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Influence of Tillage and Weed Management Strategies on Weed Dynamics, Growth and Yield of Maize (*Zea mays* L.)

Samprikta Priyadarshini[1], Gurpreet Singh[1], Sandeep Menon[1], Ajeet Jakhad[1], Nachiketa[1] 10.18805/IJARe.A-6467

ABSTRACT

Background: This study evaluates the impact of various tillage systems and weed management practices on maize (*Zea mays* L.) growth and yield under Punjab agro-ecological conditions. During the time of study three tillage methods, conventional, minimum and zero tillage were combined with chemical weed control treatments focusing on post-emergence herbicides.

Methods: Design of experiment used was split plot design and total number of treatments were 21.

Result: The results show that, the combined mix application of mesotrione (70 g/ha) and atrazine (0.5 kg/ha) post-emergence under conventional tillage proved most effective in suppressing dominant weeds including *Parthenium hysterophorus* and *Amaranthus viridis*, resulting in the lowest total weed counts (8.26 no/m^2) and total weed dry weight (9.18 g/m^2). This treatment also produced superior crop growth parameters: highest plant height (217.09 cm), plant dry weight (153.81 g), cob length (15.20 cm), cob girth (13.31 cm), number of grai rows per cob (13.41), grain yield (4.39 t/ha) and stover yield (7.23 t/ha). While conventional tillage preserved soil health, conventional tillage combined with integrated chemical weed control maximized maize productivity by effectively reducing weed competition. The findings highlight that a balanced approach integrating optimal tillage and targeted herbicide application is vital for enhancing maize yield and sustainability in Punjab's maize cropping system.

Key words: *Kharif*, Maize, Tillage, Weed management practices.

INTRODUCTION

The cereals occupy about 54 per cent of the total cropped area of which maize occupies about 3.61 per cent of the total cropped area of India. In India, it is cultivated on an area of 8.69 million ha with a production of 21.81 million tonnes and the productivity of 2509 kg/ha contributing nearly 9.0 per cent of the total food-grains production in the country. Maize (*Zea mays* L.) is the world's widely grown highland cereal and primary staple food crop in many developing countries. It ranks third most important food grain crop after rice and wheat in India providing food, feed, fodder and also serves as a source of basic raw material for number of industrial products for food (25%), animal feed (12%), poultry feed (49%), starch (12%), brewery (1%) and seed (1%). Maize is known as 'Queen of Cereals' because of its high production potential and wider adaptability (Kumar *et al*., 2017). Grain alcohol can be made by fermenting and distilling maize starch, which has been hydrolysed and enzyme-treated to generate syrups, particularly high-fructose corn syrup, a sweetener. The major maize producing states are Karnataka, Rajasthan, Andhra Pradesh, Bihar, Maharashtra and Uttar Pradesh, which shared 60 per cent of area and 70 per cent production in the country (Trivedi *et al*., 2017). Maize has become an important component in efforts to achieve sustainable agricultural development because to its high productivity potential, resilience to varied agro-climatic conditions and multipurpose use as food, feed and raw material for biofuel and processing industries. Overall, the area under maize agriculture is declining due to changing climatic conditions, water constraints and other factors. (Jakhad *et al*., 2025).

[1]Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India.

Corresponding Author: Gurpreet Singh, Department of Agronomy, Lovely Professional University, Phagwara-144 411, Punjab, India. Email: gurpreet.25331@lpu.co.in

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India generates 516 mt of total crop residue annually, where of maize contribute 110 Mt, respectively (Mishra *et al*., 2024). Maize stover consists of approximately 50% stalks, 22% leaves, 15% cob and 13% husk on dry matter basis. Nowadays, the use of maize stalk as animal fodder is gradually decreasing and instances of field burning of stover is increasing due to non-availability of agriculture labour for timely harvest, increase in transportation cost and lack of sufficient time to take up next season crops (Indian Ecological Society, 2023).

Tillage is a mechanical manipulation action exerted on soil to modify soil conditions for nurturing crops. Tillage practice suppresses weeds, controls soil erosion and maintains adequate soil moisture. Tillage creates an ideal seedbed condition for seedling emergence, development and unimpeded root growth. Zero tillage, soil preparation is minimal, only enough to bury the seed. Zero tillage has been practiced since the beginning of agriculture until the

invention of animal-drawn ploughs. However, zero tillage with scientific bases, as an alternative to conventional tillage, began in the 1940s with the discovery of hormonal herbicides that allow farmers to control weeds without resorting to cultivators or hoes. Nowadays, there are approximately 90 million hectares worldwide under zero tillage. Zero tillage increases the mechanical resistance and the apparent density of soil and curbs the soil evaporation rate (Rahman *et al*., 2021). Under conventional agricultural systems, principle indicator of non-sustainability is soil erosion and declining of soil organic matter as mainly caused by: heavy field traffic induced degradation of soil structure, water and wind erosion leading to poor infiltration rate, crusting of soil surface, soil compaction, poor recycling of organic materials and also monocropping. Due to reduced tillage activity, soil compaction get decrease, soil micro flora activity get increase. It is helpful for the higher nutrient availability and improves soil structure by secreting sticky organic substances (Ganapathi *et al*., 2024).

Minimum tillage augments soil's physicochemical and biological properties through reducing soil erosion thus allowing soil organic matter build up. Minimum tillage can moderate soil surface conditions improve crop yields and increase net farm benefits due to reduced production costs. The key principle of minimum tillage is that it requires restriction of soil disturbance to a precise area where the crop is sown resulting into a minimum soil turnover of around 10% of the area for farming (Qamar and Khan, 2014). Conventional tillage is the use of agricultural practices that have minimal soil disturbances. Conventional tillage advanced the sowing date and resulted in proper placement of seed, early emergence of wheat seedlings and availability of higher nutrient and moisture content, which might have helped the crop to compete with the crop sown under conventional tillage and recorded higher values for available soil moisture storage in the soil profile (0-90 cm depth) than conventional tillage. Conventional tillage techniques on a sandy loam soil indicated that maize productivity was the highest (5.66 t/ha) under Fresh Irrigated Raised Bed system, followed by no till and the lowest (4.39 t/ha) in conventional tillage. Zero tillage had higher energy use efficiency in maize-wheat system. It might be due to lower energy input with zero tillage as compared to conventional tillage (Trivedi *et al*., 2017).

Worldwide yield losses in maize due to weeds are estimated to be around 37%. "Farmers usually give prime importance to few cultural practices and neglect other factors like weed control" (Tanisha *et al*., 2022). "Maize crops are infested with a variety of weeds and subjected to intense weed competition, resulting in huge losses. Weeds are a major problem in rainy season crops due to favourable growth conditions, primarily wide spacing and initial slow growth, frequent rains, causing huge losses ranging from 28 to 100%". To get maximum production of maize, weed management is compulsory. During early growth stages of maize due to continuous rainfall there was too much moisture in the field, hence cultural and mechanical methods of weed control are not possible (Singh *et al*., 2023).

Weeds are one of the greatest limiting factors to efficient crop production. As a consequence of structural and financing problems the cultural condition of the soil deteriorates and weeds proliferate; many species are hard to kill. The highest competitive ability of *Cirsium arvense* was found mainly in dry conditions and tillage intensity did not affect seed production of *Echinochloa crusgalli* and *Chenopodium album* in the canopy of maize, with the exception that *Echinochloa crusgalli* produced more 786 seeds in chisel than in mouldboard plough tillage maize crop. Conventional tillage can increase the density of perennial weeds and some annual grasses. Herbicides are used to retain weed-free conditions, during the early stage of growth, either by cultural or mechanical means or through pre-planting, pre-emergence and post-emergence herbicide applications (Kaul *et al*., 2023). Topramezone and mesotrione are relatively new herbicides registered for annual broadleaf weed control in maize. Carotenoid depletion causes disruption of chlorophyll in growing shoot tissues resulting in a bleaching effect which quickly turns necrotic in susceptible plant species. Mesotrione has been available commercially since 2001 and more recently topramezone has been available to maize growers as a competitive alternative herbicide. Annual grass control with topramezone or mesotrione is not well known. Mesotrione applied post-emergence provides control of *Echinochloa crus-galli* and *Digitaria species*, while *Setaria species* are not controlled. Keeping the above problem in maize, decided to plan "Impact of various tillage practices and weed control practices on growth and yield of Maize (*Zea mays* L.)". A search for a suitable cereal-legume intercropping system in Punjab that incorporates appropriate weed management practices has become imperative, as weed management was previously recognized as a critical factor in the system's ability to enhance productivity under Punjab conditions. The present work aimed to identify a suitable cereal legume intercropping system for Punjab that integrates effective weed management practices to enhance overall productivity.

MATERIALS AND METHODS

Study area

The experiment was conducted at the research farm of department of Agronomy, School of Agriculture at Lovely Professional University, Phagwara. This research location was situated in the Northern plain zone, specifically between 31°14′43″N latitude and 75°42′00″E at 243 m mean sea level. The meteorological data was gathered from the Agromet observatory of the university located at 31°14′41″N, 75°42′05″E latitude and longitude during the crop growing season. In the crop season temperatures was as high as 38.4°C and as low as 15.3°C.

Design and layout

Design of experiment used split plot design and total number of treatments were 21. The treatment details are in Main plot (Tillage practices) 1. Zero tillage, 2. Minimum tillage and 3. Conventional tillage and Sub plot (Weed control practices) 1. Control, 2. Weed free, 3. Atrazine 1.0 kg/ha (Pre-emergence), 4. Topramezone 140 g/ha (Post-emergence), 5. Mesotrione 125 g/ha (Post- emergence), 6. Topramezone 70 g/ha + Atrazine 0.5 kg/ha (Post-emergence) and 7. Mesotrione 70 g/ha + Atrazine 0.5 kg/ha (Post -emergence) and post-emergence herbicides were applied (typically 20 days after sowing, targeting weeds <6 inches tall), spray volume (200-300 L/ha) and nozzle type (flat-fan).

Variety (Maize)

Maize variety NK 7328 hybrid was sown as a flatbed with spacing 60 cm × 20 cm on July 2, 2024. 20 kg/ha (Maize) seed rate was used. The maize crop was harvested on October 20, 2024.

Weed studies

A 1 m^2 quadrant was used in each plot to randomly choose two spots from which the number of weeds was counted at monthly interval after planting. The count of weeds was given as the number of weeds per square meter. The weeds collected at monthly interval from each plot are gathered and stored in a brown paper bag. They are then dried in the sun for two days and placed in a hot air oven at a temperature of 70°C. Finally, dry matter weight was recorded. For weed data, the most commonly used transformation formula is the square root transformation, specifically $\sqrt{x+1}$ where x is the original weed dry weight value. This transformation helps stabilize variance and normalize the data for statistical analysis, especially when dealing with small or zero values.

Growth analysis of maize

The mean value per plant was determined for each experimental unit by recording the plant height of five tagged plants at growth stage. Initial plant population and final plant population in m^2 were used to estimate the average plant density. Five plants were randomly chosen and their plant height were measured using a centimeter scale. The resulting height was in cm. Dry matter of the crop was referred to as stover yield after the separation of cobs from the plant. The dry weight of selected plants from each plot was recorded and converted to per hectare land. The formula provided by Donald and Hamblin (1976) was employed to calculate the harvest index.

Yield attributes of maize

The mean value per plant was determined for each experimental unit by recording the number of cobs of five tagged plants at harvest. The total number of grains rows per cob and the number of grains per row were used to estimate the average number of grains per cob. Five plants were randomly chosen and their cob lengths were measured using a centimeter scale. The selected cobs were shelled and the grains from each plot of the selected plants were weighed after cleansing. The resulting weight was converted to kg/ha because net plot sampling, while common in certain experimental designs, was not employed in this split plot experiment because sampling individual tagged plants within each plot yields more precise data for treatment comparisons. The split plot design involves complex error structures and treatment levels, so mean values obtained from multiple plants reflect true within-plot variability and support robust statistical analysis for both main and subplot factors. Using data from randomly selected plants allows more consistent and efficient examination of subplot effects, minimizing border effects and resource constraints that are often encountered with net plot methods. This approach enhances accuracy and meets the statistical requirements of split plot designs. 100 seeds were collected from the produce and weighed in grams. This was referred to as the test weight. The formula provided by Donald and Hamblin (1976) was employed to calculate the harvest index.

Statistical analysis

A one-way analysis of variance (ANOVA) at the 95% confidence level was used to find any significant differences between treatments. The LSD test was employed as a post-hoc analysis to determine whether the means differed significantly. CVSTAT software program was used for all statistical studies. The relationship between the weed density and weed smothering efficiency was examined using a linear regression equation.

RESULTS AND DISCUSSION

Weed parameters

Species wise weed count (plants/m^2)

Digera arvensis

The highest weed count of *Digera arvensis* (Table 1) was recorded in the untreated control (6.56 plants/m^2), indicating severe infestation where no weed management was practiced. Complete suppression was observed in the weed-free treatment (0.00 plants/m^2). Among herbicide treatments, the lowest counts were seen with atrazine (3.33), topramezone (3.50), topramezone + atrazine (3.33) and mesotrione + atrazine (3.32) post-emergence applications, all statistically at par and significantly lower than the control. These findings are supported by Anand *et al.* (2025), which show that both pre-and post-emergence herbicide combinations substantially reduce broadleaf weed populations in maize, aiding efficient crop establishment and reducing competition.

Cynodon dactylon

For *Cynodon dactylon*, (Table 1) the maximum count appeared in the control plot (7.15 plants/m^2), underscoring the resilience of this perennial grass without intervention. Weed-free plots had no infestation (0.00 plants/m^2). Effective reductions were achieved with atrazine (4.22),

topramezone (5.33) and topramezone + atrazine (4.18), which were at par and notably lower than the control. Post-emergence herbicide strategies, as confirmed by Jeevan *et al.* (2022), provide moderate suppression of *Cynodon dactylon* but rarely achieve complete control due to its robust rhizomatous growth, emphasizing the need for integrated management.

Amaranthus viridis

The untreated control resulted (Table 1) in the highest *Amaranthus viridis* density (1.83 plants/m^2), while weed-free plots achieved total suppression (0.00 plants/m^2). Among herbicidal interventions, topramezone + atrazine (6.55) presented an anomaly with an unexpectedly high count, but other treatments like Atrazine (2.18), topramezone (2.39), mesotrione + atrazine (1.18) and mesotrione (1.65) significantly reduced populations, with atrazine and topramezone being at par with each other. CABI (2022) and Braz *et al.* (2022) supports the efficacy of atrazine and HPPD-inhibitor mixes in controlling pigweed species in maize systems.

Parthenium hysterophorus

Parthenium weed was most prevalent in the control plot (6.36 plants/m^2) and eliminated entirely in weed-free conditions (0.00 plants/m^2) in (Table 1). Among chemical treatments, atrazine (1.18), topramezone (1.65), mesotrione (1.18), topramezone + atrazine (1.18) and mesotrione + atrazine (0.70) all significantly reduced *Parthenium hysterophorus* incidence compared to control, with mesotrione + atrazine showing the lowest count among the herbicide plots. These observations align with recent field studies of Bianchini *et al*. (2020) and Hasan *et al.* (2024) highlighting the strong suppression of *parthenium* using integrated pre-and post-emergence herbicide programs.

Species wise weed dry weight (g)

Digera arvensis

The highest dry weight of *Digera arvensis* (Table 2) was observed in the untreated control (8.52 g), indicating prolific growth in the absence of management, while the lowest was under weed-free conditions (0.00 g). All herbicide treatments, including atrazine, topramezone and combinations with mesotrione, significantly reduced *Digera arvensis* biomass, with these treatments performing statistically on par with each other. The effect of tillage method was not significant, suggesting that chemical weed management plays a more crucial role in controlling this species than the choice of tillage. Consistent with prior findings, weed-free and herbicide-treated plots drastically reduce weed biomass compared to untreated controls. Atrazine and post-emergence herbicides, such as topramezone and mesotrione (alone or in combination), significantly suppress *Digera arvensis*, matching earlier reports that herbicidal treatments suppress this broadleaf weed by over 50% from weedy checks. (Rai *et al.,* 2018; Prasad *et al.,* 2020).

Cynodon dactylon

For *Cynodon dactylon*, (Table 2) a troublesome perennial grassy weed, dry weight ranged from 7.21 g/m^2 in the

Table 1: Effect of tillage and weed management practices on species wise weed count of maize at 60 DAS.

Treatment details	Species wise weed count			
	Digera arvensis	*Cynodon dactylon*	*Amaranthus viridis*	*Parthenium hysterophorus*
Main plots (Various tillage)				
Zero tillage	3.91* (16.00)**	4.78 (23.43)	2.59 (9.14)	1.76 (6.86)
Minimum tillage	3.99 (17.14)	4.76 (23.43)	2.68 (10.86)	2.08 (6.86)
Conventional tillage	3.75 (14.86)	4.62 (22.29)	2.51 (9.71)	1.72 (6.29)
SE m (±)	0.04	0.06	0.03	0.02
C.D. at 5%	0.17	0.22	0.12	0.09
Sub plots (Weed control practices)				
Control	6.56 (42.67)	7.15 (50.67)	1.83 (5.33)	6.36 (40.00)
Weed free	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
Atrazine (1.0 kg/ha) (Pre-emergence)	3.33 (10.67)	4.22 (17.33)	2.18 (5.33)	1.18 (1.33)
Topramezone (140 g/ha) (Post-emergence)	3.50 (12.00)	5.33 (28.00)	2.39 (5.33)	1.65 (2.67)
Mesotrione (125 g/ha) (Post- emergence)	4.22 (17.33)	4.37 (18.67)	1.65 (2.67)	1.18 (1.33)
Topramezon (70 g/ha) + Atrazine (0.5 kg/ha) (Post-emergence)	3.33 (10.67)	4.18 (17.33)	6.55 (42.67)	1.18 (1.33)
Mesotrione (70 g/ha) + Atrazine (0.5 g/ha) (Post-emergence)	3.32 (10.67)	4.07 (16.00)	1.18 (1.33)	0.70 (0.00)
SEm (±)	0.07	0.09	0.05	0.03
C.D. at 5%	0.21	0.25	1.18	0.10
Interaction (A*B) C.D. at 5%	NS	NS	NS	NS

*Data subjected to $\sqrt{x+1}$, square root transformation, **Values given in parenthesis are the mean of the original values.

untreated control down to 0.00 g/m^2 in weed-free plots. The combination of mesotrione + atrazine was particularly effective (3.60 g/m^2) to controlling the dry matter production of *Cynodon dactylon* at 60 DAS, mesotrione alone and topramezone + atrazine combined applications also providing substantial reduction in bio mass production of it. The efficacy of these treatments highlights the importance of integrated herbicide interventions for managing this resilient grass, whereas differences due to tillage systems remained marginal. Grassy weeds like *Cynodon dactylon* show substantial reduction under combined chemical strategies, notably mesotrione + atrazine. The efficacy of herbicides on controlling the weeds, especially with integration of post-emergence molecules for grassy weed management has been documented by (Rai *et al.,* 2018).

Amaranthus viridis

Amaranthus viridis, a fast-growing annual weed, was best controlled under weed-free conditions, showing (0.00 g) dry weight in (Table 2). The maximum dry weight (3.68 g) was observed with the topramezone + atrazine treatment, which, despite being a combination, was less effective on this species than singular herbicide interventions like mesotrione + atrazine (1.12 g) and mesotrione (1.52 g). These findings imply that specific combinations may not always provide broader control and the sensitivity of *Amaranthus viridis* to certain herbicides plays a key role in determining efficacy. Marked reduction in dry weight through herbicide combinations is attributed to the sensitivity of this weed to both broad-spectrum and specific post-emergence herbicides, validating current best practices for *Amaranthus* control in maize. (Poojitha *et al.,* 2021).

Parthenium hysterophorus

Parthenium hysterophorus (Table 2) presented the highest dry matter accumulation in the control (7.37 g), underscoring its strong competitive ability. Weed-free and all chemical treatments significantly curtailed its biomass, with the lowest dry weight in the mesotrione + atrazine treatment (0.70 g). This demonstrates that robust weed management interventions are essential to suppress this highly invasive and allelopathic weed, as conventional tillage practices alone were not sufficient to produce statistically significant differences. *Parthenium* is a highly competitive weed; failing to control it leads to a severalfold biomass increase and sharp maize yield decline. Chemical management substantially decreases its dry biomass, agreeing with recent research underscoring the critical importance of weed-free periods especially in early crop growth stages (Schultz and Kumar, 2015; Rehman *et al.,* 2020).

Total weed count (plants/m^2)

The range of total weed count (Table 3) among the main plots (tillage practices) was narrow from 10.18 under conventional tillage to 10.40 under zero tillage. The lowest weed count was noted in conventional tillage (10.18), but differences among main plots were not statistically significant. For the subplots (weed management

Table 2: Effect of weed management practices on species wise weed dry weight (gm^{-2}) of maize.

Treatment details	Species wise weed count			
	Digera arvensis	*Cynodon dactylon*	*Amaranthus viridis*	*Parthenium hysterophorus*
Main plots (Various tillage)				
Zero tillage	5.76* (33.77)**	5.03 (25.78)	2.01 (4.42)	2.02 (9.14)
Minimum tillage	5.86 (35.73)	4.68 (22.93)	2.07 (4.88)	2.74 (11.81)
Conventional tillage	5.68 (32.97)	4.58 (21.93)	1.82 (3.94)	1.99 (8.99)
SEm (±)	0.06	0.06	0.02	0.03
C.D. at 5%	NS	0.22	0.09	0.10
Sub plots (Weed control practices)				
Control	8.52 (72.27)	7.21 (51.45)	1.37 (2.28)	7.37 (53.78)
Weed free	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)	0.00 (0.71)
Atrazine (1.0 kg/ha) (Pre-emergence)	5.14 (25.93)	4.68 (21.52)	1.87 (3.67)	1.57 (3.45)
Topramezone (140 g/ha) (Post- emergence)	5.39 (28.66)	5.04 (25.37)	2.27 (4.64)	2.44 (6.98)
Mesotrione (125 g/ha) (Post- emergence)	6.00 (35.65)	4.26 (17.73)	1.52 (2.14)	1.46 (2.77)
Topramezon (70 g/ha) + Atrazine (0.5 kg/ha) (Post-emergence)	5.19 (26.49)	4.41 (19.11)	3.68 (13.11)	1.48 (2.88)
Mesotrione (70 g/ha) + Atrazine (0.5 g/ha) (Post-emergence)	5.17 (26.36)	3.60 (13.03)	1.12 (1.12)	0.70 (0.00)
SEm (±)	0.11	0.09	0.04	0.04
C.D. at 5%	0.31	0.25	0.10	0.11
Interaction (A*B) C.D. at 5%	NS	NS	NS	NS

*Data subjected to $\sqrt{x+1}$, square root transformation, **Values given in parenthesis are the mean of the original values.

practices), weed count ranged widely from 0 in the weed free treatment (lowest) to 17.63 in the weedy check control (highest). Atrazine (8.09), mesotrione (9.19) and mesotrione + atrazine (8.26) were statistically at par, all significantly reducing weed count compared to the control. This pattern showed that active weed management, especially with pre-emergence atrazine or combinations involving mesotrione, is highly effective in reducing weed populations. These findings are in line with recent research identifying the superior efficacy of integrated herbicidal regimes over cultural (tillage-only) approaches for weed suppression in maize systems (Thukkaiyannan and Satheeshkumar, 2024; Sepat and Singh, 2024).

Total weed dry weight (g m^{-2})

In terms of total weed dry weight (Table 3), values among the main plots ranged narrowly between 10.88 g (Conventional Tillage, lowest) and 11.11 g (Minimum tillage, highest), In subplots, the range was wider, with the weed free plots having the lowest dry weight (0 g) and the control plots the highest (18.26 g). Atrazine (8.97 g), mesotrione (10.49 g), topramezone (10.99 g) and mesotrione + atrazine (9.18 g) all showed significantly reduced weed biomass and were at par, showing strong suppression compared to the untreated control. These results highlight that the implementation of an effective chemical weed management program especially using atrazine and post-emergence combinations offers substantial reductions in weed biomass. This observation is supported by contemporary field studies emphasizing that herbicidal interventions can reduce weed dry matter by 70-80% and play a much larger role in controlling total weed pressure than tillage variations. (Hemlata *et al.,* 2023; Sepat and Singh, 2024).

Growth parameters

Plant population

The highest plant population (Table 4) among tillage treatments was recorded under conventional tillage (9.14), which was at par with minimum tillage (8.57), while the lowest was observed under zero tillage (7.86). In weed management, atrazine (1.0 kg/ha) pre-emergence showed the highest plant population (10.33), closely followed by mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence (10.00). Control recorded the lowest population (7.67) and weed free was also low (6.00). Conventional tillage generally enhances plant population by improving soil structure and seed-soil contact, ensuring better germination and establishment. Its ability to reduce soil compaction compared to zero tillage is a key factor, especially in fine-textured soils, as reported by Cakpo *et al.* (2025). Weed management treatments like herbicides and post-emergence mixes significantly increase plant population by reducing early competition, supporting high crop emergence (Naeem *et al.,* 2022).

Plant height (cm)

The highest plant height (212.42 cm) was recorded in weed-free plots, followed by the treatment with mesotrione + atrazine (post-emergence) at 70 g/ha + 0.5 kg/ha, while the lowest plant height (191.85 cm) was observed in the control treatment showed in (Table 4). Among tillage practices, conventional tillage resulted in the tallest plants (206.00 cm), followed by minimum tillage (204.33 cm), with zero tillage showing the shortest plant height (202.77 cm), which was statistically similar to the others. Conventional tillage improves soil structure, promoting better root development and nutrient availability, which supports

Table 3: Effect of weed management practices on total weed count and total weed dry weight (gm) of maize.

Treatment details	Total weed count	Total weed dry weight (g)
Main plots (Various tillage)		
Zero tillage	10.40* (130.36)**	10.94 (113.14)
Minimum tillage	10.22 (125.83)	11.11 (113.71)
Conventional tillage	10.18 (132.45)	10.88 (112.00)
SEm (±)	0.12	0.12
C.D. at 5%	0.47	NS
Sub plots (Weed control practices)		
Control	17.63 (333.01)	18.26 (310.67)
Weed free	0.00 (0.71)	0.00 (0.71)
Atrazine (1.0 kg/ha) (Pre-emergence)	8.09 (80.02)	8.97 (65.33)
Topramezone (140 g/ha) (Post-emergence)	9.96 (120.36)	10.99 (98.67)
Mesotrione (125 g/ha) (Post-emergence)	9.19 (109.68)	10.49 (84.00)
Topramezon (70 g/ha) + Atrazine (0.5 kg/ha) (Post-emergence)	10.41 (102.57)	10.15 (108.00)
Mesotrione (70 g/ha) + Atrazine (0.5 g/ha) (Post-emergence)	8.26 (83.81)	9.18 (68.00)
SEm (±)	0.18	0.22
C.D. at 5%	0.52	0.63
Interaction (A*B) C.D. at 5%	NS	NS

*Data subjected to $\sqrt{x+1}$, square root transformation, **Values given in parenthesis are the mean of the original values.

greater plant height (Feng *et al*., 2024). Effective weed management, such as manual weeding or the use of pre-emergence herbicides, reduces competition for light and nutrients, thereby minimizing the negative impact of weeds on plant growth, as confirmed over the years as reported by (Babu and Senthivel, 2019).

Plant dry weight (g)

Mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence (Table 4) had the highest plant dry weight (153.81g), which was at par with topramezone (70 g/ha) + atrazine (0.5 kg/ha) (151.85 g) and atrazine (1.0 kg/ha) pre-emergence (147.57 g), the lowest was recorded in the control (131.64 g). For the main plot, conventional tillage also achieved the highest dry weight (147.27 g), followed by minimum tillage (143.76 g) and the lowest under zero tillage (141.12 g). Higher dry biomass under conventional tillage is attributable to enhanced soil aeration and root proliferation, supporting vigorous growth and productive canopies. (Birla *et al.,* 2023). Superior weed control with a combination of pre- and post-emergence herbicides, or keeping plots weed free, markedly boosts crop biomass by preventing yield-reducing resource competition (Naeem *et al.,* 2022).

Yield parameters

Length of cobs (cm)

The highest cob length (Table 5) was observed under conventional tillage (13.06 cm), which was at par with minimum tillage (12.77 cm); the lowest was in zero tillage (12.46 cm). Among weed control plots, the mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence treatment produced the longest cobs (15.20 cm), followed by weed free (14.04 cm) and atrazine (1.0 kg/ha) pre-emergence (13.41 cm), while control had the shortest cobs (10.72 cm). Conventional tillage generally leads to increased cob length due to improved soil aeration, nutrient availability and reduced compaction, which enhance root growth and crop vigour (Tukur *et al.,* 2024; Gao *et al.,* 2024). Effective weed management, particularly the integration of post-emergence herbicides, maximizes cob length by minimizing resource competition during critical crop growth periods (Nimanwad, 2020; Hemlata *et al.,* 2023).

Grith of cobs (cm)

The widest cob girth (Table 5) was recorded for conventional tillage (11.10 cm), at par with minimum tillage (10.77 cm); the narrowest was in zero tillage (10.46 cm). For weed control, mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence resulted in the widest cobs (13.31 cm), followed by weed free (12.04 cm) and atrazine (1.0 kg/ha) pre-emergence (11.41 cm); the narrowest was in control (8.72 cm). Conventional tillage increases cob girth by promoting uniform seedbed conditions and robust early growth, which result in enhanced assimilate distribution to developing cobs (Tukur *et al.,* 2024). Among weed treatments, application of both pre-and post-emergence herbicides produces the largest cob girth by suppressing weed competition through the crop cycle (Hemlata *et al.,* 2023).

Number of grain rows/cob

The maximum rows per cob (Table 5) were recorded under conventional tillage (11.20), statistically similar to minimum tillage (10.87); the lowest was in zero tillage (10.56). In weed management, the highest row number was in the mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence plot (13.41), closely followed by weed free (12.14) and atrazine (1.0 kg/ha) pre-emergence (11.51); the lowest was in control (8.82). Higher number of rows per cob under conventional tillage can be attributed to improved soil structure, which enhances nutrient availability and supports reproductive development in maize. This is consistent with multi-seasonal research showing tillage positively

Table 4: Effect of weed management practices on growth parameters of maize.

Treatment details	Plant population (No.)	Plant height (cm)	Plant dry weight (g)
Main plots (Various tillage)			
Zero tillage	7.86	202.77	141.12
Minimum tillage	8.57	204.33	143.76
Conventional tillage	9.14	206.00	147.27
SEm (±)	0.10	2.24	1.57
C.D. at 5%	0.37	8.79	6.17
Sub plots (Weed control practices)			
Control	7.67	191.85	131.64
Weed free	6.00	212.42	137.05
Atrazine (1.0 kg/ha) (Pre-emergence)	10.33	208.57	147.57
Topramezone (140 g/ha) (Post-emergence)	9.00	195.41	142.72
Mesotrione (125 g/ha) (Post-emergence)	8.33	200.64	143.72
Topramezon (70 g/ha) + Atrazine (0.5 kg/ha) (Post-emergence)	8.33	204.59	151.85
Mesotrione (70 g/ha) + Atrazine (0.5 g/ha) (Post-emergence)	10.00	217.09	153.81
SEm (±)	0.15	3.42	2.40
C.D. at 5%	0.42	9.80	6.88
Interaction (A*B) C.D. at 5%	NS	NS	NS

Table 5: Effect of weed management practices on yield parameters of maize.

Treatment details	Length of cob (cm)	Girth of cob (cm)	No. of grain rows/cob	Grain yield (t/ha)	Stover yield (t/ha)
Main plots (Various tillage)					
Zero tillage	12.46	10.46	10.56	3.13	5.53
Minimum tillage	12.77	10.77	10.87	3.30	5.70
Conventional tillage	13.06	11.10	11.20	3.39	5.98
SEm (±)	0.14	0.12	0.12	0.05	0.07
C.D. at 5%	0.56	0.47	0.47	0.19	0.29
Sub plots (Weed control practices)					
Control	10.72	8.72	8.82	2.14	4.54
Weed free	14.04	12.04	12.14	4.07	6.47
Atrazine (1.0 kg/ha) (Pre-emergence)	13.41	11.41	11.51	3.55	5.95
Topramezone (140 g/ha) (Post-emergence)	11.31	9.31	9.41	2.47	4.87
Mesotrione (125 g/ha) (Post-emergence)	11.96	9.96	10.06	3.04	5.44
Topramezon (70 g/ha) + Atrazine (0.5 kg/ha) (Post-emergence)	12.70	10.70	10.80	3.22	5.62
Mesotrione (70 g/ha) + Atrazine (0.5 g/ha) (Post-emergence)	15.20	13.31	13.41	4.39	7.23
SEm (±)	0.22	0.18	0.18	0.07	0.11
C.D. at 5%	0.63	0.52	0.52	0.21	0.32
Interaction (A*B) C.D. at 5%	NS	NS	NS	NS	NS

influences yield components (Tukur *et al.,* 2024; Kumar *et al.,* 2025). Integrated herbicide programs maintain the highest row counts by providing complete weed suppression during sensitive developmental windows, reducing stress on developing cobs (Hemlata *et al.,* 2023).

Grain yield (t/ha)

The highest grain yield was with conventional tillage (3.39 t/ha) showed in (Table 5), at par with minimum tillage (3.30 t/ha); the lowest was with zero tillage (3.13 t/ha). Mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence attained the maximum grain yield (4.39 t/ha), followed by weed free (4.07 t/ha) and atrazine (1.0 kg/ha) pre-emergence (3.55 t/ha); control had the lowest grain yield (2.14 t/ha). The superior grain yield under conventional tillage arises from better seed placement, optimal root proliferation and higher soil fertility, supporting greater cob development and grain filling. Gao *et al.* (2024); Hirwe *et al.* (2025) emphasize the effectiveness of herbicide-based weed control particularly combined pre- and post-emergence treatments in boosting maize grain yield due to greatly diminished crop-weed competition throughout the season.

Straw yield (t/ha)

Conventional tillage produced the highest straw yield (5.98 t/ha), with minimum tillage (5.70 t/ha) close behind (Table 5), the lowest was with zero tillage (5.53 t/ha). In weed management, mesotrione (70 g/ha) + atrazine (0.5 kg/ha) post-emergence gave the greatest stover yield (7.23 t/ha), surpassed only slightly by weed free (6.47 t/ha) and atrazine (1.0 kg/ha) pre-emergence (5.95 t/ha); the lowest was control (4.54 t/ha). Straw yield mirrors trends in grain yield, with conventional tillage offering better biomass accumulation due to favorable physical and chemical conditions in the soil (Gao *et al.,* 2024). Integrated weed management, especially treatments combining herbicides and hand weeding or sequential applications, consistently result in higher stover yields because of vigorous growth with minimal resource competition (Vardhan *et al.,* 2018).

CONCLUSION

Research shows that both conventional tillage and minimum tillage have some advantages concerning the preservation of soil tender and crop sustainability. But the combination of conventional tillage with chemical weed management especially the use of mesotrione and atrazine blends control of invasive weeds maximally and fully utilizes maize morphological flowering and yield stages. Efficient control of invasive weeds is very important to manage yield damage of competitive parasitic weeds like *Parthenium hysterophorus*. This is the main scope for better management of maize productivity while maintaining crop management sustainably. This approach not only helps to achieve better biomass and grain yield but also increases resource use efficiency and sustainable agriculture.

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Ethical issues

None.

Disclaimers

The authors of this article are the only ones who wrote the statements, opinions and conclusions. These do not necessarily represent the views or positions of the institutions they work for. The authors are solely responsible for the content's accuracy and honesty and they are not liable for any damages from using or applying the information in this article.

Informed consent

This study did not involve the use of animals or human participants. Hence, ethical approval and informed consent were not required.

Conflict of interest

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