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Effect of Tillage and Weed Management on Maize (*Zea mays* L.) Yield and Nutrient Uptake

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The field experiment was carried out during two consecutive *kharif* seasons of 2018 and 2019 at Agricultural Research Station, Tandur, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Telangana. The study employed a strip-plot design, where tillage methods (conventional and reduced) were assigned to vertical plots and various weed management practices were allotted to horizontal plots, replicated thrice. N, P and K uptake by maize was highest in conventionally tilled plots than in reduced tillage plots with no significant difference between them. The removal of N, P and K by weeds was highest in the weedy check treatment. Hand weeding twice at 20 and 40 DAS recorded higher N, P and K uptake which was on par with Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS and Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (PoE). Results revealed that there is no significant difference ($p<0.05$) between tillage practices with respect to the yield of maize. Higher grain yields of maize were obtained with two hand weedings which was on par with Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS and Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (PoE). The interaction effect of tillage and weed management practices was found to be non-significant. Conventional tillage along with hand weeding twice at 20 and 40 DAS resulted in higher plant dry matter and consequently highest N, P and K nutrients uptake by the plants and lead to higher yield.

Keywords: Atrazine; conservation agriculture; maize; nutrient uptake; reduced tillage; tembotrione; weed.

1. INTRODUCTION

Maize (*Zea mays* L.) is a cornerstone of global agriculture, serving as a vital food staple, animal feed and a raw material for industries such as starch, oil and biofuels (Das S et al, 2008). “In India, the adoption of hybrid varieties, particularly in non-traditional maize-growing regions, has markedly enhanced productivity, transforming the nation from a net importer to achieving self-sufficiency with export potential” (Commodity online, 2020). “Currently, maize cultivation spans 9.56 million hectares in India, yielding 28.76 million metric tons annually, averaging 3006 kg per hectare” (Indiastat, 2019). “This production supports diverse sectors including human consumption, livestock feed and industrial uses like food processing and biofuels. Historically, conventional agriculture relied heavily on intensive tillage for weed control and yield enhancement, albeit at the cost of soil erosion and degradation. This has prompted a shift towards Conservation Agriculture (CA) principles, emphasizing minimal soil disturbance, crop rotation, and residue retention to optimize resource use efficiency and mitigate climate change impacts by carbon sequestration and reducing greenhouse gas emissions” (Farooq M et al, 2011). However, “CA adoption in rainfed regions faces challenges such as limited machinery availability, competition for crop residues and effective weed management. Weeds pose significant challenges in maize cultivation, causing yield losses averaging 12.8% despite management efforts and up to 29.2% in cases of inadequate control” (Dogan MN et al, 2004). “Early weed management within the first 30 days after crop emergence is crucial to mitigate yield reductions. Factors such as wide plant spacing, high fertilizer application rates and slow maize germination further exacerbate weed growth, necessitating efficient cultural or chemical control methods. Moreover, extensive tillage practices may not always be necessary if weeds can be managed effectively through alternative means” (Birla D et al, 2023, Singh D et al, 2024). Comprehensive field research is indispensable to evaluate the impact of different tillage methods and weed management practices on weed dynamics, crop productivity, and nutrient uptake in maize. Such studies provide essential insights for optimizing agricultural practices to enhance sustainability and productivity in maize production systems, both irrigated and rainfed.

2. MATERIALS AND METHODS

During the *kharif* seasons of 2018 and 2019, a field study was conducted at Agricultural Research Station (ARS), Tandur, located at an altitude of 461 m above mean sea level (17° 15’ N latitude and 77° 35’ E longitude). The region received a total rainfall of 374.70 mm over 31 rainy days in *kharif,* 2018 and 675.20 mm over 49 rainy days in *kharif,* 2019. The crop was grown entirely under rainfed conditions. The soil in the experimental field was clay loam in texture, non-saline (0.30 dSm^{-1}), with a neutral pH (7.91). Organic carbon content was low (0.37%), while available nitrogen and phosphorus were moderate (228 kg ha^{-1} and 23 kg ha^{-1}, respectively) and available potassium was high (405 kg ha^{-1}). The experiment was laid out in a strip plot design with three replications. The treatments comprised of two tillage methods *viz.*, conventional tillage (T_1) and reduced tillage (T_2) assigned to vertical plots (378 m^2) and seven weed management practices *viz.*, Weedy check (W_1), Weed free (W_2), Intercropping with cowpea (W_3), Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS (W_4), Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (PoE) (W_5), Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* paraquat 24% SL @ 1.0 kg *a.i.* ha^{1} (PoE) (W_6) and Sorghum + Parthenium leach @ 15 L ha^{-1} each (PE) *fb* Sorghum + Parthenium leach @ 15 L ha^{-1} each (PoE) (W_7) which were allotted to the horizontal plots (54 m^2). Buffer strips of 1 m width were kept between the plots. Description of the tillage methods is furnished in Table 1.

"Maize hybrid DHM-117 was planted by hand-dibbling on a flat bed with a spacing of 60 × 20 cm. General cultivation practices were followed, excluding tillage and standard weed management. Herbicides and leaches were applied: pre-emergence one day after sowing, early-post emergence at 15 days after sowing (DAS) and post-emergence at 25 DAS using a knapsack sprayer equipped with a flat fan nozzle. Paraquat was applied with a hood. Hand weeding was performed in the weed-free treatment using a hand hoe at 20 and 40 DAS" (Chopra P and Angiras NN, 2008). Additionally, "an intercropping system was implemented, with two rows of cowpea (*Vigna unguiculata* L.) variety TPTC-29 planted between each pair of maize rows. Oven-dried powders of allelopathic plants (Sorghum and Parthenium) were soaked in water in 1:10 (w/v) for 48 hours. Finally, extracts were filtered through muslin cloth to obtain respective water extracts" (Cheema ZA and Khaliq A, 2000). "The nutrient management strategy employed in the study involved applying a uniform dose of 180 kg N, 60 kg P_2O_5 and 50 kg K_2O ha^{-1} to all plots. Phosphorus and potassium were applied entirely as basal in the form of DAP and MOP, respectively. Nitrogen, calculated based on its proportion supplied through DAP, was split into three applications: 1/3rd as basal, 1/3rd at 30 days after sowing (DAS), and the remaining 1/3rd at 60 DAS. To investigate the nutrient uptake of maize plants and weeds, plant samples was from collected from each plot at various intervals for chemical analysis. Composite samples from three replications per treatment were oven-dried at 80°C for 72 hours, followed by grinding and sieving through a 2 mm sieve" (Chopra P and Angiras NN, 2008). Nitrogen content was analyzed using the Modified Kjeldhal method (Jackson ML, 1973), phosphorus content using the Vanadomolybdo-phosphoric acid yellow color method (Jackson ML, 1973), and potassium content using the Flame photometer method (Richards LA, 1954). The data, collected in accordance with a strip plot design as recommended by Gomez and Gomez (1984), were averaged, tabulated and subjected to statistical analysis. These methods ensure robust assessment of nutrient uptake dynamics between maize plants and weeds under different treatment conditions.

2.1 Harvest Index (HI)

Harvest index is defined as the ratio of economic yield to total biological yield. It is calculated by using formula given by Donald (Donald CM, 1962).

Table 1. Tillage practices adopted in maize crop

Tillage	No. of Tillage Operations	Tillage Implement	Timing of Tillage Operations
Conventional tillage (CT)	2	Cultivator	▪ Summer season ▪ Before sowing
	1	Rotavator	Before sowing
Reduced tillage (RT)	1	Cultivator	Before sowing
	1	Blade harrow	

Harvest index (%) = Economic yield (seed yield in kg ha-1) / Biological yield (seed yield + stover yield in kg ha-1)

2.2 Maize Equivalent Yield (MEY)

Maize equivalent yield (MEY) under intercropping with cowpea was calculated by using the following formula (Tripathi B and Singh, CM, 1983).

$$\text{MEY (kg ha}^{-1}\text{)} = \frac{Y_C \times P_C}{P_M} + \text{Yield of maize in intercropping treatment (kg ha}^{-1}\text{)}$$

Where, Y_C = Yield of cowpea in the intercropping treatment (kg ha^{-1}), P_C = Price of cowpea (₹ kg^{-1}) and P_M = Price of maize (₹ kg^{-1}).

3. RESULTS AND DISCUSSION

3.1 Nutrient Uptake

3.1.1 Nutrient uptake by weeds

In the study presented, it was observed that weeds exhibited a higher uptake of potassium compared to nitrogen and phosphorus. This finding suggests potential nutrient preferences or efficiencies among the weed species present, indicating their competitive advantage for potassium in the soil environment. Such insights into nutrient uptake dynamics by weeds are crucial for understanding their impact on crop nutrient availability and overall productivity in agricultural systems. Further exploration of these dynamics could inform more effective weed management strategies tailored to optimize nutrient utilization in maize cultivation.

3.1.2 Effect of tillage practices

“Nutrient uptake (N, P, and K) by weeds under conventional tillage did not significantly differ from that under reduced tillage across both years. However, a notable trend emerged where weeds under reduced tillage exhibited higher nutrient uptake. This phenomenon can be attributed to the increased accumulation of weed biomass due to less effective weed control practices associated with reduced tillage systems. These findings underscore the critical role of efficient weed management strategies in influencing nutrient dynamics within agroecosystems. Further investigation into how these nutrient dynamics impact overall crop productivity would provide valuable insights into optimizing agricultural practices” (Chopra P and Angiras NN, 2008).

3.1.3 Effect of weed management practices

Weed management practices significantly decreased the N, P and K uptake by weeds during both the years. Minimum N, P and K uptake by weeds was noticed with Weed free which was on par with Atrazine @ 0.5 kg *a.i.* ha^{-1} + Tembotrione @ 120 g *a.i.* ha^{-1} (Early PoE) *fb* HW at 40 DAS and Atrazine @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione @ 120 g *a.i.* ha^{-1} (PoE). While, the highest N, P and K uptake by weeds was recorded with Weedy check. Effective weed management practices, such as hand weeding and herbicide application, are crucial for optimizing nutrient uptake by crops. Weeds, known for their rapid growth and competitive nature, can outcompete crops for essential nutrients, leading to higher nutrient removal from the soil, particularly evident in unchecked weedy conditions. By implementing timely and effective weed control measures during critical growth stages, weed density and biomass accumulation are minimized. This reduction not only limits nutrient uptake by weeds but also enhances nutrient availability for crops, promoting more efficient nutrient utilization and ultimately improving crop growth and yield. Studies underscore the significant impact of these practices, highlighting the need to manage weeds proactively to maintain optimal nutrient conditions for crop production. Similar findings were reported by Samant et al (2015) and Sinha et al (2000).

3.1.4 Interaction effect

Non-significant effect of tillage and weed management interaction was recorded with nitrogen removal by weeds.

3.1.5 Nutrient uptake by maize crop

The nutrient uptake of maize is influenced by various factors such as crop type, soil characteristics, weather conditions, fertilization practices, and agronomic techniques. Effective weed control methods create favorable conditions for maize, allowing it to absorb nutrients more effectively while reducing nutrient competition from weeds. In the study, higher dry matter production in the 2019 season resulted in increased nutrient removal by the maize crop compared to the previous season *i.e.,* 2018. Potassium uptake was notably higher than nitrogen and phosphorus, highlighting its importance for maize growth, photosynthesis, and metabolic processes. This underscores the significance of managing weeds and optimizing nutrient availability to enhance maize productivity.

3.2 Effect of Tillage Practices

The data indicate that conventional tillage resulted in higher nitrogen (N), phosphorus (P), and potassium (K) uptake by maize compared to reduced tillage throughout the growing season (30, 60, 90 days after sowing, and at harvest), although these differences were not statistically significant. Conventional tillage practices promoted soil loosening, facilitating superior root development and reducing weed competition over the crop's growth cycle. This environment likely contributed to increased nutrient uptake by the maize plants.

3.3 Effect of Weed Management Practices

N, P and K uptake were significantly influenced by weed management practices in maize crop during both the years. Higher N, P and K uptake was obtained with Weed free which was at par with Atrazine @ 0.5 kg *a.i.* ha^{-1} + Tembotrione @ 120 g *a.i.* ha^{-1} (Early PoE) *fb* HW at 40 DAS and Atrazine @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione @ 120 g *a.i.* ha^{-1} (PoE). While, the lowest N, P and K uptake was found with Weedy check at all the growth intervals. The observed higher nutrient uptake by crops under treatments involving hand weeding and pre/post-emergence herbicide application likely stems from improved resource availability and reduced competition from weeds throughout the growth stages. This management strategy creates a favorable environment for maize, facilitating continuous access to nutrients essential for growth and development. These findings are consistent with studies by (Chopra P and Angiras NN, 2008) and (Pradeep R et al, 2017), which similarly highlighted the beneficial effects of weed control on crop nutrient uptake. In contrast, the significantly lower nutrient uptake observed in the weedy check underscores the negative impact of poor weed management, leading to reduced maize biomass production and subsequently limiting nutrient acquisition over the growth period. Similar findings were reported by (Prithwiraj D et al, 2018) and (Shrinivas CS et al, 2014).

3.4 Interaction Effect

Effect of tillage and weed management practices interaction on N, P and K uptake in maize was found non-significant.

3.5 Yield and Harvest Index

Data pertaining to the yield and harvest index of maize was presented in Table 4.

Table 2. Nitrogen, Phosphorous and Potassium removal (kg ha^{-1}) by weeds in maize as influenced by tillage and weed management practices

	Nitrogen			Phosphorous			Potassium		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)									
T_1	12.23	15.21	13.72	5.57	7.17	6.37	16.40	20.61	18.51
T_2	14.63	18.13	16.38	6.73	8.49	7.61	19.20	23.74	21.47
SE(m)±	**0.42**	**0.51**	**0.46**	**0.19**	**0.24**	**0.21**	**0.49**	**0.55**	**0.52**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**14.38**	**14.05**	**14.16**	**14.49**	**14.11**	**13.93**	**12.81**	**11.46**	**12.06**
Horizontal plots : Weed management (W)									
W_1	32.88	39.72	36.30	14.04	17.27	15.66	40.04	48.26	44.15
W_2	2.07	3.04	2.56	1.49	2.21	1.85	4.29	6.21	5.25
W_3	16.13	20.42	18.28	6.97	9.07	8.02	19.66	25.06	22.36
W_4	2.48	3.53	3.01	1.71	2.50	2.10	5.04	7.20	6.12
W_5	2.96	4.73	3.85	2.12	2.97	2.54	6.14	8.39	7.27
W_6	9.12	10.98	10.05	5.18	6.45	5.81	15.00	18.25	16.63
W_7	28.38	34.28	31.33	11.55	14.36	12.96	34.43	41.87	38.15
SE(m)±	**0.67**	**0.79**	**0.73**	**0.26**	**0.36**	**0.40**	**0.70**	**0.83**	**0.76**
CD (p=0.05)	**2.09**	**2.45**	**2.26**	**0.81**	**1.12**	**1.25**	**2.15**	**2.55**	**2.35**

	Nitrogen			Phosphorous			Potassium		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
CV (%)	**12.38**	**11.69**	**11.96**	**10.55**	**11.42**	**14.21**	**9.64**	**9.17**	**9.37**
Interaction									
T×W									
SE(m)±	**0.89**	**1.13**	**1.01**	**0.36**	**0.52**	**0.44**	**0.94**	**1.13**	**1.04**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T									
SE(m)±	**0.90**	**1.11**	**1.00**	**0.35**	**0.51**	**0.50**	**0.93**	**1.12**	**1.02**
CD (p=0.05)	**NS**	**NS**	**645**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3a. Nitrogen uptake (kg ha^{-1}) by maize at 30 and 60 DAS as influenced by tillage and weed management practices

	30 DAS			60 DAS		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots: Tillage practices (T)						
T_1	29.73	31.51	30.62	87.38	92.70	90.04
T_2	26.63	28.09	27.36	77.82	83.55	80.68
SE(m)±	**0.69**	**0.74**	**0.63**	**1.76**	**2.10**	**1.93**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**11.32**	**11.42**	**10.09**	**9.77**	**10.92**	**10.41**
Horizontal plots : Weed management (W)						
W_1	17.26	18.26	17.76	50.07	49.93	50.00
W_2	38.09	40.50	39.30	109.23	119.26	114.25
W_3	22.83	24.89	23.86	71.84	78.22	75.03
W_4	34.96	36.50	35.73	102.59	113.10	107.84
W_5	36.31	38.35	37.33	101.49	110.19	105.84
W_6	28.79	30.33	29.57	86.47	90.49	88.48
W_7	19.02	19.79	19.41	56.50	55.69	56.10
SE(m)±	**1.21**	**1.10**	**1.18**	**2.82**	**3.11**	**3.24**
CD (p=0.05)	**3.74**	**3.39**	**3.63**	**8.71**	**9.59**	**10.00**
CV (%)	**10.57**	**9.05**	**9.97**	**8.39**	**8.66**	**9.31**
Interaction						
T×W						
SE(m)±	**1.53**	**1.54**	**1.50**	**3.93**	**4.45**	**3.90**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**1.60**	**1.51**	**1.57**	**3.90**	**4.32**	**4.15**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3b. Nitrogen uptake (kg ha^{-1}) by maize at 90 DAS and harvest as influenced by tillage and weed management practices

	90 DAS			Harvest		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)						
T_1	120.01	131.62	125.81	125.88	134.81	130.35
T_2	107.87	118.99	113.43	111.82	120.62	116.22
SE(m)±	**2.18**	**2.41**	**2.39**	**2.42**	**2.83**	**2.70**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**8.79**	**8.82**	**9.18**	**9.33**	**10.16**	**10.04**
Horizontal plots : Weed management (W)						
W_1	66.66	72.78	69.72	66.93	73.26	70.09

	90 DAS			Harvest		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
W_2	153.59	169.73	161.66	163.46	175.47	169.47
W_3	98.44	106.99	102.71	100.47	108.24	104.35
W_4	146.51	162.72	154.62	154.58	166.45	160.51
W_5	142.67	158.31	150.49	150.38	161.46	155.92
W_6	113.60	124.72	119.16	118.30	126.37	122.34
W_7	76.08	81.89	78.99	77.82	82.78	80.30
SE(m)±	**3.72**	**4.09**	**4.13**	**4.46**	**4.63**	**4.50**
CD (p=0.05)	**11.47**	**12.61**	**12.73**	**13.75**	**14.29**	**13.88**
CV (%)	**8.00**	**8.00**	**8.46**	**9.20**	**8.90**	**8.95**
Interaction						
T×W						
SE(m)±	**4.80**	**5.51**	**5.23**	**5.60**	**5.82**	**5.57**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**4.95**	**5.58**	**5.44**	**5.90**	**6.05**	**5.84**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3c. Phosphorous uptake (kg ha^{-1}) by maize at 30 and 60 DAS as influenced by tillage and weed management practices

	30 DAS			60 DAS		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)						
T_1	6.06	6.65	6.35	21.44	23.75	22.24
T_2	5.31	5.82	5.57	18.57	20.91	19.74
SE(m)±	**0.17**	**0.16**	**0.18**	**0.57**	**0.60**	**0.52**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**14.09**	**12.34**	**14.38**	**13.18**	**12.30**	**11.30**
Horizontal plots : Weed management (W)						
W_1	3.04	3.37	3.20	10.33	10.91	10.62
W_2	8.12	8.92	8.52	28.45	32.22	30.34
W_3	4.32	4.90	4.61	16.20	18.53	17.37
W_4	7.38	7.97	7.67	26.56	30.41	28.48
W_5	7.79	8.51	8.15	25.84	29.17	27.50
W_6	5.69	6.23	5.96	20.52	22.46	21.49
W_7	3.46	3.76	3.61	12.12	12.61	12.36
SE(m)±	**0.28**	**0.30**	**0.27**	**0.93**	**1.02**	**0.94**
CD (p=0.05)	**0.87**	**0.94**	**0.85**	**2.87**	**3.15**	**2.90**
CV (%)	**12.27**	**11.98**	**11.39**	**11.42**	**11.24**	**10.91**
Interaction						
T×W						
SE(m)±	**0.36**	**0.32**	**0.40**	**1.22**	**1.17**	**5.57**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**0.37**	**0.37**	**0.38**	**1.24**	**1.28**	**5.84**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3d. Phosphorous uptake (kg ha^{-1}) by maize at 90 DAS and harvest as influenced by tillage and weed management practices

	90 DAS			Harvest		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)						
T_1	32.58	36.33	34.46	34.53	37.74	36.13
T_2	28.35	31.83	30.09	29.44	32.53	30.99
SE(m)±	**0.85**	**0.92**	**1.08**	**0.88**	**0.95**	**0.88**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**12.85**	**12.39**	**14.56**	**12.72**	**12.39**	**12.06**
Horizontal plots : Weed management (W)						
W_1	15.19	17.02	16.10	15.78	17.71	16.74
W_2	44.20	49.52	46.86	47.05	51.15	49.11
W_3	24.10	26.74	25.42	24.86	27.35	26.11
W_4	41.82	47.03	44.42	44.32	48.35	46.34
W_5	39.82	44.78	42.30	42.13	45.87	44.00
W_6	30.34	33.86	32.10	31.36	35.05	33.20
W_7	17.80	19.61	18.71	18.39	20.46	19.43
SE(m)±	**1.46**	**1.55**	**1.51**	**1.59**	**1.75**	**1.66**
CD (p=0.05)	**4.52**	**4.79**	**4.68**	**4.91**	**5.39**	**5.11**
CV (%)	**11.80**	**11.20**	**11.53**	**12.22**	**12.21**	**12.13**
Interaction						
T×W						
SE(m)±	**1.75**	**1.83**	**1.83**	**1.83**	**1.92**	**1.80**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**1.87**	**1.97**	**1.89**	**2.01**	**2.16**	**2.05**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3e. Potassium uptake (kg ha^{-1}) by maize at 30 and 60 DAS as influenced by tillage and weed management practices

	30 DAS			60 DAS		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)						
T_1	26.65	28.22	27.44	92.32	97.87	95.10
T_2	23.83	24.93	24.38	82.35	88.33	85.34
SE(m)±	**0.52**	**0.85**	**0.68**	**1.81**	**1.98**	**1.97**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**9.47**	**14.80**	**12.09**	**9.54**	**9.75**	**10.04**
Horizontal plots : Weed management (W)						
W_1	15.37	16.29	15.83	53.19	52.99	53.09
W_2	34.21	36.41	35.31	115.13	125.62	120.38
W_3	20.39	22.25	21.32	76.16	82.85	79.51
W_4	31.36	32.77	32.07	108.24	119.25	113.74
W_5	32.59	33.44	33.02	107.14	116.24	111.69
W_6	25.78	27.19	26.48	91.52	95.69	93.60
W_7	16.97	17.67	17.32	59.96	59.06	89.86
SE(m)±	**0.98**	**1.18**	**1.02**	**3.05**	**3.10**	**3.10**
CD (p=0.05)	**3.04**	**3.66**	**3.15**	**9.42**	**9.57**	**9.57**
CV (%)	**9.59**	**10.96**	**9.67**	**8.58**	**8.17**	**8.44**
Interaction						

	30 DAS			60 DAS		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
T×W						
SE(m)±	**1.21**	**1.67**	**1.21**	**3.84**	**4.50**	**3.98**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**1.29**	**1.61**	**1.27**	**4.00**	**4.38**	**4.07**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3f. Potassium uptake (kg ha^{-1}) by maize at 90 DAS and harvest as influenced by tillage and weed management practices

	90 DAS			Harvest		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical plots : Tillage practices (T)						
T_1	127.32	140.64	133.98	134.99	144.50	139.75
T_2	115.78	127.26	121.52	121.15	129.31	125.23
SE(m)±	**2.93**	**2.64**	**2.85**	**3.26**	**3.29**	**3.43**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**11.01**	**9.04**	**10.22**	**11.68**	**11.03**	**11.89**
Horizontal plots : Weed management (W)						
W_1	72.58	78.69	75.63	73.08	79.41	76.24
W_2	164.13	181.18	172.65	175.77	187.59	181.68
W_3	106.47	114.98	110.73	108.92	116.58	112.75
W_4	156.79	173.25	165.02	165.81	177.62	171.71
W_5	148.93	168.65	158.79	159.25	172.39	165.82
W_6	122.42	133.03	127.73	129.43	135.77	132.60
W_7	82.55	19.61	85.21	84.22	89.01	86.61
SE(m)±	**4.95**	**4.57**	**4.64**	**5.35**	**5.15**	**5.33**
CD (p=0.05)	**15.27**	**14.08**	**14.31**	**16.48**	**15.88**	**16.44**
CV (%)	**9.95**	**8.36**	**8.89**	**10.23**	**9.22**	**9.87**
Interaction						
T×W						
SE(m)±	**6.32**	**6.15**	**6.11**	**7.25**	**6.34**	**6.33**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T						
SE(m)±	**6.54**	**6.24**	**6.21**	**7.28**	**6.61**	**6.70**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 4. Yield and Harvest Index of maize as influenced by tillage and weed management practices

	Grain Yield (kg ha^{-1})			Stover Yield (kg ha^{-1})			Harvest Index (%)		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
Vertical Plots : Tillage (T)									
T_1	5036	5268	5152	7028	7297	7242	40.83	41.05	40.94
T_2	4555	4855	4705	6540	6842	6712	40.01	40.58	40.30
SE(m)±	**84.52**	**97.72**	**85.71**	**110.20**	**128.90**	**111.57**	**0.75**	**0.79**	**0.84**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CV (%)	**8.08**	**8.85**	**7.97**	**7.44**	**8.36**	**7.33**	**8.56**	**8.96**	**9.53**
Horizontal Plots: Weed Management (W)									
W_1	2483	2673	2578	5156	5352	5415	32.40	33.09	32.74
W_2	6465	6786	6625	7984	8357	8221	44.79	44.85	44.82
W_3	4308	4542	4425	6262	6511	6437	40.73	41.07	40.90

	Grain Yield (kg ha^{-1})			**Stover Yield (kg ha^{-1})**			**Harvest Index (%)**		
Treatments	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**	**2018**	**2019**	**Pooled**
	(MEY)	(MEY)	(MEY)						
W_4	6266	6620	6442	7876	8234	8105	44.33	44.59	44.46
W_5	6083	6389	6236	7802	8147	8025	43.78	43.95	43.87
W_6	5013	5273	5143	6814	7131	7022	42.35	42.65	42.50
W_7	2955	3145	3050	5493	5755	5614	34.56	35.50	35.03
SE(m)±	**156.69**	**178.71**	**152.20**	**203.50**	**231.09**	**201.03**	**1.31**	**1.35**	**1.29**
CD (p=0.05)	**482.83**	**550.68**	**468.99**	**627.05**	**712.06**	**619.43**	**4.04**	**4.15**	**3.98**
CV (%)	**8.00**	**8.65**	**7.56**	**7.35**	**8.01**	**7.06**	**7.96**	**8.10**	**7.80**
Interaction									
T×W									
SE(m)±	**217.00**	**225.51**	**207.00**	**288.23**	**323.29**	**285.30**	**1.65**	**1.48**	**1.78**
CD (p=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
W×T									
SE(m)±	218.76	236.71	209.46	287.73	323.54	283.96	1.72	1.65	1.76
CD (p=0.05)	NS	NS	645	NS	NS	NS	NS	NS	NS

MEY: Maize Equivalent Yield

3.5.1 Grain yield

Grain yield, also known as economic yield, results from factors such as cob length, cob girth, number of kernel rows cob^{-1}, number of kernels row^{-1}, number of kernels cob^{-1}, weight of cob, weight of grain cob^{-1}, and test weight, collectively contributing to higher productivity. Maize and cowpea yielded 3719 and 200 kg ha^{-1}, respectively in 2018, and 3888 and 230 kg ha^{-1} in 2019 under intercropping conditions. The fluctuation in maize grain yields between 2018 and 2019 can largely be attributed to variations in rainfall distribution, which directly influence soil moisture levels. Adequate moisture in the soil is critical for nutrient availability, thereby impacting crop growth and development (User, 2024). (Lobell DB and Asner GP, 2003) underscore that weather conditions, including rainfall patterns, account for about 30% of year-to-year production variability in key crops such as maize. This variability is further substantiated by Vetsch and Randall (2004), who observed significant seasonal effects on maize grain yields in Minnesota, USA.

3.5.2 Effect of tillage practices

The grain yield of maize was not significantly influenced by different tillage methods during both years of study and pooled means. However, yields were numerically higher with conventional tillage compared to reduced tillage. Increased grain yield in conventional tillage is attributed to deeper root spread, more root activity, reduced bulk density, weed density, weed dry matter, and increased nutrient and water availability, enhancing water and nutrient uptake (2004 et al, 2019) and Khan et al (2017). Conversely, reduced tillage, which disturbs the soil less, resulted in lower grain yield, possibly due to inferior plant growth and yield attributes (Feng Y et al, 2006).

3.5.3 Effect of weed management practices

Weed management practices had a significant effect on grain yield during both the years and pooled means. The maximum grain yield was produced by Hand weeding twice at 20 and 40 DAS which was on par with Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS and Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1}. Effective weed management strategies play a crucial role in optimizing grain yield in maize. Treatments with reduced weed competition enable crops to efficiently utilize nutrients, moisture, light, and space throughout the growing season, thereby enhancing both vegetative growth and reproductive potential. This is supported by research indicating that reduced competition from weeds allows maize plants to allocate more resources towards grain production, leading to higher yields. In contrast, the weedy check treatment exhibited significantly lower grain yield, attributed to heightened competition between crops and weeds. This competition restricted crop growth, evidenced by reduced stature and yield attributes, ultimately resulting in diminished maize grain yield. The results corroborate the findings of Prithwiraj et al (2018).

3.5.4 Interaction effect

Interaction effect of tillage and weed management practices on grain yield of maize was found to be non-significant.

3.5.5 Stover yield

Dried stover yield refers to the function of the genetic makeup of crop, soil nutrient status and management strategies.

3.6 Effect of Tillage Practices

The stover yield in the maize crop was not significantly influenced by tillage practices during both years and pooled means. However, conventional tillage had produced higher stover yield as compared to reduced tillage. Conventional tillage's ability to mitigate subsoil compaction likely facilitates better root penetration, enhancing water and nutrient uptake, which can positively impact stover yield. Reduced tillage, on the other hand, may restrict the root development in compacted subsoil layers, potentially limiting crop growth and stover production. Similar findings were reported by Khurshid et al (2009).

3.7 Effect of Weed Management Practices

Weed management practices exerted a significant influence on the stover yield during both years and pooled means. Significantly higher stover yield was recorded with Hand weeding twice at 20 and 40 DAS which was at par with Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS and Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (8025 kg ha^{-1}). Effective weed control can significantly enhance crop productivity by reducing competition for essential resources such as light, water, and nutrients. This reduction in competition allows maize plants to allocate more resources towards developing leaf area, thereby optimizing photosynthesis and increasing overall biomass production, including stover yield. These results conformed to the findings of Sanodiya et al (2013) and Triveni et al (2017).

3.8 Interaction Effect

Interaction effect of tillage and weed management practices on straw yield of maize was found to be non-significant.

3.8.1 Harvest index

The harvest index (HI) in maize is a critical parameter that reflects the efficiency of resource allocation towards grain production. A higher harvest index indicates that a larger proportion of the total biomass produced by the crop is allocated to economic yield, *i.e*., the grain. This efficiency is crucial for maximizing agricultural productivity and ensuring economic returns for farmers.

3.8.2 Effect of tillage practices

Conventional tillage often involves more intensive soil preparation, which reduces weed competition and improves soil structure. This creates a favorable growth environment where maize plants can more effectively absorb water and nutrients essential for growth. Reduced weed density under conventional tillage allows maize plants to access nutrients more efficiently. This enhances the physiological processes involved in grain filling and development, leading to a higher proportion of biomass allocated to grain. Maize plants under conventional tillage allocate more of their resources (such as carbohydrates and nutrients) towards grain formation rather than other vegetative tissues. This optimization in resource allocation contributes to a higher harvest index. Similar findings were reported by Anjum et al (2019).

3.8.3 Effect of weed management practices

Different weed management practices had a significant influence on the harvest index during both years and pooled means. Higher harvest index was observed with Hand weeding twice at 20 and 40 DAS which was on par with Atrazine 50% WP @ 0.5 kg *a.i.* ha^{-1} + Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} (early PoE) *fb* HW at 40 DAS, Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* Tembotrione 42% SC @ 120 g *a.i.* ha^{-1} and Atrazine 50% WP @ 1.0 kg *a.i.* ha^{-1} (PE) *fb* paraquat 24% SL @ 1.0 kg *a.i.* ha^{1} (PoE). The weedy check exhibiting the lowest harvest index among all treatments underscores the detrimental effect of weed competition on maize yield. Effective weed management practices, such as herbicide applications and manual weeding, contribute to improved harvest index by reducing weed interference and optimizing resource availability for maize growth. This allows maize plants to allocate more energy towards biomass and kernel production, thereby enhancing overall productivity. These results are consistent with the findings of Sandhya (Sandhya Rani, 2019, Parameswari YS et al, 2017).

3.9 Interaction Effect

Interaction effect of tillage and weed management practices on harvest index of maize was found to be non-significant.

4. CONCLUSION

Conventional tillage along with hand weeding twice at 20 and 40 DAS resulted in higher plant dry matter and consequently highest N, P and K nutrients uptake by the plants and lead to higher yield.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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