}$) transformation before analysis plant dry matter accumulation in ZT was significantly higher than CT and FIRBS which were at par with each other. Whereas, minimum values of these parameters were in CT which was followed by FIRBS. Number of cobs per meter row length and number of grains per cob were not affected by different planting. Results are also supported by the findings of Khedwal *et al.* (2017).

Among various weed control treatments, weed free treatment had maximum plant height, plant dry matter accumulation and number of grains per cob which remained significantly higher than all herbicidal treatments (which remained at par with each other) while significantly lower values of these parameters were recorded in weedy check as compared to other treatments. Different weed control treatments failed to affect number of cobs per meter row length. These results are also supported by the finding of Barla *et al.* (2016). Kaur *et al.* (2020) and Iqbal *et al.* (2020) also recorded the higher values for all the growth and yield parameters with the weed free treatments, followed by application of atrazine as pre-emergence as compared to the untreated control.

Effect on crop yield and harvest index

Crop yield (grain yield, stover yield and biological yield) and harvest index of maize were significantly affected by different planting and weed control methods (Table 4). Zero tillage provided maximum harvest index and crop yield which was higher than FIRBS and CT but it was statistically at par with both. Lowest grain yield was obtained by CT compared to ZT and FIRBS. This might be due to better plant stand and more number of grain/ cob, and lesser weed infestation under ZT. Similarly, Khedwal *et al.* (2017) also noticed that tillage operation resulted in significant effect on yield of maize.

Among various weed control treatments, significantly higher crop yield was observed in weed free (presented in Table 4). It was mainly due to minimum crop-weed competition through out the crop growth period, thus enabling the crop for maximum utilization of nutrients, moisture, light and space which had influence on growth components and yield attributes. Among the herbicidal treatments, maximum crop yield was recorded in atrazine @ 750 g/ha. Kakade *et al.* (2016) also recorded the higher maize yield with application of 50 per cent WP atrazine at 1.0 kg/ha as pre-emergence as compared to the untreated control. In current study, lowest yield was recorded in weedy check as a consequence of greater removal of nutrients and moisture by weed and severe crop weed competition resulting in poor sources and sink development with poor yield attributes. These results are conformity with finding of Barla *et al.* (2016) and Kaur *et al.* (2020). Iqbal *et al.* (2020) also reported that

Table 3. Effect of different planting methods and weed control treatments on growth and yield attributes of maize

Treatments	Plant height (cm) at maturity	Plant dry matter accumulation (g/m^2) at maturity	No. of cobs per meter row length	No. of grains per cob
Planting methods				
Conventional tillage (CT)	182.42	305.59	5.75	471.94
Zero tillage (ZT)	187.17	316.82	5.95	477.72
Furrow irrigated raised bed system (FIRBS)	185.25	306.54	5.87	472.76
SEm±	1.00	1.26	0.12	3.47
CD (p=0.05)	3.55	4.46	NS	NS
Weed control treatment				
Atrazine 750 g/ha (PRE)	186.22	313.56	6.00	478.66
Atrazine 500 g/ha (PRE)+ 1 HW 35 DAS	186.85	312.45	5.83	477.57
Pendimethalin 1000 g/ha (PRE)	186.78	312.20	5.75	477.59
Tembotrione 120 g/ha + S 1000 ml/ha (POST)	186.63	312.06	5.83	477.77
Weed free	190.81	323.99	6.16	518.78
Weedy check	172.40	283.64	5.58	414.47
SEm±	0.56	1.95	0.20	7.26
CD (p=0.05)	1.61	5.57	NS	20.77

Table 4. Effect of different planting and weed control treatments on yields and harvest index of maize

Treatments	Grain yield (q/ha)	Stover yield (q/ha)	Biological yield (q/ha)	Harvest index (%)
Planting methods				
Conventional tillage (CT)	48.50	64.53	113.03	42.91
Zero tillage (ZT)	52.43	68.76	121.19	43.26
Furrow irrigated raised bed system (FIRBS)	49.60	65.70	115.3	43.02
SEm±	0.87	0.71	1.42	-
CD (p=0.05)	2.42	2.02	4.38	-
Weed control treatment				
Atrazine 750 g/ha (PRE)	51.86	66.73	118.59	43.73
Atrazine 500 g/ha (PRE)+ 1 HW 35 DAS	49.76	66.00	115.76	42.99
Pendimethalin 1000 g/ha (PRE)	51.46	65.63	117.09	43.95
Tembotrione 120 g/ha + S 1000 ml/ha (POST)	49.40	65.96	115.36	42.82
Weed free	54.30	70.46	124.76	43.52
Weedy check	44.30	63.90	108.2	40.94
SEm±	0.46	0.20	0.33	-
CD (p=0.05)	1.46	1.89	2.84	-

the maximum maize yield was registered in the pre-emergence application of atrazine at 1.2 kg/ha.

Conclusion

Planting of maize in zero tillage condition resulted in significantly higher crop yield with lower weed density and their dry weight as compared to conventional tillage and FIRBS methods of planting. Pre-emergence application of atrazine (750 g/ha) under zero tillage was found effective for controlling weeds with higher weed control efficiency and getting higher crop yield in *kharif* maize. This study concluded that zero tillage for maize cultivation, holds great promise for enhancing agricultural productivity and sustainability.

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