Indian Journal of Weed Science (2023) **55**(3): 249–254
http://dx.doi.org/10.5958/0974-8164.2023.00046.1

RESEARCH ARTICLE

Effect of herbicide and straw mulch on weed growth, productivity and profitability of wheat under different tillage practices in Eastern India

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Received: 30 August 2022 | Revised: 17 July 2023 | Accepted: 20 July 2023

ABSTRACT

The purpose of this study was to evaluate the impact of straw mulch and herbicides on weed growth and productivity of wheat (*Triticum aestivum* L.) under different tillage practices. Two tillage practices in main plot [zero tillage (ZT) and conventional tillage (CT)], eight weed management practices in sub-plot [pendimethalin (PMT) at 0.75 kg/ha, clodinafop-propargyl + metsulfuron-methyl (CP + MSM) at 0.40 kg/ha, straw mulching (SM) at 4.0 t/ha, PMT at 0.75 kg/ha followed by (*fb*) CP + MSM at 0.40 kg/ha, PMT at 0.75 kg/ha *fb* SM 4 t/ha, SM 4 t/ha *fb* CP + MSM 0.40 kg/ha, three hand weeding and weedy check] were assigned in a split plot design replicated thrice. Zero tillage had lower density as well as biomass of *Digitaria sanguinalis* (L.) Scop., *Gnaphalium indicum* (L.), *Polygonum plebeium* R.Br., *Spilanthes calva* DC and total weed than CT. Pendimethalin *fb* CP + MSM recorded significantly lowest total weed density and biomass. Compared to pendimethalin *fb* CP + MSM, pendimethalin *fb* SM enhanced grain yield of wheat by 9.6, 5.5 and 7.5% in first year, second year and when pooled over the years, respectively. Zero tillage among tillage practices and PMT *fb* SM or PMT *fb* CP + MSM among weed management practices appeared to be effective for better weed management and higher productivity as well as profitability of wheat.

Keywords: Chemical control, Clodinafop-propargyl, Conventional tillage, Estern India, Metsulfuron- methyl, Rice straw mulch, Zero tillage

INTRODUCTION

Weeds are the major biotic constraint in the production of wheat (*Triticum aestivum* L.). Unchecked weed growth reduces crop yield to the extent of 24 to 65 % (Kumar *et al.* 2013a) in context of India, whereas, specifically in Eastern India, the yield loss is in the range of 32 to 46% (Duary *et al.* 2021). *Digitaria sanguinalis* (L.) Scop., is a common weed in the region, particularly in the rainy season. This weed's existence has been seen throughout the winter and post-winter seasons in recent years. The soil in this area is acidic and has a low water holding capacity, making it ideal for this weed to thrive. Bispyribac-sodium has been used as a common herbicide to manage weeds in rice for the last decade, however it has been proven ineffective against *D. sanguinalis* (Mahajan and Chauhan 2013). This could potentially be the cause for the establishment of the *D. sanguinalis* colony in winter as well. The weed germinates along with or before the emergence of the succeeding crop after rice harvest. The onset of winter in this region is late and short, allowing *D. sanguinalis* to survive the winter.

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In Eastern India, due to late harvesting of rice, often there are delays in the sowing of wheat resulting in short vegetative growth period of wheat. Zero tillage (ZT) allows early sowing of wheat hence, reducing risks of terminal heat stress during the grain-filling phase, better nutrient management and saves water (Gathala *et al.* 2013), reduces the weed infestation and which may lead to increase in grain yield (5.9-11.9%) (Bhardwaj *et al.* 2004). It has been estimated that ZT requires less fuel consumption, facilitates lower cost of production and higher net income in comparison to conventional tillage (CT) (Stanzen *et al.* 2017).

Burning of paddy straw is a major source of air pollution, in the form of greenhouse gas emissions (CO_2, CH_4, NO_2) and particulate matter (Gupta *et al.* 2004) which deteriorates the soil health (Buttar *et al.* 2022). The straw ash also reduces the efficacy of different pre-emergence (PE) herbicides (Chhokar *et al.* 2009). Thus, instead of burning the residue, we can use it as mulching material to suppress the weed growth and density. Rice residue as mulch reduces the emergence and growth of *Echinochloa colona* (L.) Link., *Echinochloa crus-galli* (L.) Beauv and

Dactyloctenium aegyptium (L.) Willd., in rice-wheat cropping system (Kumar *et al.* 2013b). Straw mulch not only suppresses the weed infestation but also enhances the soil water content and yield of wheat (Sidhu *et al.* 2007). Effective and season-long weed control cannot be achieved by sole application of herbicide and/or crop residue as mulch (Chauhan and Abugho 2013). However, integrated use of herbicides and mulch can suppress the weed growth to achieve the increment in crop yield in a sustainable manner (Fatima and Duary 2020, Fatima *et al.* 2021).

Little research data are available on the dynamics of major weeds under different tillage systems with integrated approach of herbicide and straw mulching. Keeping this background in view, the present investigation was undertaken to gather information on the population dynamics and growth of some major weed species and productivity and production economics of late sown wheat under different tillage practices with integration of herbicide and straw mulching in Eastern India.

MATERIALS AND METHODS

A field study was conducted at the Agriculture Farm of the Institute of Agriculture, Visva-Bharati University, West Bengal, India during the winter season (December-April 2016-17 and November-March 2017-18). The field is geographically located at about 23^{0}40.1052 N latitude and 87^{0}39.5212 E longitude with an average altitude of 56 m above the mean sea level of sub-humid red lateritic agro-ecological zone of the tropics. The soil of the experiment field was sandy loam (*Ultisol*) in texture, slightly acidic in reaction with pH 5.8, low in organic carbon (0.42%), low in available N (139.2 kg/ha), medium in available P (10.1 kg/ha) and low in available K (121.2 kg/ha).

The experiment was conducted in a split-plot design, with two tillage practices in the main plot and seven weed management practices and one control (weedy check) in the sub plot (**Table 1**), which were replicated thrice. Sowing was done with zero till ferti-cum-seed drill machine, which covers 11 rows. Row to row distance was maintained at 20 cm. Glyphosate was applied at 1.0 kg/ha in ZT before crop sowing. All the pre- and post-emergence herbicides were applied with a battery-operated knapsack sprayer equipped with a flat fan nozzle and a spray volume of 500 L/ha. The wheat variety *"HD 2824"* was sown at second week of December 2016 and fourth week of November 2017 in 2016-17 and 2017-18, respectively and harvested at first week of April 2017 and last week of March 2018 in 2016-17 and 2017-18, respectively. Seed rate for both ZT and CT was 100 kg/ha. The recommended dose of 120 kg nitrogen, 60 kg phosphorus and 60 kg potash/ha were applied to the crop.

Density and biomass of different weeds was taken by placing a quadrat of 50 × 50 cm (0.25 m^2) randomly in the sampling area. The weeds were uprooted, cleaned by washing, placed in sunlight for few hours and were kept in a hot air oven for drying at 70 ^{0}C for 72 hours or more till constant weights were recorded. Grain and straw yields were determined by middle 3×2 m^2 area of each plot.

Weed density and biomass data were subjected to square root ($\sqrt{x+0.5}$) transformation and the transformed data was used for analysis. Statistical analysis of the data was done using R-3.6.3 with a split plot design at a 5% level of significance. The original data have been given in parentheses in each table along with the transformed values.

RESULT AND DISCUSSION

The experimental field was infested with *Digitaria sanguinalis* (L.) Scop., and *Echinochloa colona* (L.) Link., among the grasses; *Eclipta alba* (L.), *Gnaphalium indicum* (L.), *Polygonum plebeium* R.Br., *Spilanthes calva* DC., *Solanum nigrum* (L.) and *Sphaeranthus indicus* (L.) among broad-leaf

Table 1. Details of the treatments

Treatment	Abbreviation	Rate of application	Application time (Day after sowing)
Tillage			
Zero tillage	ZT		
Conventional tillage	CT		
Weed management practice			
Pendimethalin (PE) (stomp 30 EC)	PMT	0.75 kg	1
Clodinafop-propargyl + metsulfuron-methyl (PoE)	CP + MSM	0.40 kg	30
Straw mulching alone	SM	4 t	20
Pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl	PMT *fb* CP + MSM	0.75 kg *fb* 0.40 kg	1 *fb* 35
Pendimethalin *fb* straw mulching	PMT *fb* SM	0.75 kg *fb* 4 t	1 *fb* 20
Straw mulching *fb* clodinafop-propargyl + metsulfuron-methyl	SM *fb* CP + MSM	4 t *fb* 0.40 kg	20 *fb* 30
Hand weeding		-	25 *fb* 35 *fb* 45
Weedy check		-	-

fb: followed by; PE: Pre-emergence; PoE: post-emergence weeds. Out of which, predominant weeds were *P. plebeium* (45.6-61.8% of total weed density), *D. sanguinalis* (12.1-25.2%), *S. calva* (11.5-17.8%) and *G. indicum* (10.8-14.0%).

In the first year of investigation, weed density was statistically equal between tillages (**Table 2**). However, in the second year, ZT recorded significantly lower density of *G. indicum*, *P. plebeium* and total weed (by 14.7%). There was reduction in total weed density with ZT by 10% even when pooled over the years. Glyphosate sprayed before to wheat sowing killed emerging weeds, resulting in a reduction in weed seed in the upper soil layer, which could be the cause for low weeds under ZT. Malik *et al.* (2000), Sen *et al.* (2010), Mishra *et al.* (2022) previously reported lower density of grassy weed (*Phalaris minor* Retz.), broad-leaf weed (*Solanum nigrum* L., *Chenopodium album* L., *Melilotus* sp., *Medicago denticulata* L.) and total weed density in ZT than CT. Tillage exposes weed seed on the upper layer of the soil and enable seedlings to emerge from deeper in the soil, which may account for a higher weed population than un-tilled soil (Singh *et al.* 2001, Franke *et al.* 2007, Chauhan 2012).

During both the seasons, pendimethalin alone provided excellent control of the grassy weed *D. sanguinalis* (0 no./m^2). Pendimethalin could control this weed very effectively as earlier documented by Mahajan and Chauhan (2013). *Spilanthes calva* emerged and grew vigorously in the pendimethalin treated plot (density 59-73 no./m^2), along with other broad-leaf weeds [*G. indicum* (density 5-16 no./m^2) and *P. plebeium* (density 0-3 no./m^2)] in the later stage (60 DAS) of wheat growth. It might be because pre-emergence herbicides lost their effectiveness after 15 days of application (Sudha *et al.* 2016). Ready-mix herbicide CP + MSM was found less effective against *D. sanguinalis* (only 5.0-36.5% reduction in density). Clodinafop-propargyl is an aryloxyphenoxypropionate herbicide. However, this herbicide poorly controls *Phalaris minor* Retz., a grassy weed of wheat as reported by Kaur *et al.* (2017). Aryloxyphenoxypropionate compounds are successfully used for post-emergence weed control in rice and wheat. However, they have no efficacy on problematic grass weeds including *D. sanguinalis* and *E. crus-galli* (Gao *et al.* 2022). In red and lateritic belt of West Bengal *D. sanguinalis* is one of the most problematic grass weeds in aerobic situations throughout the year. It has been observed that this weed is not controlled by cyhalofop-butyl and other herbicides like bispyribac-sodium in direct-seeded rice (Jaiswal 2022). However, it (CP + MSM) controlled *G. indicum*, *S. calva* and *P. plebeium* significantly and was found at par with three hand weeding. Broad-leaf such as *Melilotus alba*, *C. album* and *Anagallis arvensis* L. are susceptible to metsulfuron methyl as reported by Malik *et al.*

Table 2. Species wise and total weed density at 60 DAS of wheat under different tillage and weed management practices

Treatment	Weed density (no./m^2) at 60 DAS														
	D. sanguinalis			*G. indicum*			*P. plebeium*			*S. calva*			Total weed		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice															
ZT	2.63 (11)a*	4.68 (38)a	3.65 (25)d	2.02 (8)a	2.34 (10)b	2.18 (9)c	3.82 (40)a	4.38 (45)b	4.10 (43)e	3.03 (15)a	3.91 (26)a	3.47 (21)b	6.55 (74)a	8.68 (121)b	7.61 (98)d
CT	3.01 (15)a	4.94 (43)a	3.97 (29)c	2.05 (8)a	2.71 (14)a	2.37 (11)d	3.52 (34)a	5.19 (55)a	4.36 (45)d	3.20 (17)a	4.15 (30)a	3.67 (24)e	6.66 (75)a	9.51 (142)a	8.08 (109)e
Weed management practice															
PMT	0.71 (0)d	0.71 (0)d	0.71 (0)d	2.33 (5)c	4.00 (16)c	3.17 (11)c	1.90 (3)c	0.71 (0)e	1.30 (2)e	7.71 (59)a	8.59 (73)b	8.15 (66)b	8.22 (67)c	9.47 (89)d	8.84 (78)d
CP + MSM	6.17 (38)a	8.84 (78)b	7.50 (58)b	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	6.95 (48)c	3.85 (24)c	0.71 (0)e	0.71 (0)e	0.71 (0)e	6.17 (38)d	11.24 (126)c	8.70 (82)c
SM	3.87 (14)b	8.49 (72)b	6.17 (43)b	3.54 (12)b	5.33 (28)b	4.43 (20)b	9.68 (93)b	10.84 (117)b	10.25 (106)b	4.53 (20)c	7.09 (50)c	5.81 (35)c	11.88 (141)b	16.35 (267)b	14.11 (205)b
PMT *fb* CP + MSM	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)f	0.71 (0)g	0.71 (0)g
PMT *fb* SM	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	3.71 (13)d	4.33 (18)d	4.01 (16)d	3.71 (13)e	4.33 (18)f	4.01 (16)f
SM *fb* CP + MSM	3.33 (11)c	7.19 (51)c	5.25 (31)c	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	2.72 (7)d	1.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	3.32 (11)e	7.89 (62)e	5.60 (36)e
Hand weeding	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)f	0.71 (0)g	0.71 (0)g
Weedy check	6.39 (40)a	11.10 (123)a	8.74 (82)a	6.85 (46)a	7.33 (53)a	7.09 (50)a	14.24 (203)a	14.96 (223)a	14.60 (213)a	6.17 (38)b	9.38 (87)a	7.76 (63)a	18.12 (328)a	22.34 (488)a	20.10 (408)a

fb: followed by; original figures in parentheses were subjected to square-root transformation ($\sqrt{x+0.5}$) before statistical analysis; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test

(2013). *Digitaria sanguinalis*, *G. indicum*, *P. plebeium* and *S. calva* were absent in treatment PMT *fb* CP + MSM. Because pendimethalin was effective against *D. sanguinalis* and ready-mix CP + MSM effectively killed broad-leaf weeds (*G. indicum*, *P. plebeium* and *S. calva*) that emerged after two weeks of pendimethalin application. Straw mulch (SM) alone reduced the total density of weeds by 45.2, 57.0 and 49.7% in first year, second year and when pooled over the years, respectively over untreated control. We noticed that straw mulch alone reduced weeds in the inter-row zone (between two rows of crop) but not in the intra-row zone (in crop row). In comparison to PMT alone, the placement of straw mulch (SM) after PMT lowered the emergence of *G. indicum* (100%), *P. plebeium* (100%) and *S. calva* (65.7-79.3%). Mulching smothers weeds by blocking light and creating a physical barrier that prevents their germination and emergence (Kumar *et al.* 2013b; Bahadur *et al.* 2015).

Weed biomass

In unweeded control, *D. sanguinalis* contributed 33.1-42.6% of total weed biomass (**Table 3**). Among broad-leaf weeds, *P. plebeium* was found to be dominant in both the years (37.3-53.0% of total weed biomass). Lower biomass of *D. sanguinalis*, *G. indicum*, *P. plebeium*, *S. calva* and total weed (by 19.3%) was observed in ZT than in CT (**Table 3**). Tillage reduces soil surface resistance to root penetration (Verhulst *et al.* 2010). This explains why weed biomass in CT was higher. Our findings were similarly consistent with those of Sen *et al.* (2010), Mishra *et al.* (2022).

Among weed management practices, pendimethalin alone was seen to be ineffective against *S. calva* (biomass 6.4 g/m^2) and registered 12.5% higher biomass compared to weedy check (biomass 5.6 g/m^2). Ready-mix CP + MSM showed excellent control over *G. indicum* (by 100%), *S. calva* (100%) and *P. plebeium* (89.9%), but it lowered *D. sanguinalis* biomass by 40.4% only. However, sequential application of PMT *fb* CP + MSM resulted in complete reduction of weed biomass and was comparable to PMT *fb* SM (with 96.9% biomass reduction) and SM *fb* CP + MSM (with 86.2% biomass reduction). These findings were comparable with those of Kaur *et al.* (2017). Pendimethalin *fb* placement of straw mulch suppressed the growth and development of a wide range of weeds as previously reported by Fatima and Duary (2020).

Grain and straw yield

There was no significant effect of tillage on the grain and straw yield (**Table 4**). However, zero tillage recorded higher grain yield of wheat over CT by 4.8% possibly due to lower weed density and biomass under ZT. In current study, the grain yield of

Table 3. Species wise and total weed biomass at 60 DAS of wheat under different tillage and weed management practices

Treatment	Weed biomass (g/m^2) at 60 DAS														
	D. sanguinalis			*G. indicum*			*P. plebeium*			*S. calva*			Total weed		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice															
ZT	1.75 (4.0)^{a*}	2.45 (8.8)^{b}	2.10 (6.4)^{e}	1.00 (0.7)^{a}	1.16 (1.4)^{b}	1.08 (1.1)^{c}	1.68 (4.8)^{a}	1.82 (5.4)^{b}	1.74 (5.1)^{e}	1.26 (1.5)^{a}	1.34 (1.7)^{b}	1.30 (1.6)^{b}	2.73 (11.1)^{a}	3.41 (17.4)^{b}	3.06 (14.2)^{e}
CT	1.83 (4.4)^{a}	2.73 (11.3)^{a}	2.28 (7.9)^{d}	0.93 (0.5)^{a}	1.30 (1.9)^{a}	1.11 (1.2)^{d}	1.73 (5.6)^{a}	2.04 (6.4)^{a}	1.89 (6.0)^{d}	1.27 (1.6)^{a}	1.66 (3.3)^{a}	1.47 (2.5)^{e}	2.87 (12.3)^{a}	4.02 (23.0)^{a}	3.42 (17.6)^{d}
Weed management practice															
PMT	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.00)^{e}	0.91 (0.3)^{c}	1.33 (1.3)^{c}	1.11 (0.8)^{c}	0.96 (0.4)^{c}	0.71 (0.0)^{e}	0.83 (0.2)^{e}	2.75 (7.0)^{a}	2.45 (5.5)^{b}	2.60 (6.4)^{b}	2.94 (7.9)^{c}	2.70 (6.8)^{e}	2.79 (7.5)^{e}
CP + MSM	3.03 (8.7)^{b}	4.49 (19.7)^{b}	3.76 (14.3)^{b}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	2.44 (5.5)^{c}	1.57 (2.7)^{c}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	3.03 (8.7)^{c}	5.07 (25.2)^{c}	4.05 (17.0)^{c}
SM	2.65 (6.5)^{c}	4.01 (15.6)^{c}	3.33 (11.1)^{c}	1.33 (1.3)^{b}	2.28 (4.7)^{b}	1.80 (3.1)^{b}	4.02 (15.7)^{b}	3.65 (12.8)^{b}	3.83 (14.3)^{b}	1.36 (1.4)^{c}	2.09 (3.9)^{c}	1.72 (2.6)^{c}	5.04 (24.9)^{b}	6.14 (37.2)^{b}	5.59 (31.3)^{b}
PMT *fb* CP + MSM	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{f}	0.71 (0.0)^{g}	0.71 (0.0)^{g}
PMT *fb* SM	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	1.28 (1.1)^{c}	1.75 (2.7)^{d}	1.51 (1.8)^{c}	1.28 (1.1)^{e}	1.75 (2.6)^{f}	1.51 (1.9)^{f}
SM *fb* CP + MSM	1.72 (2.5)^{d}	3.71 (13.2)^{d}	2.71 (7.9)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	1.20 (0.9)^{d}	0.95 (0.6)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	1.72 (2.5)^{d}	3.85 (14.3)^{d}	2.78 (8.5)^{d}
Hand weeding	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{d}	0.71 (0.0)^{e}	0.71 (0.0)^{e}	0.71 (0.0)^{f}	0.71 (0.0)^{g}	0.71 (0.0)^{g}
Weedy check	4.08 (16.1)^{a}	5.68 (31.7)^{a}	4.87 (24.0)^{a}	1.95 (3.3)^{a}	2.70 (6.8)^{a}	2.32 (5.1)^{a}	5.13 (25.8)^{a}	5.32 (27.8)^{a}	5.22 (26.85)^{a}	1.91 (3.2)^{b}	2.90 (7.9)^{a}	2.40 (5.6)^{a}	7.01 (48.6)^{a}	8.66 (74.4)^{a}	7.83 (61.6)^{a}

fb: followed by; original figures in parentheses were subjected to square-root transformation ($\sqrt{x+0.5}$) before statistical analysis; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 4. Grain and straw yield and economics of wheat under different tillage and weed management practices

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Net return (×10^3 ₹/ha)			Return per ₹ invested		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice												
ZT	3.44^{a}	3.14^{a}	3.29^{de}	5.03^{a}	4.61^{a}	4.82^{a}	37.29^{a}	35.55^{a}	36.42^{bc}	2.1^{a}	2.0^{a}	2.1^{ab}
CT	3.29^{a}	2.97^{a}	3.13^{cd}	4.90^{a}	4.39^{a}	4.64^{a}	30.78^{b}	27.39^{b}	29.08^{c}	1.8^{b}	1.7^{b}	1.8^{c}
Weed management practice												
PMT	2.90^{d}	3.06^{de}	2.98^{de}	4.32^{b}	4.70^{a}	4.51^{a}	29.05^{c}	36.78^{bc}	32.88^{bc}	2.0^{bcd}	2.2^{ab}	2.0^{ab}
CP + MSM	3.02^{cd}	2.66^{f}	2.84^{f}	4.69^{b}	4.05^{b}	4.37^{b}	32.13^{c}	27.72^{d}	29.92^{d}	2.1^{bc}	1.9^{c}	2.0^{c}
SM	3.35^{bc}	2.87^{e}	3.10^{e}	5.21^{a}	4.21^{b}	4.71^{b}	33.14^{c}	25.98^{d}	29.56^{d}	1.9^{cd}	1.7^{d}	1.8^{d}
PMT *fb* CP + MSM	3.66^{ab}	3.43^{bc}	3.55^{bc}	5.39^{a}	4.87^{a}	5.12^{a}	43.04^{ab}	41.92^{a}	42.48^{a}	2.3^{a}	2.3^{a}	2.3^{a}
PMT *fb* SM	4.05^{a}	3.63^{ab}	3.84^{ab}	5.52^{a}	5.06^{a}	5.29^{a}	43.81^{a}	40.17^{ab}	41.99^{ab}	2.1^{ab}	2.0^{b}	2.1^{b}
SM *fb* CP + MSM	3.59^{b}	3.24^{cd}	3.41^{cd}	5.30^{a}	5.03^{a}	5.16^{a}	35.64^{bc}	33.29^{c}	34.47^{c}	1.9^{bcd}	1.9^{c}	1.9^{c}
Hand weeding	4.06^{a}	3.65^{a}	3.85^{a}	5.51^{a}	5.07^{a}	5.28^{a}	36.15^{abc}	32.78^{c}	34.45^{d}	1.8^{de}	1.7^{d}	1.7^{d}
Weedy check	2.29^{e}	1.91^{g}	2.09^{g}	3.79^{c}	2.98^{c}	3.38^{c}	19.29^{d}	13.19^{e}	16.24^{e}	1.7^{e}	1.5^{e}	1.6^{e}

fb: followed by; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test

wheat was reduced by 43.6% in 2016-17, 47.7% in 2017-18 and 45.7% when pooled over the years due to weed competition. The highest grain yield (4.06 t/ha in 2016-17 and 3.65 t/ha in 2017-18) and straw yield (5.51 t/ha in 2016-17 and 5.07 t/ha in 2017-18) was recorded under the treatment hand weeding, which was at par with pendimethalin *fb* SM and PMT *fb* CP + MSM. As compared to pendimethalin (PMT) *fb* CP + MSM, SM and PMT, placement of SM after PMT enhanced grain yield by 7.5, 19.2 and 22.3%, respectively. The weed-free environment created by pendimethalin facilitated crop establishment at early stage, followed by SM, which suppressed growing weeds, conserved moisture and extended maturity time (5-6 days), leading to better yield. Straw mulch increases soil moisture storage (Ji and Unger 2001) and productivity (Verma and Acharya 2004). Higher soil water content improves wheat yield with rice straw mulch (Sidhu *et al.* 2007). The weed species *Spilanthes calva*, *G. indicum* and *P. plebeium* rendered 16.0% yield loss where pendimethalin was applied alone as compared to sequential application of PMT and CP + MSM. In comparison with sole application of CP + MSM, PMT *fb* CP + MSM increased the yield of wheat by 20%. This showed that effective and timely weed management through the integration of various weed management practices reduced the density and dry matter accumulation of various weed species throughout the crop's life cycle, as well as the competition for nutrients, moisture, light and space, resulting in higher grain and straw yields. Similar observations on integrated weed management were also reported by Singh (2014), Kaur and Singh (2019).

Economics

Significantly more net returns (17.4% higher in 2016-17 and 20.7% in 2017-18) and return per rupee invested (2.1 in 2016-17 and 2.0 in 2017-18) were recorded in ZT than in CT (**Table 4**). The results agreed with the findings of Stanzen *et al.* (2017). Pendimethalin *fb* SM fetched the highest net return (40,170-43,810 ₹/ha) and was at par with PMT *fb* CP + MSM (41,920-43,040 ₹/ha). Pooled analysis also showed that ZT, along with pendimethalin *fb* CP + MSM had higher net return over the years. In both years, pendimethalin *fb* CP + MSM fetched the highest return per rupee invested (2.3). The data when pooled over the years also proved that the sequential application of pendimethalin *fb* CP + MSM along with ZT had a higher return per rupee invested. Singh (2014) also reported that ZT along with herbicide increased profit.

It is evident from the results that zero tillage reduced total weed density and biomass. Pendimethalin effectively controlled *D. sanguinalis, G. indicum* and *P. plebeium*, but it was not able to control *S. calva*. Broad-leaf weeds *G. indicum, P. plebeium* and *S. calva* were effectively controlled by clodinafop-propargyl + metsulfuron-methyl, but the efficacy against *D. sanguinalis* was low. Straw mulch alone suppressed the growth of weeds but was not as effective as herbicides. Emergence of weeds such as *G. indicum, P. plebeium* and *S. calva* after the application of pendimethalin were controlled by sequential application of clodinafop-propargyl + metsulfuron methyl or straw mulch. Pre-emergence pendimethalin *fb* straw mulch and pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl recorded higher yield and economic return. In term of economics, significantly higher net returns and return per rupee invested were registered in zero tillage. Thus, zero tillage and pendimethalin *fb* straw mulch or pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl may be an effective weed management option for wheat in Eastern India.

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