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RESEARCH ARTICLE

Effect of tillage and weed control measures on the yield and economic efficiency of maize under rainfed conditions of semi-arid region

V.K. Wasnik[1], P.K. Ghosh[2], Hanamant M. Halli*[3] and G. Gupta[1]

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ABSTRACT

A field experiment was conducted for two years (2015 and 2016) to study the impact of tillage and weed management practices on weed control, grain yield and the economic efficiency of maize (*Zea mays* L.) in the semi-arid region of central India. The study was conducted in split-plot design with two tillage practices: conventional tillage (CT) and zero tillage (ZT), randomly allotted to main plots and four weed control treatments, *viz.* pre-emergence application (PE) of atrazine 1.0 kg/ha; post-emergence application (PoE) of 2, 4-D 0.75 kg/ha; hand weeding twice at 20 and 40 days after sowing (DAS) and weedy check, into subplots and replicated thrice. CT recorded significantly lowest weed density and biomass and highest maize grain yield (3.01 t/ha), net returns (₹ 29.77×10^3/ha) and maize production efficiency (28.07 kg/ha/day). Amongst weed control treatments the hand weeding twice at 20 and 40 DAS resulted in the lowest weed density and biomass and highest maize grain yield (3.17 t/ha) and production efficiency (29.64 kg/ha/day). However, atrazine 1.0 kg/ha PE has resulted in to the highest net returns (₹ 30.30×10^3/ha) and maize economic efficiency (₹ 283/ha/day). Thus, CT with hand weedings twice at 20 and 40 DAS and atrazine 1.0 kg/ha PE at 2 DAS proved better to improve weed control efficiency and attain higher maize grain yield, and economic efficiency.

Keywords: Economics, Maize, Production efficiency, Weed management, Zero tillage

INTRODUCTION

Maize (*Zea mays* L.) is one of the third most important cereal crop next to rice and wheat in global agriculture. Recently maize growing area is gradually increasing due to increasing demand from the poultry or livestock sector (37%) and other purposes coupled with the assured market price. Globally, maize is cultivated on an area of 193.7 mha with average productivity of 5.75 t/ha (FAOSTAT 2020, Halli *et al.* 2021). India has an area of 9.2 mha maize area with production of 27.8 Mt and average productivity of 2.97 t/ha (DACNET 2020). About 83% of the maize area is under rainfed conditions (*Kharif*) and experiences various biotic and abiotic stresses. Among biotic stresses, weed infestation is the major limitation causing an economic loss of approximately 25.3 to 60% in maize in addition to indirect losses such as competition for growth resources, harboring other crop pests, and interfering management practices (Gharde *et al.* 2018). However, crop management practices like tillage, planting methods, irrigation, and weed control practices were found to reasonably manage the weeds and iimprove the crop yield (Halli *et al.* 2021a,b).

Tillage is one of the important and primary operations being practiced in maize and provides favorable conditions for better crop growth and development. Tillage also improves soil physical, chemical, biological properties, and suppresses the weed growth which enables the crop to grow and yield well (Gathala *et al.* 2011). To increase the crop yield and soil health maintenance, adaptation of optimum tillage practices are necessary (Gangwar *et al.* 2006). It was also inferred from many studies that zero tillage (ZT) in combination with a surface crop residue improved the soil water balance by improving the water availability and other physical properties of the soil (Sommer *et al.* 2012). Though conservation agricultural (CA) practices are cost-effective and environmentally friendly, weeds are one of the key challenges. Therefore, evaluation of tillage practices from the point of weed management is necessary for maize to produce a higher grain yield.

During critical growth stages competition between crop-weed could reduced maize yield by over 30% (Ahmed *et al.* 2014). In India, manual hand weeding is an age-old method of weed control in

[1] ICAR-Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh 284003, India

[2] ICAR-National Institute of Biotic Stress Management, Raipur, Chhattisgarh 493225, India

[3] ICAR-National Institute of Abiotic Stress Management Baramati, Maharashtra 413115, India

* Corresponding author email: hmhalli4700@gmail.com

most the cultivated crops. More than 50% of labor time is devoted to weeding and is mainly done by the family women and children (Tesfay *et al*. 2014). In this context, the present study was carried out to quantify the effect of tillage and herbicide treatments on weed control efficiency, grain yield, and the economics of maize.

MATERIALS AND METHODS

Experimental location, weather, and soil

The field trial was conducted during *Kharif* season of 2015 and 2016 at Central Research Farm, ICAR- Indian Grassland and Fodder Research Institute, Jhansi. The location is geographically situated at an altitude of 270 m above mean sea level on 25°27' N latitude and 78°33' E longitude. The region falls under Agro-climatic zone VIII Central Plateau and Hills region (Bundelkhand Agro-climatic Zone 6 of the Uttar Pradesh). The weather parameters recorded at the study site during the crop growth period indicated that mean weekly maximum temperature ranged from 31.7-37.3°C with an average of 34.7°C during 2015 and it ranged from 30.3-35.0°C with an average of 33.1°C during 2016. Likewise, the mean weekly minimum temperature for the corresponding period varied from 16.9-25.3°C (2015) and 16.3-26.5°C (2016). The total rainfall received during the cropping period was 466.0 mm in 2015 and 510.2 mm in 2016. The average evaporation rate recorded was 6.4 mm in 2015 and 5.5 mm in 2016 as measured by the USWB-class A pan.

The soil type of the experimental site was clay loam with the bulk density (1.26 Mg/m), particle density (2.37 Mg/m), pH (7.15), electrical conductivity (0.34 dS/m), organic carbon (0.52%), available nitrogen (230.98 kg/ha), available phosphorus (15.15 kg/ ha), and available potassium (137.83 kg/ha).

Experimental details and crop husbandry

The experiment was laid out in split-plot design, two tillage practices, *viz*. CT; conventional tillage (CT) and zero tillage (ZT) were randomly allotted to the main plot and four weed control treatments, *viz*. pre-emergence application (PE) of atrazine 1.0 kg/ha; post-emergence application (PoE) of 2,4-D 0.75 kg/ ha; hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check were allotted to subplots with three replications. Single cross normal maize hybrid "*HM-11*" with medium and semi dent grain type (released by CCSHAU, Karnal, Haryana, 2009) was sown at 60 × 25 cm spacing. Sowing was done by using a zero tillage seed drill with a seed rate of 20 kg/ha. The recommended dose of fertilizer 150 kg N, 60 kg P, and 40 kg K/ha were applied using urea, single super phosphate, and muriate of potash. Fifty percent of N and 100% of P and K were applied as basal dose at the time of sowing and the remaining 50% N was applied in two equal splits at knee high and tasseling stage. As per the treatments, atrazine 1.0 kg/ha PE was applied at 2 DAS; and 2,4-D 0.75 kg/ha PoE was applied at 20 DAS. Herbicides were sprayed using a hand-operated knapsack sprayer fitted with a flat-fan nozzle, whereas, two hand weeding were performed manually at 20 and 40 DAS. The crop was grown under rainfed conditions, however, protective irrigations were applied during dry spells of monsoon.

Observations on weeds

Periodical weed measurements such as density and dry weight (biomass) were recorded at 30 and 60 DAS using the quadrat of 0.5 m^2 and grouped into grassy, broad-leaved, and sedges. To determine weed biomass, weeds were uprooted and shade dried followed by oven drying at 70°C for 72 hours to get the constant weight and then weighed. The weed control efficiency was calculated by using the following formulae,

$$WCE(\%) = \frac{DWC - DWT}{DWC} \times 100$$

Where, WCE: Weed control efficiency; DWC: Dry weight of weeds in control plot; DWT; Dry weight of weeds in the treated plot.

Observations on maize crop and economics

Measurements on maize plant height and dry matter accumulation were recorded at harvest. The crop was harvested after attaining physiological maturity and sufficient drying at the field. Later yield attributes such as test weight, the number of grains per cob, and final grain and stover yield were recorded from the twenty representative plants treatment-wise. The shelling percentage was computed by dividing the weight of the grain with the weight of the cob and multiplied by 100. Whereas, gross returns was calculated by considering the prevailing maize grain and stover prices and respective yield treatment wise, similarly net returns was calculated by subtracting the total cost of cultivation from gross returns. Further, maize production efficiency in terms of kg/ha/day was calculated by dividing maize grain yield by total crop duration.

Statistical analysis

Data on density and biomass of weeds were subjected to square-root transformation ($\sqrt{x+0.5}$)

before analysis of variance. Analysis of variance (ANOVA) was done to determine treatment effects by using SAS 9.3 program. The post-hoc mean separation was performed to test the significance at 5% level across all the variables using Tukey's honest test.

RESULTS AND DISCUSSION

Weed flora

Weed flora observed at different growth stages of the maize consisted of five species of grasses, *viz. Cynodon dactylon* (L.) Pers, *Dactyloctenium aegyptium* (L.) Beauv, *Digitaria sanguinalis* (L.) Scop, *Echinochloa colona* (L.) Link and *Echinochloa crus-galli* (L.) Beauv; fourteen species of broad-leaved weeds, *viz. Alternanthera polygonoides* (L.) R.Br., *Celosia argentea* Linn, *Commelina benghalensis* Linn, *Commelina diffusa* L., *Corchorus olitorius, Corchorus trilocularis, Digera arvensis, Euphorbia hirta, Leucas aspera* Link, *Phyllanthus niruri, Physalis minima* L., *Trianthema portulacastrum* L., *Trichodesma indicum and Tridax procumbens and* one sedge, *viz. Cyperus rotundus* L. Among the grasses, *Echinochloa colona* and *Echinochloa crus-galli* were predominant. *Celosia argentea* Linn, *Commelina diffusa* L., *Digera arvensis, Corchorus olitorius* and *Trianthema portulacastrum* L. were the major broad-leaved weeds. The favorable monsoon conditions might have promoted almost all weeds to germinate and emerge as reported by Kakade *et al.* (2020).

Weed density and biomass

Tillage practices influenced the weed density and biomass in maize at 30 and 60 DAS. The highest total weeds density (7.22 and 7.98/m^2) and weed biomass (3.53 and 4.67 g/m^2) at 30 and 60 DAS, respectively, were recorded with zero tillage. Whereas, conventional tillage practice recorded the lowest total weed density (5.86 and 6.69/m^2) and biomass (2.88 and 3.96/m^2) at 30 and 60 DAS respectively, in maize (**Table 1** and **2**). Among the weed control treatments, significantly lowest total weed density (3.16 and 3.98/m^2) and biomass (1.58 and 2.38 g/m^2) at 30 and 60 DAS were noticed with hand weeding twice at 20 and 40 DAS closely followed by atrazine 1.0 kg/ha PE (**Table 1** and **2**). Atrazine treatment controlled the grassy weeds more effectively, whereas 2.4-D was more effective against the broad-leaved weeds. These results on total weed density and biomass in *Kharif* maize under zero tillage are in agreement with the findings of Stanzen *et al.* (2016). The removal of weeds manually twice at 20 and 40 DAS through hand weeding directly prevented the weeds germination, growth and multiplication compared to the sole application of atrazine or 2,4-D. The later emerged weeds were not controlled in case of herbicides application. The lowest weed density and biomass with hand weeding twice was also reported by Mahajan *et al.* (2002), Jain *et al.* (2007), Singh *et al.* (2015), Stanzen *et al.* (2016) and Weber *et al.* (2017). Therefore, the combined practice of conventional tillage with hand

Table 1. Effect of tillage practices and weed control treatments on weed density in maize (pooled data of 2 years)

Treatment	Weed density (no./m^2)							
	Grassy		Broad-leaved		Sedges		Total	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
Tillage practice								
Conventional tillage (CT)	4.07^b	4.92^b	3.48^a	3.75^a	2.49^b	2.70^b	5.86^b	6.69^b
Zero tillage (ZT	5.74^a	6.29^a	3.17^b	3.42^b	3.11^a	3.60^a	7.22^a	7.98^a
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment								
Atrazine 1.0 kg/ha PE at 2 DAS	2.79^c	3.48^c	2.49^b	2.88^b	1.69^c	2.04^c	4.05^c	4.89^c
2,4-D 0.75 kg/ha PoE at 20 DAS	4.10^b	4.91^b	2.15^c	2.37^c	2.64^b	2.89^b	5.29^b	6.12^b
Hand weeding twice at 20 and 40 DAS	2.34^d	3.10^d	1.69^d	1.92^d	1.41^d	1.75^d	3.16^d	3.98^d
Weedy check	10.40^a	10.95^a	6.98^a	7.17^a	5.46^a	5.93^a	13.65^a	14.37^a
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction								
CT × Atrazine 1.0 kg/ha PE at 2 DAS	1.97^f	3.00^f	2.51^c	2.99^c	1.47^{fg}	1.89^e	3.42^f	4.55^e
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	3.11^e	4.16^d	2.33^c	2.46^d	2.43^d	2.31^d	4.49^d	5.27^d
CT × Hand weeding twice at 20 and 40 DAS	1.37^g	2.37^g	1.80^{de}	2.12^e	1.20^g	1.45^f	2.40^g	3.38^f
CT × Weedy check	9.83^b	10.17^b	7.29^a	7.44^a	4.84^b	5.17^b	13.13^b	13.59^b
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	3.62^d	3.97^{de}	2.47^c	2.76^c	1.90^e	2.19^d	4.69^d	5.22^d
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	5.08^c	5.66^c	1.96^d	2.28^{ef}	2.84^c	3.47^c	6.09^c	6.97^c
ZT × Hand weeding twice at 20 and 40 DAS	3.31^e	3.81^e	1.59^e	1.73^g	1.62^{ef}	2.06^{de}	3.91^e	4.58^e
ZT × Weedy check	10.96^a	11.73^a	6.68^b	6.90^b	6.08^a	6.68^a	14.17^a	15.15^a
LSD (p=0.05)	0.0004	0.0023	0.0147	0.0997	0.0007	<.0001	0.0064	<.0001

Values are transformed ($\sqrt{x+0.5}$), DAS; days after sowing. Means with the same letter within the column are not statistically different (p=0.05).

weeding twice at 20 and 40 DAS could effectively control the weeds emergence and subsequently emerged weed growth in maize.

Weed control efficiency (WCE)

Higher WCE (80.83%) was observed with conventional tillage compared to zero tillage which observed the minimum WCE (70.02%) (**Table 2**). Likewise, higher WCE (84.74%) was recorded with hand weeding twice at 20 and 40 DAS followed by atrazine 1.0 kg/ha PE (80.88%) and 2,4-D 0.75 kg/ha PoE (74.16%). Complete removal of the first flush of weeds at 20 DAS and subsequent flush at 40 DAS through hand weeding resulted in higher WCE due to effective control of weeds for a longer period resulting in low weed biomass. These results are in agreement with the findings of Parameshwari (2013) that better weed control was obtained under conventional tillage. Thus, the higher WCE could be achieved under conventional tillage practice with hand weeding twice at 20 and 40 DAS.

Maize growth and yield attributes

Tillage and weed control practices significantly influenced the growth attributes of maize. An increase in maize plant height (213.8 cm) and dry matter accumulation (140.2 g/pl) at harvest was recorded under conventional tillage over zero tillage. However, days to 50% flowering and days to maturity were not influenced by tillage and weed control measures (**Table 3**). The magnitude of increase in maize plant height and dry matter accumulation was maximum between 60 DAS and at harvest due to better weed control at early satges. The improved growth was also related to reduced weed intensity and pressure throughout the crop growth confirming the findings of Stanzen *et al*. (2016). Similarly, among weed control measures, maximum plant height (219.2 cm) and dry matter accumulation (143.3 g/pl) at harvest were recorded with hand weeding twice at 20 and 40 DAS followed by atrazine 1.0 kg/ha PE and 2,4-D 0.75 kg/ha PoE. The lowest maize plant height (186.5 cm) and dry matter accumulation (127.2 g/pl) at harvest were recorded in weedy check due to the associated highest weed density and biomass. The reduction in weed density and biomass, and robust root growth under hand weeding twice has increased the water and nutrient uptake of maize which led to the significant increase in growth attributes as observed by Rao *et al*. (2009) and Parameshwari (2013).

Tillage practices and weed control measures ultimately influenced the maize yield parameters (**Table 3**). The conventional tillage improved the grain yield (38.70%), stover yield (17.26%) and crude protein content (4.1%) of maize compared to zero tillage (**Table 3** and **4**). Similalrly, hand weeding twice at 20 and 40 DAS improved the maize yield attributes and recorded highest grain yield (22.16%), stover yield (34.4%), and crude protein content

Table 2. Weed biomass and weed control efficiency (WCE) as influenced by tillage practices and weed control treatments in maize (pooled data of 2 years)

Treatment	Weed biomass (g/m^2)								WCE (%) at 60 DAS
	Grassy		Broad- leaved		Sedges		Total		
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	
Tillage practice									
Conventional tillage (CT)	*2.30^{b}	3.00^{b}	1.90^{a}	2.27^{a}	0.75^{b}	1.63^{b}	2.88^{b}	3.96^{b}	80.83^{a}
Zero tillage (ZT	3.14^{a}	3.80^{a}	1.73^{b}	2.10^{b}	0.80^{a}	2.00^{a}	3.53^{a}	4.67^{a}	70.02^{b}
LSD (p=0.05)	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment									
Atrazine 1.0 kg/ha PE at 2 DAS	1.63^{c}	2.14^{c}	1.37^{b}	1.77^{b}	0.73^{c}	1.26^{c}	2.05^{c}	2.90^{c}	80.88^{b}
2,4-D 0.75 kg/ha PoE at 20 DAS	2.27^{b}	2.96^{b}	1.23^{c}	1.50^{c}	0.75^{b}	1.66^{b}	2.53^{b}	3.59^{b}	74.16^{c}
Hand weeding twice at 20 and 40 DAS	1.40^{d}	1.92^{d}	0.99^{d}	1.26^{d}	0.72^{d}	1.12^{d}	1.58^{d}	2.38^{d}	84.74^{a}
Weedy check	5.57^{a}	6.57^{a}	3.68^{a}	4.23^{a}	0.90^{a}	3.22^{a}	6.67^{a}	8.40^{a}	-
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction									
CT × Atrazine 1.0 kg/ha PE at 2 DAS	1.23^{f}	1.87^{f}	1.41^{c}	1.83^{c}	0.72^{ef}	1.20^{e}	1.75^{f}	2.71^{e}	81.06^{b}
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	1.75^{e}	2.53^{d}	1.31^{c}	1.54^{d}	0.73^{de}	1.40^{d}	2.09^{e}	3.13^{d}	76.16^{c}
CT × Hand weeding twice at 20 and 40 DAS	0.97^{g}	1.52^{g}	1.00^{e}	1.36^{e}	0.72^{f}	1.00^{f}	1.20^{g}	2.05^{f}	85.27^{a}
CT × Weedy check	5.23^{b}	6.07^{b}	3.89^{a}	4.36^{a}	0.85^{b}	2.91^{b}	6.49^{b}	7.96^{b}	-
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	2.03^{d}	2.42^{de}	1.34^{c}	1.70^{c}	0.74^{d}	1.31^{de}	2.34^{d}	3.08^{d}	80.71^{b}
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.79^{c}	3.40^{c}	1.16^{d}	1.45^{de}	0.78^{c}	1.93^{c}	2.97^{c}	4.05^{c}	72.15^{d}
ZT × Hand weeding twice at 20 and 40 DAS	1.83^{e}	2.32^{e}	0.98^{e}	1.17^{f}	0.72^{ef}	1.25^{e}	1.96^{e}	2.72^{e}	84.20^{a}
ZT × Weedy check	5.91^{a}	7.07^{a}	3.47^{b}	4.09^{b}	0.95^{a}	3.52^{a}	6.85^{a}	8.84^{a}	-
LSD (p=0.05)	0.0286	0.0084	0.0049	0.3310	<.0001	<.0001	0.0001	<.0001	0.0010

*Values are transformed ($\sqrt{x+0.5}$), Means with the same letter within the column are not statistically different (p=0.05).

(4.18%) over control. Maximum grain and stover yield might be due to less crop-weed competition because of vigorous crop growth and greater dry matter accumulation. The favorable soil physical condition due to optimum tillage practices promoted the root growth and enhanced the uptake of water and nutrients. This might be attributed to efficient partitioning of metabolites and translocation of photosynthates towards sink, which translated into increased yield attributes and grain yield as reported by Parameshwari (2013), Triveni *et al.* (2017). Hence, practicing conventional tillage and hand weedings twice at 20 and 40 DAS produced higher grain yield of maize by controlling the weeds and favouring the crop growth.

Table 3. Effect of tillage practices and weed control treatments on growth and yield attributes of maize (pooled data of 2 years)

Treatment	Plant height (cm) at harvest	Dry matter (g/pl) at harvest	Days to 50% silking	Days to maturity	No. of grains/ cob	100 grain weight (g)	Shelling (%)	Crude protein content (%)
Tillage practice								
Conventional tillage (CT)	213.8^{a}	140.2^{a}	65.54^{a}	102.79^{a}	337.92^{a}	26.40^{a}	77.79^{a}	9.93^{a}
Zero tillage (ZT	195.5^{b}	128.6^{b}	67.19^{a}	105.23^{a}	310.09^{b}	22.61^{b}	73.32^{b}	9.54^{b}
LSD (p=0.05)	<.0001	<.0001	NS	NS	<.0001	<.0001	<.0001	0.046
Weed control treatment								
Atrazine 1.0 kg/ha PE at 2 DAS	212.2^{b}	135.7^{b}	66.08^{a}	103.29^{ab}	340.01^{b}	24.80^{b}	76.84^{b}	9.81^{a}
2,4-D 0.75 kg/ha PoE at 20 DAS	200.8^{c}	131.1^{c}	66.67^{a}	104.33^{ab}	315.97^{c}	23.16^{c}	73.94^{c}	9.63^{a}
Hand weeding twice at 20 and 40 DAS	219.2^{a}	143.3^{a}	65.83^{a}	102.25^{b}	349.11^{a}	27.88^{a}	80.01^{a}	9.95^{a}
Weedy check	186.5^{d}	127.2^{d}	66.88^{a}	106.17^{a}	290.92^{d}	22.18^{d}	71.42^{d}	9.55^{a}
LSD (p=0.05)	<.0001	<.0001	NS	NS	<.0001	<.0001	<.0001	NS
Interaction								
CT × Atrazine 1.0 kg/ha PE at 2 DAS	225.0^{a}	141.5^{b}	65.00^{a}	102.83^{b}	351.50^{b}	26.43^{b}	78.38^{b}	9.96^{ab}
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	207.5^{b}	135.8^{c}	66.00^{a}	103.17^{b}	322.89^{d}	24.07^{c}	76.21^{cd}	9.85^{ab}
CT × Hand weeding twice at 20 and 40 DAS	226.8^{a}	150.1^{a}	65.00^{a}	101.33^{b}	362.44^{a}	31.72^{a}	81.96^{a}	10.17^{a}
CT × Weedy check	196.1^{cd}	133.6^{cd}	66.17^{a}	103.83^{ab}	314.83^{e}	23.40^{c}	74.59^{d}	9.75^{ab}
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	199.3^{c}	130.4^{d}	67.17^{a}	103.75^{ab}	328.53^{d}	23.17^{c}	75.30^{d}	9.67^{ab}
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	194.1^{d}	126.3^{e}	67.33^{a}	105.50^{ab}	309.05^{e}	22.26^{cd}	71.67^{e}	9.42^{ab}
ZT × Hand weeding twice at 20 and 40 DAS	211.6^{b}	136.7^{c}	66.67^{a}	103.17^{b}	335.78^{c}	24.05^{c}	78.06^{bc}	9.73^{ab}
ZT × Weedy check	176.9^{e}	120.8^{f}	67.58^{a}	108.50^{a}	267.00^{f}	20.96^{d}	68.25^{f}	9.35^{b}
LSD (p=0.05)	0.002	0.486	NS	NS	351.50^{b}	0.002	0.179	NS

Values are transformed ($\sqrt{x+0.5}$), Means with the same letter within the column are not statistically different (p=0.05)

Table 4. Effect of tillage practices and weed control treatments on grain and stover yield of maize

Treatment	Yield (t/ha)					
	Grain			Stover		
	2015	2016	Pooled	2015	2016	Pooled
Tillage practice						
Conventional tillage (CT)	2.86^{a}	3.16^{a}	3.01^{a}	6.37^{a}	6.68^{a}	6.52^{a}
Zero tillage (ZT)	2.13^{b}	2.22^{b}	2.17^{b}	5.49^{b}	5.63^{b}	5.56^{b}
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment						
Atrazine 1.0 kg/ha PE at 2 DAS	2.74^{b}	3.01^{b}	2.87^{b}	6.10^{b}	6.50^{b}	6.30^{b}
2,4-D 0.75 kg/ha PoE at 20 DAS	2.27^{c}	2.46^{c}	2.37^{c}	5.64^{c}	5.78^{c}	5.71^{c}
Hand weeding twice at 20 and 40 DAS	3.04^{a}	3.31^{a}	3.17^{a}	6.80^{a}	7.12^{a}	6.96^{a}
Weedy check	1.92^{d}	1.96^{d}	1.94^{d}	5.16^{d}	5.20^{d}	5.18^{d}
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction						
CT × Atrazine 1.0 kg/ha PE at 2 DAS	3.24^{b}	3.68^{b}	3.46^{b}	6.60^{b}	7.10^{b}	6.85^{b}
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.54^{c}	2.83^{c}	2.69^{c}	5.84^{c}	6.04^{c}	5.94^{c}
CT × Hand weeding twice at 20 and 40 DAS	3.58^{a}	4.03^{a}	3.80^{a}	7.76^{a}	8.26^{a}	8.01^{a}
CT × Weedy check	2.06^{e}	2.09^{f}	2.08^{f}	5.27^{ef}	5.32^{ed}	5.29^{f}
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	2.24^{d}	2.34^{e}	2.29^{e}	5.60^{d}	5.89^{c}	5.75^{d}
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	2.00^{e}	2.10^{f}	2.05^{f}	5.44^{ed}	5.53^{d}	5.49^{e}
ZT × Hand weeding twice at 20 and 40 DAS	2.50^{c}	2.59^{d}	2.55^{d}	5.85^{c}	5.99^{c}	5.92^{d}
ZT × Weedy check	1.78^{f}	1.83^{g}	1.81^{g}	5.06^{f}	5.09^{e}	5.07^{g}
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means with the same letter within the column are not statistically different (p=0.05)

Economics and maize production efficiency

Different management practices such as tillage and weed control treatments influenced the cost of production and economic returns. Significantly highest gross returns (₹ 64.61×10^3/ha), net returns (₹ 29.77×10^3/ha), and benefit-cost ratio (1.84) were recorded with conventional tillage. Despite the higher cost of cultivation (₹ 34.84×10^3/ha) due to repeated tillage operations and fuel prices conventional tillage still maintained the higher returns, mainly due to higher grain and stover yield of maize over zero tillage (**Table 4** and **5**). Thus, this practice witnessed the highest production efficiency (28.07 kg/ha/day) and economic efficiency (₹ 278.2/ha/day). In contrast, the lower cost of cultivation (₹ 30.73×10^3/ha), net returns (₹ 18.47×10^3/ha), and economic efficiency (₹ 172.6/ha/day) were recorded under zero tillage. This was mainly due to poor returns over investment due to increased weed competition and decreased maize grain and stover yield under zero tillage. Similarly, among weed control treatments, hand weeding twice at 20 and 40 DAS recorded the higher cost of cultivation (₹ 39.12×10^3/ha), gross returns (₹ 68.46×10^3/ha), and production efficiency (29.64 kg/ha/day). Interestingly, pre-emergence application of atrazine 1.0 kg/ha registered the highest net returns (₹ 30.30×10^3/ha), benefit cost ratio (1.94), and economic efficiency (₹ 283.0/ha/day) compared to hand weeding twice at 20 and 40 DAS. The higher benefit cost ratio was due to the lower cost of weed control in maize with the application of atrazine. Previous authors reported highest net returns, benefit cost ratio, and economic efficiency in maize were attained with the pre-emergence application of herbicides; saflufenacil 68 g/l + diamethanamid-p 600 g/l (Yadav *et al.* 2018). Thus, adoption of conventional tillage plus the application of atrazine 1.0 kg/ha as pre-emergence could be economical option due to reduced cost on weed management.

It was concluded that conventional tillage plus hand weeding twice at 20 and 40 DAS produced significantly higher grain yield (3.80 t/ha) and stover yield (8.01 t/ha) yield in maize due to improved weed control efficiency resulting into lower weed growth and better crop growth and yield attributes. However, pre-emergence application of atrazine 1.0 kg/ha at 2 DAS as under conventional tillage was found to be an alternate and economically efficient weed management practice with higher grain yield of maize under semi-arid conditions of central India as the cost and availability of labor also play an important role in deciding choice of weed control practices.

Table 5. Economics and production efficiency of maize cultivation in response to tillage practices and weed control treatments (pooled data of 2 years)

Treatment	Cost of cultivation (x10^3 ₹/ha)	Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	Benefit-cost ratio	Production efficiency (kg/ha/day)	Economic efficiency (₹/ha/day)
Tillage practices						
Conventional tillage (CT)	34.84[a]	64.61[a]	29.77[a]	1.84[a]	28.07[a]	278.17[a]
Zero tillage (ZT	30.73[b]	49.20[b]	18.47[b]	1.61[b]	20.27[b]	172.58[b]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Weed control treatment						
Atrazine 1.0 kg/ha PE at 2 DAS	31.64[b]	61.94[b]	30.30[a]	1.94[a]	26.82[b]	283.00[a]
2,4-D 0.75 kg/ha PoE at 20 DAS	30.84[c]	52.63[c]	21.79[c]	1.70[c]	22.12[c]	203.67[c]
Hand weeding twice at 20 and 40 DAS	39.12[a]	68.46[a]	29.34[b]	1.74[b]	29.64[a]	274.25[b]
Weedy check	29.55[d]	44.59[d]	15.04[d]	1.51[d]	18.10[d]	140.58[d]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Interaction						
CT × Atrazine 1.0 kg/ha PE at 2 DAS	33.91[c]	72.41[b]	38.50[b]	2.14[a]	32.31[b]	359.67[b]
CT × 2,4-D 0.75 kg/ha PoE at 20 DAS	32.71[d]	58.06[c]	25.34[c]	1.77[c]	25.08[c]	236.67[c]
CT × Hand weeding twice at 20 and 40 DAS	41.52[a]	81.02[a]	39.49[a]	1.95[b]	35.52[a]	369.17[a]
CT × Weedy check	31.23[e]	46.97[f]	15.74[g]	1.50[e]	19.38[f]	147.17[g]
ZT × Atrazine 1.0 kg/ha PE at 2 DAS	29.38[f]	51.48[e]	22.09[d]	1.75[c]	21.33[e]	206.33[d]
ZT × 2,4-D 0.75 kg/ha PoE at 20 DAS	28.97[g]	47.21[f]	18.24[f]	1.63[d]	19.16[f]	170.67[f]
ZT × Hand weeding twice at 20 and 40 DAS	36.72[b]	55.91[d]	19.19[e]	1.52[e]	23.77[d]	179.33[e]
ZT × Weedy check	27.86[h]	42.21[g]	14.35[h]	1.52[e]	16.82[g]	134.00[h]
LSD (p=0.05)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means with the same letter within the column are not statistically different ($p < 0.05$). The prevailing price of maize grain and stover were ₹ 1500 and 300 per quintal, respectively.

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