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Impact of Crop Establishment Methods and Weed Management Practices on Productivity and Profitability of Rice-Wheat System in Indo Gangetic Plains

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Authors' contributions

This work was part of Ph. D thesis work of Author HSRK carried out at Banaras Hindu University. This work carried out in collaboration among all authors. Author HSRK designed the study, performed the statistical analysis and wrote the first draft of the manuscript under the supervision of Authors UPS, SPS and YS. Author USS managed the analyses of the study, literature searches and preparation of graphs. All authors read and approved the final manuscript.

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ABSTRACT

Declining productivity of rice-wheat system in Indo–Gangetic Plains poses risk to conventional practices because of high production cost and low input use efficiency. Four crop establishment methods (CEM) and four weed management practices (WMP) were compared in a 2–year study to determine the productivity and profitability of rice-wheat system. Growth, yield traits and yields of rice was uninfluenced by CEM. Zero tillage rice (ZTR)–zero tillage wheat (ZTW) exhibited highest improvement in mean wheat yield, system productivity and profitability by 7.5%, 4.0% and 16.0%, respectively over conventional tillage rice (CTR)–conventional tillage wheat (CTW). CTR–ZTW recorded minimum total weed density and biomass in system. Post emergence application of

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bispyribac 25 g ha^{-1} + azimsulfuron 35 g ha^{-1} (bis + azim) in rice at 20 days after sowing (DAS)/days after transplanting (DAT); clodinofop 60 g ha^{-1} + carfentrazone 20 g ha^{-1} (clod + carf) in wheat at 30–35 DAS minimized total weed density and biomass, increased growth, productivity and profitability of the system. Results suggest that higher growth, productivity and profitability of rice–wheat system may be achieved by adoption of ZTR–ZTW with application of bis + azim in rice and clod + carf in wheat.

Keywords: Rice-wheat system; crop establishment methods; weed management practices; system productivity and profitability; Indo Gangetic Plains.

1. INTRODUCTION

Rice-wheat system occupies 13.5 million hectare in Indo–Gangetic Plains (IGP) of India, Bangladesh, Nepal and Pakistan. It is a vital for food security and livelihood for millions of rural and urban poor [1]. Challenges associated with conventional production system include declining factor productivity and shrinking profits due to increase in the energy demand and labour costs. Manual rice transplanting in random geometry after puddling is a traditional practice require more tillage, water, capital and energy, deteriorates soil health and creates unfavourable conditions for succeeding crops [2]. Puddling leads formation of hard–pan at shallow depths, deteriorates soil physical properties, inhibits root elongation, and reduces yield of succeeding wheat [3]. Conventional broadcast seeding method requires rigorous field preparation results delay in wheat planting. Planting after mid November reduces 1–1.5% yield for each day delay [4]. Wheat grown after conventional tillage rice (CTR) yield 8% less than un–puddled direct seeded rice (DSR) [5].

Intensive conventional tillage leads gradual decline in soil organic matter through accelerated oxidation and burning of crop residues. Resource conservation technologies (RCT's) such as zero tillage (ZT) improve soil health, water use, crop productivity and profitability [6,7]. Reduced till direct seeded rice (RTDSR) saves 34% labour requirement and 29% cost involved in transplanting operation [8,9]. ZT saves cost involved in field preparation and advances wheat sowing by 10–15 days [10]. Maximum benefit derived when rice–wheat grown with 'double ZT' system [11,12]. High water, labour and energy requirement demands a shift from conventional to DSR. Irrigation requirement is reduced in zero tillage wheat (ZTW) than conventional tillage wheat (CTW) as it utilizes residual water more effectively [13,14]. Higher root mass and depth in ZTW prevents lodging. Roots become surface feeder in CTW due to sub-surface compaction [15]. During 2008, the area under zero or reduced tillage wheat touched 1.76 million hectares with 0.62 million practicing farmers. The full realization of potential benefits of ZT will depend on reduction of tillage in succeeding rice crop [16]. Reluctance in adoption of ZT in rice-wheat by farming community is mainly associated with management of weeds. Successful implementation of RCT's largely depends on weed management. Intensive tillage disturbs vertical distribution of weed seeds in soil by several ways. Interaction of tillage, environment, timing and weed management practices (WMP) adopted ascertain the weed flora. Crop establishment methods are location specific needs evaluation across diverse agro-climatic conditions [17]. Based on these, a 2–year study was carried out at Varanasi, Uttar Pradesh to evaluate the impact of CEM and WMP in rice–wheat system of IGP. Precisely, we monitored indexes to assess system productivity, profitability and net returns.

2. MATERIALS AND METHODS

2.1 Study Site and Climatic Condition

A two years investigation conducted during rainy and winter seasons of 2012–13 and 2013–14 at Agricultural Research Farm (25º27' N, 82º99' E), Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. The experimental site falls under semi-arid to sub-humid received total annual rainfall of 698.6 mm during first year and 952.7 mm during second year. Rainfall received between June to September was 615.8 mm (88.1%) and 673.4 mm (70.7%) while from October to March 82.8 mm (11.9%) and 279.3 mm (29.3%) during first and second year, respectively. Mean maximum temperature of 28.8°C and 27.9°C and minimum temperature of 18.3°C and 19.3°C prevailed during year 1 and 2, respectively. The experimental field soil was combisols with pH of 7.31 and 7.28, 0.42% and 0.44% organic carbon content [18], 206.59 and

209.24 kg ha^{-1} available nitrogen [19], 25.10 and 25.86 kg ha^{-1} available phosphorus [20] and 219.60 and 221.30 kg ha^{-1} available potassium [21] during first and second year, respectively.

2.2 Experimental Design and Crop Management

Experiment was laid out in split plot design replicated thrice. Four CEM assigned to main plots and four WMP in sub plots consistsing 16 treatment combinations in a 2–year rice-wheat cropping system (Table 1). Cultivar HUR 105 used to raise transplanted and direct seeded rice adopting uniform seed rate of 30 kg ha^{-1}. Nursery sown on 25 and 20 June during 2012 (year 1) and 2013 (year 2), respectively and ZTR and RTDSR were also sown same day. Twenty eight day old seedlings were randomly transplanted manually (CTR/farmers practice). Wheat was sown after rice maturity in different CEM. Tractor drawn zero–till seed–cum–fertilizer drill used to sow DSR and ZTW at 18.5 cm row spacing. Wheat cultivar PBW 502 sown broadcasted, mixed in soil followed by (*fb*) planking (CTW) on November 23 and ZTW on 17 in CTR plots; ZTW sown in RTDSR and ZTR plots on 12 November, respectively. Thus, ZTW sowed 11 days early in RTDSR and ZTR plots, 6 days early in CTR plots than CTW. Seed rate of 120 and 100 kg ha^{-1} used for sowing of CTW and ZTW, respectively. Wet tillage (CTR) was done by rotovator *fb* transplanting in a thin film of water. After one week ± 5 cm submergence maintained till 15 days before rice harvest. One pre sowing irrigation (5 cm) given to ZTR and RTDSR and at grain filling stage to CTR (year 1). Four irrigations were applied to all CEM of wheat. CTW received one pre sowing irrigation. Recommended dose of nutrients 120 kg N, 60 kg P_2O_5, 60 kg K_2O and 5 kg Zn ha^{-1} to rice and 150 kg N, 60 kg P_2O_5 and 60 kg K_2O ha^{-1} to wheat uniformly applied through urea, diammonium phosphate, muriate of potash and zinc sulphate, respectively. Rice received half of the total N and full dose of P_2O_5, K_2O and Zn as basal and remaining N was top dressed in two equal splits i.e. at active tillering and panicle initiation stages. Wheat received half of the total N and full dose of P_2O_5 and K_2O as basal and remaining N was top dressed in two equal splits after first and second irrigations. Herbicides were applied in rice–wheat system as per schedule (Table 1). However, glyphosate at 1 kg ha^{-1} was used in ZT plots (ZTR and ZTW) as pre plant application.

Table 1. Treatment details of Crop Establishment Methods (CEM) and Weed Management Practices (WMP)

Treatments	Rice – wheat system	Tillage practices/CEM	
		Rice	**Wheat**
Main plots			
CEM_1	CTR–CTW	2 ploughing (cultivator), 1 planking *fb* wet tillage/ puddling twice (rotavator)	2 ploughing (cultivator), 1 planking
CEM_2	CTR–ZTW	--do--	No tillage, drill seeding
CEM_3	RTDSR–ZTW	2 ploughing (cultivator), 1 planking	No tillage, drill seeding
CEM_4	ZTR–ZTW	No tillage, drill seeding	No tillage, drill seeding
Sub plots			
WMP_0	Weedy check–weedy check	No weed management	No weed management
WMP_1	Weed free–weed free	2 HW (20 & 40 DAS/DAT)	2 HW (20 & 40 DAS)
WMP_2	Pendi *fb* bis–sulf + met	pendimethalin at 1 kg ha^{-1} 2 DAS/2 DAT *fb* bispyribac at 25 g ha^{-1} + non–ionic surfactant (NIS)(0.25%) at 20 DAS/DAT	sulfosulfuron at 25 g ha^{-1} + metsulfuron at 4 g ha^{-1} + NIS (0.25%) at 30–35 DAS
WMP_3	Bis + azim–clod + car	bispyribac at 25 g ha^{-1} + azimsulfuron at 35 g ha^{-1} + NIS (0.25%) at 20 DAS/20 DAT	clodinofop at 60 g ha^{-1} + carfentrazone at 20 g ha^{-1} + NIS (0.25%) at 30–35 DAS

2.3 Measurements and Observations

Total weed density (no. m^{-2}) and biomass (g m^{-2}) in rice and wheat recorded at 20, 40 and 60 DAS/DAT. An area of 0.25 m^2 randomly selected at two places in each net plot to count weed population expressed as no. m^{-2}. Collected weeds were first sun dried for two days then dried in a hot air oven at 70°C till constant weight and expressed as g m^{-2}. Growth parameters i.e. plant height, no. of tillers m^{-2} and dry matter accumulation at harvest of rice and wheat; yield attributing characters of rice (panicles m^{-2}, panicle length and grains panicle^{-1}) and wheat (no. of spikes m^{-2}, spike length, grains spike^{-1}) were recorded from five randomly selected plants hill^{-1} in each plot. 1000 grain weight of rice and wheat recorded from grains randomly taken from the bulk produce of each net plot. Rice and wheat harvested manually 15 cm (CTR, RTDSR and CTW) and 40 cm (ZTR and ZTW) above ground level. Wheat harvesting time varied, ZTW grown in RTDSR and ZTR plots harvested 10 days early while after CTR 5 days early than CTW. Rice and wheat were harvested from net plot of 12 m^2 (CT plots) and 13.04 m^2 (RT and ZT plots); and grain yields recorded at 14 per cent moisture content expressed as kg ha^{-1}. Grain yield subtracted from biological yield to measure straw yield expressed as kg ha^{-1}. Wheat yield was converted to rice equivalent yield (REY) by following equation:

$$\text{REY of wheat} = \frac{(\text{wheat yield} \times \text{wheat price})}{\text{rice price}} \qquad (1)$$

System productivity (kg ha^{-1} day^{-1}) was calculated by combining the grain yields of rice and wheat (REY) divided by 365.

2.4 Economic and Statistical Analysis

Economic analysis of treatments was done for individual years by taking into account prevailing prices of inputs and produce. The cost of land preparation, fertilizers, herbicides, weeding, labour, irrigation, harvesting, threshing and winnowing for rice–wheat were worked out on per hectare basis. Gross returns calculated based on minimum support price fixed for rice (Rs 1250 during 2012–13; Rs 1310 during 2013–14) and wheat (Rs 1350 during 2012–13; Rs 1400 during 2013–14). Cultivation cost subtracted from the gross returns to know net returns. System profitability ($ ha^{-1} day^{-1}) was worked out by dividing system net returns with 365 days. Analysis of variance (ANOVA) performed on growth parameters, yield attributes, grain and straw yields and, total density and biomass of weeds in rice and wheat. Costat software for split plot design used to determine differences among the treatments. The differences between means were compared using LSD test at P <0.05 [22]. Graphs were prepared by microsoft excel program.

3. RESULTS

3.1 Rice Growth Parameters, Yield Attributes and Yield

Rice growth parameters, yield attributes and yield found unaffected by CEM but were significantly influenced by WMP (Table 2). However, higher values recorded under ZTR. Two hand weeding (WMP_1) proved most effective in respect to plant height, number of tillers m^{-2} and dry matter at harvest over other WMP. Herbicide combinations pendi *fb* bis and bis plus azim (WMP_2 and WMP_3) stood equal in controlling weeds resulted superior growth parameters than weedy check. Combination of pre emergence (PE) and post emergence (POE) applied herbicides (pendi *fb* bis) or POE (bis + azim) shown similar results.

Yield attributes i.e. panicles m^{-2}, panicle length, grains per panicle, 1000 grain weight, grain and straw yields, and harvest index found unaffected by different CEM (Tables 2 and 3) during both the years.

WMP (WMP_1, WMP_2 and WMP_3) failed to exert any significant difference on yield attributes, grain and straw yields, and harvest index. Above all WMP proved significantly better over weedy check (WMP_0). In general, hand weeding claimed the highest values for above parameters and produced significantly greater panicle length (both years) than herbicides use (WMP_2 and WMP_3). Hand weeding (WMP_1) was significantly superior over WMP_2 but produced comparable grain yield (2012–13) with WMP_3. WMP_3 and WMP_2 gave 53.9% and 52.1% higher mean grain yield over WMP_0.

CEM and WMP interacted significantly with respect to rice grain yield during both years (Table 4). Data reveals that grain yields obtained in order of ZTR >RTDSR > CTR, respectively with all WMP except WMP_0. In general, treatment combinations with CEM and WMP_1, WMP_2 and WMP_3 found statistically similar. This response emphasize that all these weed

Table 2. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on growth and yield attributes of rice at harvest

Treatments	Plant height (cm)		No. of tillers m^{-2}		Dry matter (g m^{-2})		No. of panicles m^{-2}		Panicle length (cm)		Grains $panicle^{-1}$	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CEM												
CTR (CEM_1)	110.38	110.95	368.25	369.92	1720.50	1722.42	294.58	296.17	23.23	23.28	145.50	145.75
CTR (CEM_2)	110.94	111.30	369.58	371.17	1721.75	1725.00	296.17	298.42	23.25	23.39	145.67	146.08
RTDSR (CEM_3)	109.64	110.00	382.67	385.67	1689.75	1716.75	278.08	283.75	22.84	23.02	141.33	142.50
ZTR (CEM_4)	112.02	112.67	388.50	393.83	1719.00	1836.00	293.00	313.75	23.33	23.68	145.75	148.50
S Em±	1.08	0.81	5.28	5.74	38.60	42.37	4.51	8.09	0.29	0.17	2.49	2.43
LSD (P = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
WMP												
WMP_0	100.21	100.73	296.67	301.50	1387.75	1436.42	191.00	211.25	21.13	21.33	114.42	116.50
WMP_1	116.69	116.95	408.25	410.50	1884.25	1914.42	328.17	330.75	24.43	24.65	155.92	156.75
WMP_2	112.08	112.92	400.83	402.42	1767.42	1803.33	319.58	322.58	23.39	23.50	153.58	154.33
WMP_3	113.90	114.32	403.25	406.17	1811.58	1846.00	323.08	327.50	23.69	23.88	154.33	155.25
SEm±	0.70	0.66	3.11	2.52	18.82	17.09	2.98	5.37	0.14	0.15	1.05	1.12
LSD (P = 0.05)	2.04	1.92	9.08	7.36	54.92	49.87	8.71	15.68	0.42	0.45	3.07	3.27
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean

Table 3. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on rice yields

Treatments	1000 grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index (%)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CEM								
CTR (CEM_1)	22.55	22.55	4895	4915	6635	6648	42.25	42.29
CTR (CEM_2)	22.55	22.56	4901	4925	6650	6662	42.25	42.30
RTDSR (CEM_3)	22.45	22.48	4759	4809	6495	6563	41.73	41.76
ZTR (CEM_4)	22.56	22.57	4873	4996	6580	6752	42.12	42.48
S Em±	0.04	0.03	64	72	88	89	0.22	0.28
LSD (*P* = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
WMP								
WMP_0	21.93	21.96	3419	3527	5842	5993	36.85	37.07
WMP_1	22.76	22.76	5432	5447	6880	6907	44.12	44.13
WMP_2	22.70	22.71	5257	5309	6803	6850	43.61	43.72
WMP_3	22.73	22.73	5320	5363	6836	6874	43.76	43.90
S Em±	0.03	0.03	48	49	84	85	0.21	0.28
LSD (*P* = 0.05)	0.08	0.08	141	144	246	249	0.62	0.82
Interaction	NS	NS	*	*	NS	NS	NS	NS

**Significant at P < 0.05; LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean*

Table 4. Interaction effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on grain yield of rice

Treatments	CTR (CEM_1)	CTR (CEM_2)	RTDSR (CEM_3)	ZTR (CEM_4)	CTR(CEM_1)	CTR (CEM_2)	RTDSR(CEM_3)	ZTR (CEM_4)
	2012-13				**2013-14**			
WMP								
WMP_0	3740	3744	2966	3227	3757	3783	3033	3533
WMP_1	5360	5366	5487	5517	5377	5380	5500	5532
WMP_2	5216	5224	5240	5346	5240	5245	5310	5440
WMP_3	5263	5270	5343	5403	5287	5292	5393	5480
		S Em±	LSD (*P*=0.05)		S Em±	LSD (*P*=0.05)		
WMP at same CEM		97	283		98	287		
CEM at same/different WMP		105	308		112	327		

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean

management practices are equally effective irrespective of CEM. Weedy check plots produced higher yields under CTR than ZTR and RTDSR. Weed suppression due to puddling operation and impounded water is obvious. Application of bis + azim in ZTR gave highest grain yield while minimum recorded with weedy check in RTDSR.

3.2 Total Biomass and Density of Weeds in Rice

Total biomass (Fig. 1) and density (Fig. 2) of weeds significantly varied due to CEM and WMP during both the years. Minimum values noted in CTR (CEM_1 and CEM_2) while significantly highest values with RTDSR at 20, 40 and 60 DAT. ZTR exhibited slightly higher but comparable values with CTR. During initial growth (20 DAS/DAT) PE and POE of pendi *fb* bis (WMP_2) and at later phase (40 and 60 DAS/DAT) POE combination of bis + azim (WMP_3) most effectively reduced total biomass and density of weeds during both years.

3.3 Wheat Growth Parameters, Yield Attributes and Yield

Various CEM caused significant differences in plant height and dry matter accumulation of wheat at harvest however, tillers m^{-2} remained unaffected during both years (Table 5). Different ZTW plots (CEM_1, CEM_2 and CEM_3) exerted similar effect and recorded significantly greater plant height and dry matter accumulation over conventional practice (CTW). Such findings indicate that adoption of conventional CEM for both crops in a rice–wheat system reduces growth of wheat plants. However, ZTW grown after ZTR led to greater plant height and dry matter accumulation *fb* RTDSR. Growth parameters viz. plant height, tillers m^{-2} and dry matter accumulation at harvest varied significantly by WMP. Highest values for above parameters noted with WMP_1 closely followed and at par with WMP_2 and WMP_3. However, significantly taller plants produced by WMP_1 over other WMP.

Yield attributes and yields had significant differences because of CEM except harvest index. Spikes m^{-2}, spike length and grains spike^{-1} significantly reduced by conventional till broadcasted wheat (CTW) grown after CTR (CEM_1) than rest CEM. Yield attributes of all zero till wheat plots (CEM_2, CEM_3 and CEM_4) observed at par (Table 5) irrespective of CEM followed in rice (CTR, RTDSR and ZTR). Adoption of double zero till in rice–wheat system (CEM_4) produced highest 1000 grain weight, grain and straw yields of wheat (Table 6). Mean grain yield of wheat under CEM_4 was 7.5% higher over CTW (CEM_1). Yield attributes, grain and straw yields followed the order CEM_4 > CEM_3 > CEM_2 > CEM_1 during both years.

Yield attributes, grain and straw yields also differed significantly due to WMP during both years (Tables 5 and 6). Application of clodinofop at 60 g ha^{-1} + carfentrazone at 20 g ha^{-1} + NIS (0.25%) (WMP_3) was next best treatment after weed free (WMP_1) recorded highest yield attributes (spikes m^{-2}, spike length, grains spike^{-1} and 1000 grain weight), grain and straw yields. The sulfosulfuron 25 g ha^{-1} + metsulfuron 4 g ha^{-1} + NIS (0.25%) (WMP_2) ranked third in overall performance. Although, above WMP could not vary significantly and proved superior to weedy check only (WMP_0). Similar pattern noted for harvest index during both years. WMP_3 and WMP_2 produced mean grain yield 23.5% and 22.6% higher over WMP_0.

3.4 Total Biomass and Density of Weeds in Wheat

Crop establishment methods had significant effect on total biomass (Fig. 3) and density (Fig. 4) of weeds at 20, 40 and 60 DAS during both the years. ZTW after ZTR (CEM_4) caused significant and effective reduction in total biomass and density of weeds than other CEM at all stages (Figs. 3 and 4). On contrary, CTW–CTR (CEM_1) recorded significantly highest total biomass and density of weeds during both years.

WMP exerted significant effect on total biomass and density of weeds at 20, 40 and 60 DAS with highest values recorded in weedy check plots (Fig. 3 and 4). Values for above parameters were significantly lowest with use of sulf + met (20 DAS). Similar response recorded with clod + car at 40 and 60 DAS. Total biomass and density of weeds were comparatively higher during first year (2012–13) than second year (2013–14).

3.5 Economic Analysis of Rice–wheat System

Rice–wheat system (CEM_4) registered highest gross return, net return and B: C ratio among various CEM during both years (Fig. 5), while lowest values recorded with CTR–CTW (CEM_1). Economic analysis followed the order CEM_4 > CEM_3 > CEM_2 > CEM_1. Double ZT (ZTR–ZTW)

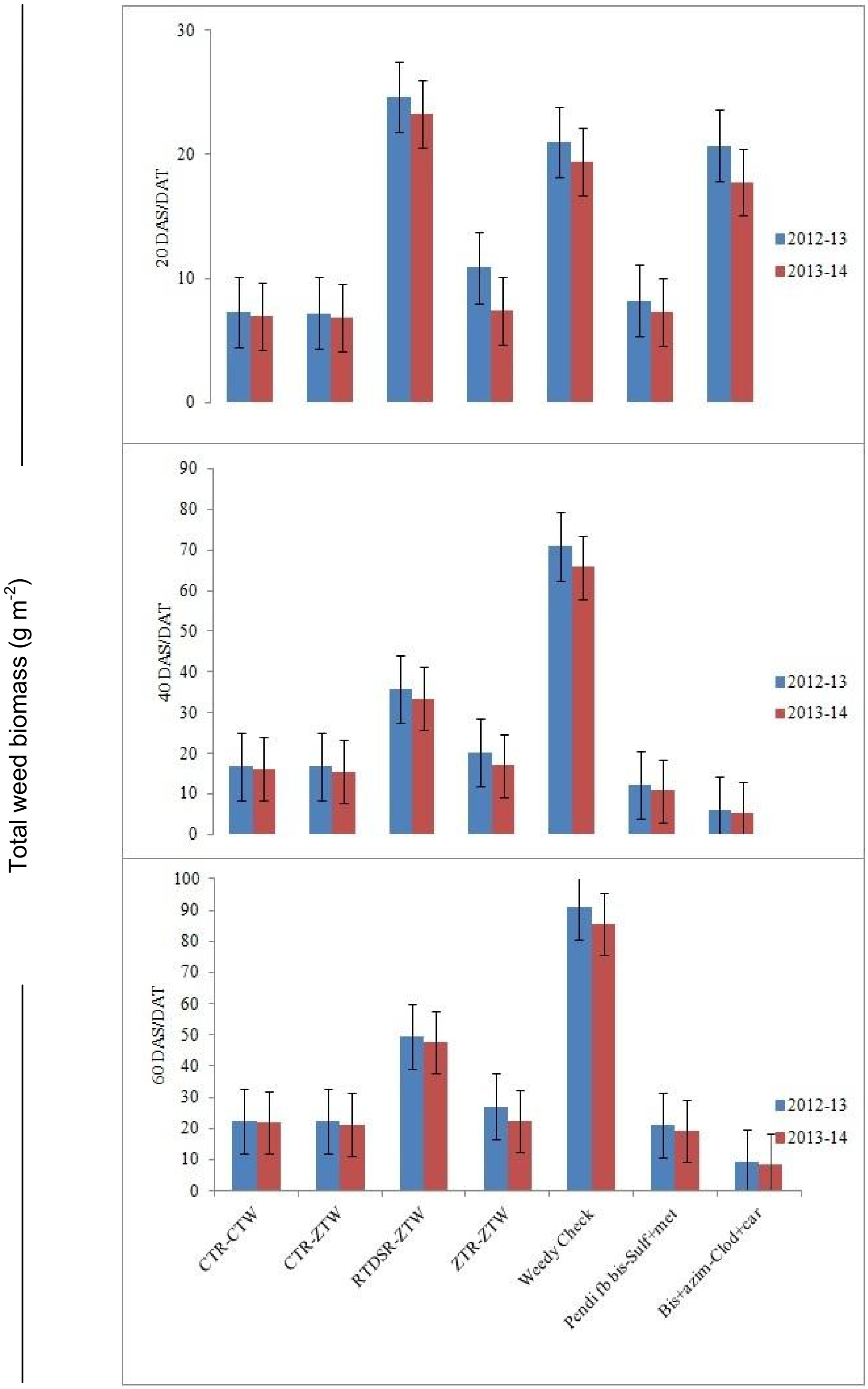

Fig. 1. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total weed biomass in rice

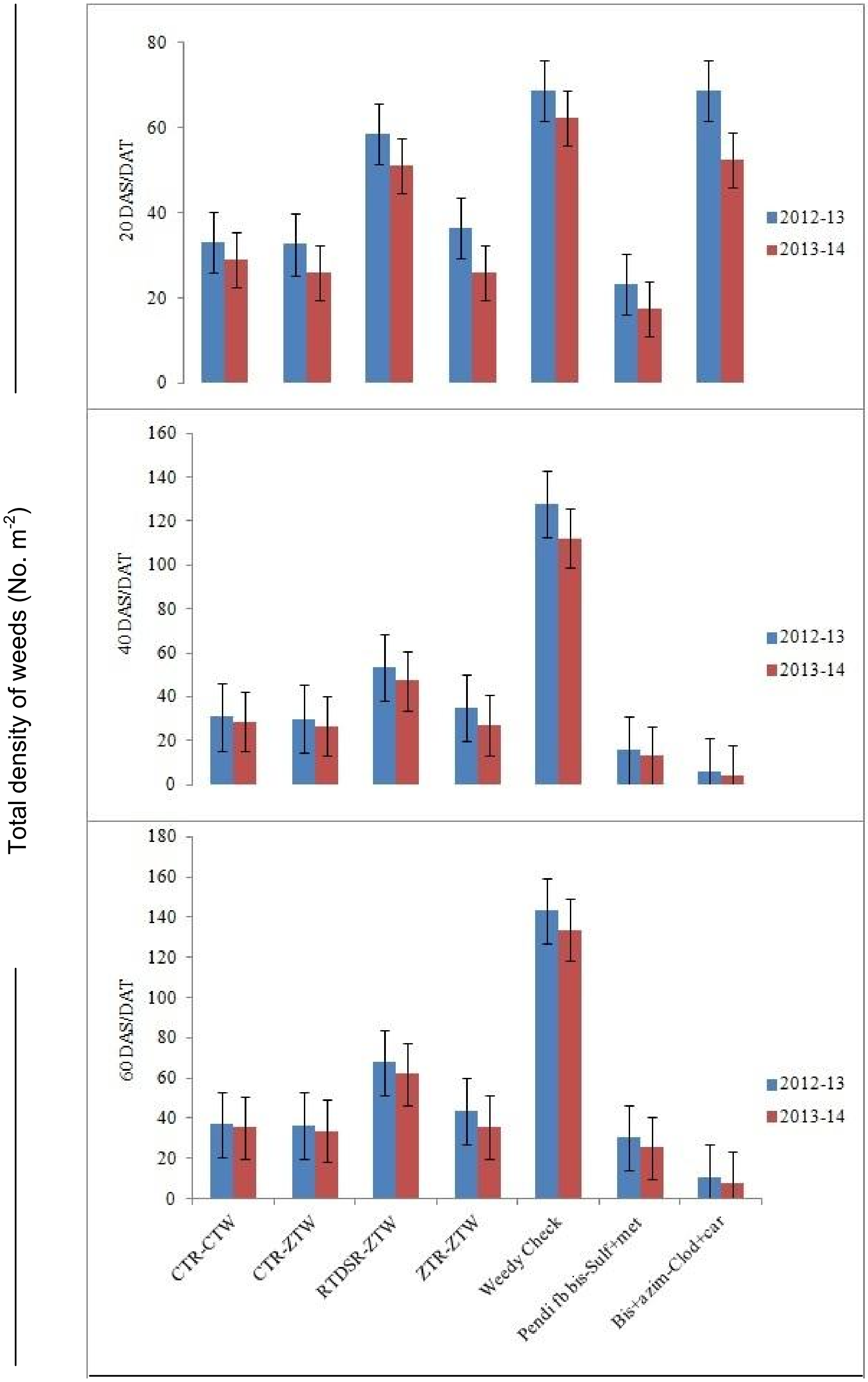

Fig. 2. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total density of weeds in rice

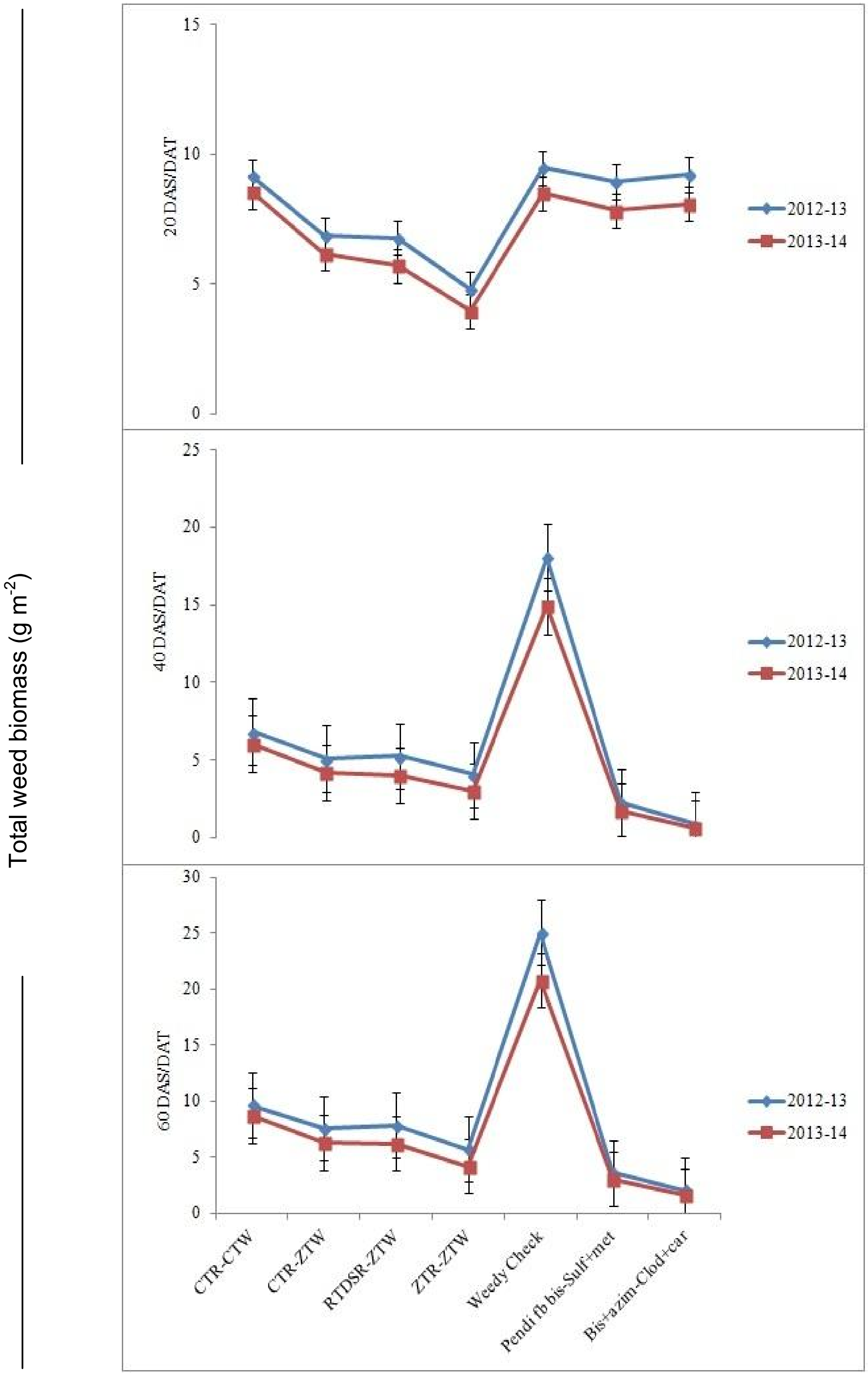

Fig. 3. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total biomass of weeds in wheat

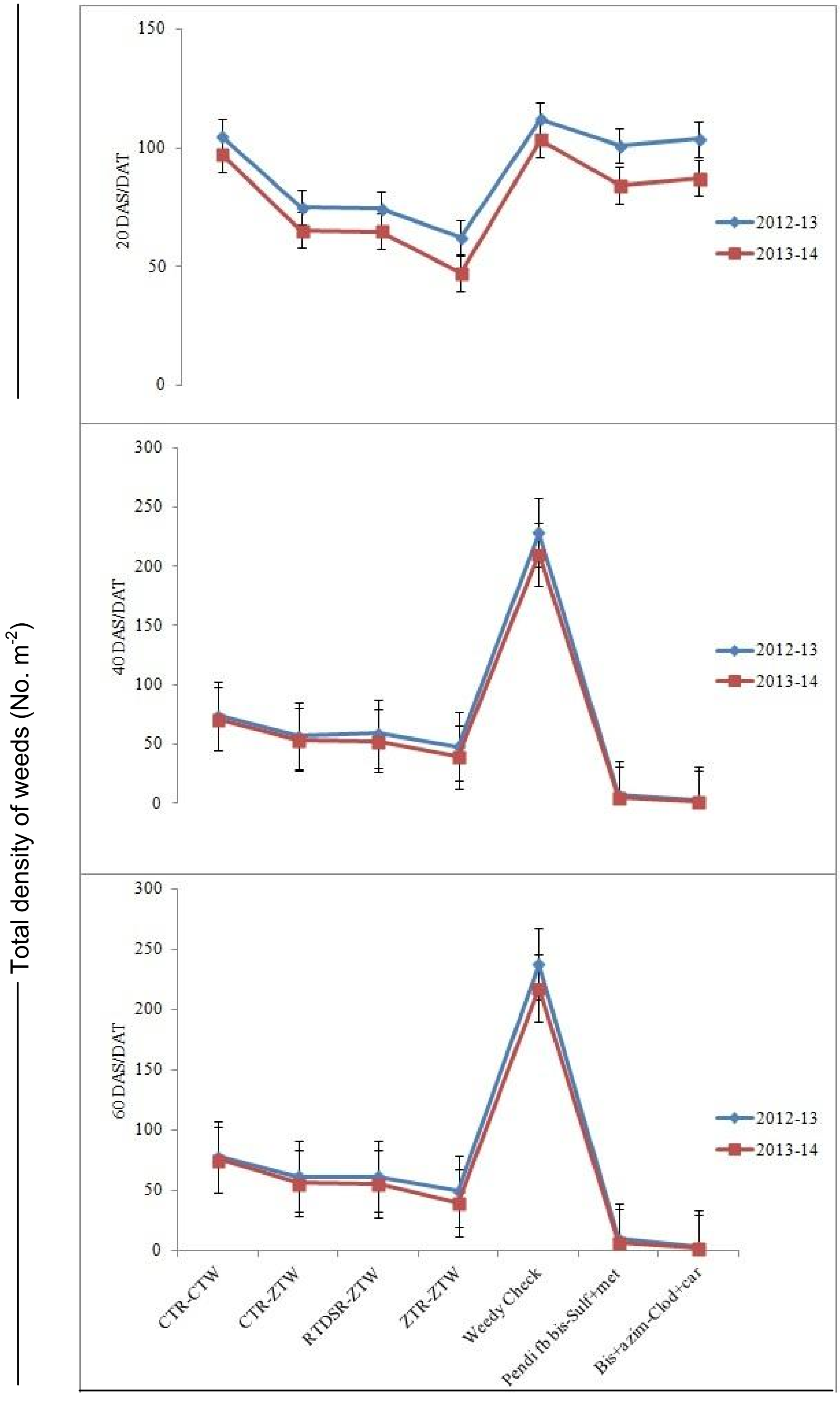

Fig. 4. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on total density of weeds in wheat

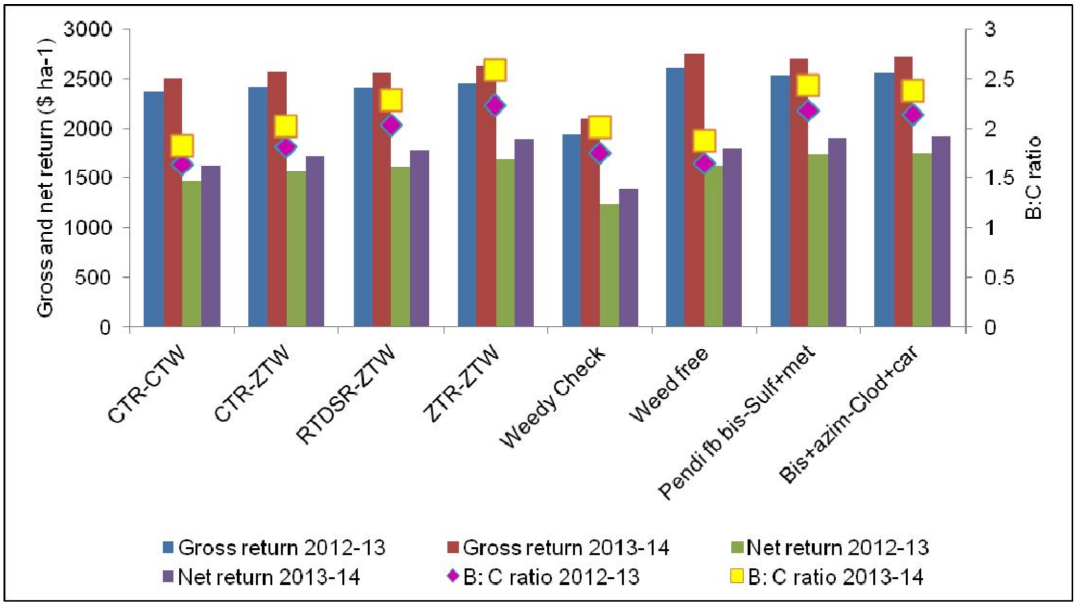

Fig. 5. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on economics of rice-wheat system (1 $ = 66.87 Rs)

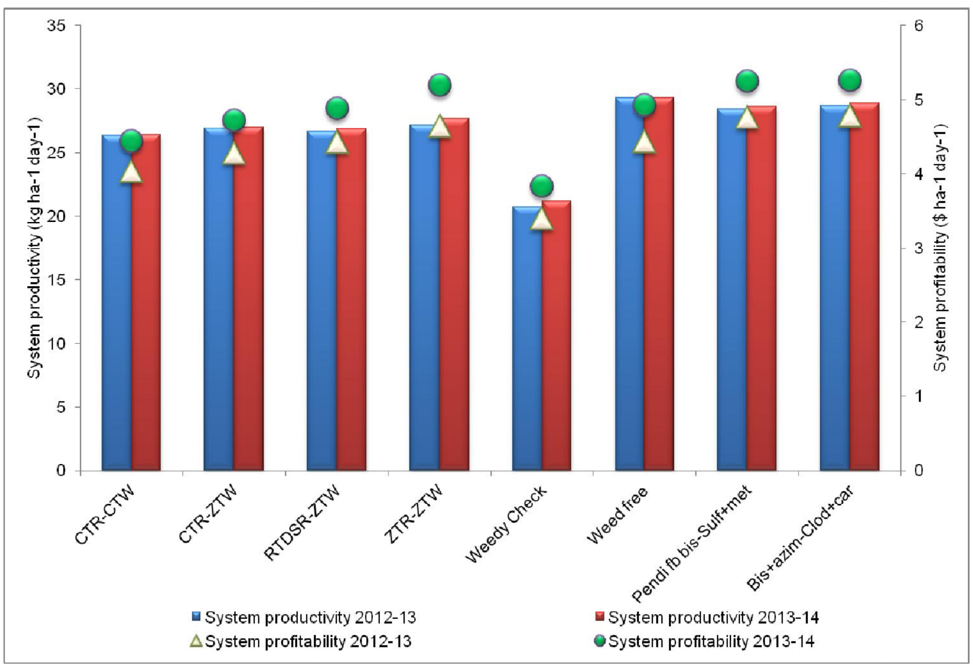

Fig. 6. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on productivity and profitability of rice-wheat system (1 $ = 66.87 Rs)

enhanced mean net return (16%) and benefit: cost ratio (38.3%) over CTR–CTW (CEM_1). Among WMP, use of bis + azim in rice and clod + carf in wheat (WMP_3) recorded highest gross return, net return and B: C ratio. Application of pendi *fb* bis in rice and sulf + met in wheat (WMP_2) was next best treatment during both years. Net return followed the order $WMP_3 > WMP_2 > WMP_1 > WMP_0$ while the benefit: cost ratio order was $WMP_2 > WMP_3 > WMP_0 > WMP_1$.

3.6 System Productivity and Profitability

System productivity did not differ due to CEM during 2012–13 (Fig. 6). During 2013–14, double ZT (CEM_4) resulted highest system productivity but was superior only to conventional planting (CEM_1). Other methods (CEM_2 and CEM_3) gave almost similar system productivity. Conventional planting of rice and wheat (CEM_1) lowered system productivity by 2.3%, 1.7% and 4.7% than CEM_2, CEM_3 and CEM_4, respectively in second year (2013–14). ZTR–ZTW (CEM_4) recorded highest system profitability during both years (Fig. 6) with 15.9% higher mean profitability than CEM_1.

After weed free (WMP_1), the second highest system productivity recorded with WMP_3 (bis + azim in rice and clod + carf in wheat) at par with WMP_2 (pendi *fb* bis in rice–sulf + met in wheat) during both years of study (Fig. 6). WMP_3 and WMP_2 produced 37.3% and 36.1% higher mean system productivity over WMP_0, respectively. WMP_3 gave highest system profitability *fb* WMP_2 and the lowest was with WMP_0. The increment in mean system profitability by WMP_3 and WMP_2 was to the extent of 39.2% and 38.7% over weedy check (WMP_0). Statistically WMP_3 and WMP_2 provided equivalent system productivity but both were superior to weedy check (WMP_0).

4. DISCUSSION

4.1 Rice Growth Parameters, Yield Attributes and Yield

Rice growth parameters, yield attributes and yield were higher with ZTR. Similar or high yield attributes and yield by ZTR in comparison to CTR reported by earlier researchers [23,24]. Higher weed control efficiency under combination of pre emergence (PE) and post emergence (POE) applied herbicides (pendi *fb* bis) or POE (bis + azim) confronted minimum weeds competition for moisture, nutrient, light and space. [25-27] reported that application of pendimethalin (PE) *fb* bispyribac or azimsulfuron or bis + azim (POE) at 15–20 DAS yielded similar to weed free condition.

4.2 Total Biomass and Density of Weeds in Rice

Crop establishment in rice is most critical since influences total density and biomass of weeds. Effective weed killing by puddling operation and continued submergence of ± 5 cm water reduced total density and biomass of weeds in CTR. [28] reported minimum weed density in transplanted rice than dry DSR. Herbicides (WMP_2 and WMP_3) exhibited similar capability to reduce total density and biomass of weeds at 20, 40 and 60 DAS during both years. However, the combination bis + azim were most promising; bispyribac controlled annual grasses effectively while perennial grasses, sedges, broad leaf weeds were controlled by azimsulfuron. [26,27] also reported that application of tank-mix bispyribac 25 g ha^{-1} with azimsulfuron 20 g ha^{-1} provided excellent control of complex weed flora.

4.3 Wheat Growth Parameters, Yield Attributes and Yield

Favourable climatic conditions during second year enhanced growth, yield attributes, grain and straw yields of wheat. Cumulative effect of rainfall and prevalence of low temperatures during February to March (data not shown) favoured spike and grain development. Delayed planting of CTW after CTR (CEM_1) results poor crop performance. However, early harvesting of DSR plots (ZTR and RTDSR) facilitated timely planting of ZTW (CEM_4 and CEM_3) than in CTR plots which in turn increased wheat yields. Late harvesting of transplanted rice is attributed to transplanting shock [29]. Yield decrement of 1% reported in IGP for each day delay in wheat sowing after optimum time i.e. November 15 [4]. Timely sown crop received congenial soil and canopy temperature for favourable root and shoot growth which enhanced light interception and dry matter production, tillers, grains ear^{-1} and 1000 grain weight finally converted into higher yield by ZTW than CTW. [30,31] reported higher yields of ZTW sown after DSR than CTW. Application of clod + carf at 30–35 DAS manifest superior growth, yield attributes, and yields due to higher weed control efficiency which reduced competition for moisture, nutrients, light and space. These results are in conformity with [32,33].

4.4 Total Biomass and Density of Weeds in Wheat

Residue retained on soil surface might have reduced germination of weed seeds and their growth; absence of inter-row soil disturbance caused minimal and late emergence of weeds. Similar findings were reported by [34,35]. Repeated ploughing in CTW caused surfacing of weed seeds and facilitated conditions for higher weed emergence. These results are similar to

Table 5. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on growth and yield attributes of wheat at harvest

Treatments	Plant height (cm)		No. of tillers m^{-2}		Dry matter (g m^{-2})		No. of spikes m^{-2}		Spike length (cm)		Grains $spike^{-1}$	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CEM												
CTW (CEM_1)	84.05	84.55	418.33	423.75	1135.75	1143.17	387.92	390.83	8.58	8.61	38.33	38.67
ZTW(CEM_2)	88.15	88.58	432.42	436.83	1288.42	1292.92	408.67	412.50	9.20	9.33	41.42	41.92
ZTW (CEM_3)	88.73	88.95	435.33	439.58	1291.08	1296.25	410.92	414.17	9.21	9.34	41.75	42.08
ZTW (CEM_4)	90.83	91.39	442.33	447.67	1302.50	1311.25	418.92	423.42	9.77	9.83	42.67	43.00
S Em±	1.30	1.11	3.98	4.70	30.68	24.29	5.91	6.08	0.16	0.16	0.68	0.69
LSD (*P* = 0.05)	4.49	3.85	NS	NS	106.17	84.05	20.47	21.04	0.57	0.54	2.34	2.40
WMP												
WMP_0	82.21	82.43	365.00	368.58	887.92	898.17	315.33	320.42	8.11	8.13	35.67	35.92
WMP_1	90.83	91.30	457.75	462.50	1382.17	1387.42	440.58	444.00	9.63	9.70	43.42	43.67
WMP_2	89.20	89.67	451.58	457.50	1371.75	1376.42	433.92	436.75	9.48	9.63	42.42	42.92
WMP_3	89.52	90.07	454.08	459.25	1375.92	1381.58	436.58	439.75	9.54	9.65	42.67	43.17
S Em±	0.34	0.29	2.65	1.79	14.99	16.16	2.66	3.30	0.06	0.07	0.42	0.39
LSD (*P* = 0.05)	0.98	0.84	7.74	5.21	43.74	47.16	7.76	9.65	0.18	0.20	1.22	1.15
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean

Table 6. Effect of Crop Establishment Methods (CEM) and Weed Management Practices (WMP) on yields of wheat

Treatments	1000 grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index (%)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CEM								
CTW (CEM_1)	41.06	41.12	4374	4413	6568	6593	39.98	39.91
ZTW(CEM_2)	42.00	42.05	4569	4616	6809	6837	40.26	40.17
ZTW (CEM_3)	42.07	42.12	4607	4671	6860	6879	40.39	40.26
ZTW (CEM_4)	42.46	42.54	4678	4765	6926	6990	40.49	40.38
S Em±	0.24	0.22	58	59	82	80	0.25	0.26
LSD (*P* = 0.05)	0.82	0.75	200	204	284	277	NS	NS
WMP								
WMP_0	39.47	39.52	3844	3932	6185	6200	38.76	38.54
WMP_1	43.02	43.07	4876	4901	7058	7074	40.94	40.89

Treatments	1000 grain weight (g)		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})		Harvest index (%)	
	2012-13	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**	**2012-13**	**2013-14**
WMP_2	42.54	42.60	4734	4801	6932	6993	40.69	40.63
WMP_3	42.56	42.64	4773	4831	6988	7032	40.71	40.65
S Em±	0.18	0.16	52	49	76	75	0.24	0.20
LSD (P = 0.05)	0.52	0.47	153	142	222	219	0.71	0.60
Interaction	NS	NS	NS	NS	NS	NS	NS	NS

LSD, Least significant difference; NS, non-significant; S Em±, standard error of mean

that of [36]. Combined effect of CEM and WMP adopted from first year seems more pronounced during second year. Further, the weather prevailed during second year was more congenial resulted higher vigour which smothered weeds to a greater extent. Application of clod + carf at 30–35 DAS minimized total density and biomass of weeds at 40 and 60 DAS. Actually efficient control of grassy weeds by clodinofop and other complex weed flora done by carfentrazone. Previous studies by [32,33] also reported similar findings.

4.5 Economic Analysis of Rice–wheat System

Transplanted rice traditionally grown in IGP is labour and energy intensive often delays planting of succeeding wheat crop. Hence, ZT may save time and energy to the considerable extent. These findings are duly supported by other workers [10,12,17]. Technology adoption in modern agriculture largely depends on its economic viability and increased cost of CEM may lower economic returns [37]. Conservation tillage facilitates reduction in labour and eliminates several operations. Maximum reduction in tillage operations occurs with double zero tillage system (CEM_4) which evinced its economic feasibility in terms of gross return, net return and benefit: cost ratio over conventional till rice–wheat system (CEM_1). Such response is obvious because of better yields, significant saving of labour and reduced cost of cultivation. These findings are in agree with [1,38]. [39] recommended replacement of conventional till rice-wheat system with zero tillage method to save labour, energy and for effective weed control. Use of herbicides (WMP_3) in rice – wheat system exhibited highest gross return, net return and benefit: cost ratio due to efficient weed control and higher system productivity.

4.6 System Productivity and Profitability

Double ZT provide stable and higher yield over CTR [1,40]. Further, steady increase in rice and wheat grain yield noticed with early maturity of crops. Lower system productivity of conventional method was due to delay in rice harvest and subsequent late planting of wheat resulted heat stress at later phase of crop. Effective CEM caused lesser weed density and dry weight resulted higher system productivity. Continuous severe weed competition caused inferior performance by weedy check. Appropriate herbicides for rice–wheat system ensued efficient control of complex weed flora contributed higher economic yield of crops. Findings of [26,27] in rice and [32,33] in wheat are in same line. Continuous ZT gives significantly higher system yields than continuous conventional or rotational tillage regardless of weed control methods [39].

5. CONCLUSION

Rice–wheat cropping system plays crucial role in economy and food security of several South Asian countries including India. Findings of two years study indicate the usefulness of the new technologies of crop establishment. Double zero till is the most promising option to address the emerging challenges in rice–wheat systems of IGP. In nutshell, it is concluded that adoption of double zero tillage enhances system productivity, profitability and is superior over conventional till rice-wheat system (farmers practice). Hence, zero tillage crop establishment method be adopted in rice–wheat system with application of bispyribac at 25 g ha^{-1} + azimsulfuron at 35 g ha^{-1} + NIS (0.25%) at 20 DAS in rice and clodinofop at 60 g ha^{-1} + carfentrazone at 20 g ha^{-1} + NIS (0.25%) at 30–35 DAS in wheat to achieve higher yield, system productivity and profitability in the Indo Gangetic Plains.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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