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Research Paper

Weed management in rice (*Oryza sativa*)–fallow for enhancement in productivity and profitability of rice–zero till *toria* (*Brassica campestris*) system

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ABSTRACT

A field experiment was conducted during 2013–14 and 2014–15 at Bhubaneswar, Odisha, India to develop management practices for rice (*Oryza sativa* L.)–*toria* (*Brassica campestris* L.) cropping system in rice fallows. During the rainy season (*kharif*), 7 crop-establishment methods were tried in rice in randomized block design with 3 replications. During winter (*rabi*) season zero-till *toria* was raised on residual soil-moisture conditions. The residual effects of 7 crop-establishment methods imposed in rice and 3 weed-management practices in succeeding *toria* were tried in split-plot design with 3 replications. Pooled over seasons, transplanting in rice + bispyribac-Na @ 0.02 kg/ha at 21 days after transplanting (DAT) + mechanical weeding at 35 DAT and sequential application of glyphosate 1.0 kg/ha as pre-planting desiccation (PPD) and quizalofop ethyl 0.05 kg/ha as post-emergence recorded the maximum rice-equivalent yield of 5,792 kg/ha and 2 treatment combinations, viz. transplanting + bispyribac-Na @ 0.02 kg/ha (21 DAT) + mechanical weeding (35 DAT) in rice and glyphosate 1.0 kg/ha (PPD) alone or quizalofop ethyl alone in *toria* recorded similar system yield. Transplanting in rice + bispyribac-Na @ 0.02 kg/ha at 21 days after sowing (DAS) + mechanical weeding (35 DAS) and glyphosate 1.0 kg/ha in *toria* gave the maximum system net return of ₹ 40,392/ha. Line sowing in direct-seeded rice with pendimethalin as pre-emergence spray + hand-weeding (35 DAS) or transplanting in rice with bispyribac-Na @ 0.02 kg/ha as post-emergence spray (21 DAS) + mechanical weeding (35 DAS) and glyphosate 1.0 kg/ha (PPD) in *toria* may be recommended for maximizing productivity and profitability.

Key words: Drum seeding, Direct-seeded rice, Net returns, Return per rupee investment, Rice-equivalent yield

Medium and lowlands remain uncropped during winter (*rabi*) season under rice–fallow situation due to lack of irrigation, cultivation of long-duration cultivars of rice, early withdrawal of monsoon rains leading to soil-moisture stress at planting time of winter crops, waterlogging and excessive moisture in November / December, lack of appropriate varieties of winter crops for late planting and socio-economic constraints like stray cattle and blue bull menace. India accounts for 79% (11.65 million ha) of the total rice–fallows of South Asia (15 million ha). The state of Odisha accounts for 10% (1.22 million ha) of total rice–fallows of India. Short-duration pulses and oilseeds can be grown profitably after harvesting of medium and lowland rainfed rice by adopting appropriate crop/ weed management practices. In India, rice is grown in an area of 44.11 million ha area, with a production of 105.48 million tonnes and productivity of 2,391 kg/ha (Agricultural Statistics at a Glance, 2016). The area, production and productivity of the crop during 2014–15 in Odisha were 4.17 million ha, 8.30 million tonnes and 1992 kg/ha, respectively. There is wide gap between state and national productivity of rice. Weeds pose a serious problem in cultivation of rice. India is one of the largest rapeseed-mustard growing countries in the world, occupying the first position in acreage with an area of 5.80 million ha and the second position in production after China, with annual production of 6.28 million tonnes and productivity of 1,083 kg/ha (MoAFW, 2016). This group of crops in India is largely grown under residual moisture conditions with poor management. In Odisha, rapeseed-mustard group of crops occupy an area of 0.145 million ha, with a production of 0.062 million tonnes and productivity 424 kg/ha, which is far below the all India average productivity of 1,083 kg/ha.

In Odisha, many farmers raise rice crop by transplanting of seedling under puddled condition. Puddling reduces

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weed biomass in rice (Farooq *et al.,* 2017). In this process, weed is converted to a very useful form of fertilizers. Puddling breaks down soil aggregates and brings the finer particles into dispersed finer solution and reduces the water and nutrient losses and creates favourable environment for rice growth. Puddling is labour-intensive and requires huge amount of water. Raising seedlings by puddling of field, followed by transplanting involves high labour cost and fossil fuels. Transplanting after puddling is associated with various constraints like late planting due to non-availability of water and labour at peak time which causes low plant population and ultimately reduction in yield. At the same time, field preparation by puddling results in alteration of soil physical properties (Kirchhof *et al*., 2000; Gathala *et al*., 2011). Omission of puddling improves soil physical properties such as bulk density, penetration resistance, soil aggregation, average mean-weight diameter of water-stable aggregates, aggregation stability and cracking behaviour (Mondal *et al*., 2016). Puddling in rice adversely affects the performance of succeeding crops (Gangwar *et al*., 2008). The area under transplanted rice is decreasing due to scarcity of water and labour. So there is need to search for alternate crop-establishment methods to increase the productivity of rice (Farroq *et al*., 2011).

Drum seeding and direct seeding in row are alternative to transplanting, due to less labour and water requirement and reduction in crop duration by 10 days and these methods provide comparable grain yield as that of transplanted rice (Yadav *et al*., 2005). The system eliminates preparation of nursery, puddling of main field for transplanting, saves labour and involves less drudgery, facilitates early sowing, reduces water requirement, enhances tolerance to water deficit, advances crop maturity by 7–10 days, reduces cost of cultivation, gives higher yield and more profit, improves soil physical conditions for succeeding crops, thereby increases the productivity and returns (Nageswari and Subramanian, 2004). Direct dry seeding in lines is a possible option. But in this method, the crop is subjected to intense weed competition.

Toria, a cool-season crop, fits well in rice-based cropping systems under rainfed condition owing to its short life-cycle, tap root-system and ability to utilize dew. Zero tillage conserves soil moisture and advances sowing of *toria* by 10–12 days, depending on soil-moisture condition. Weed infestation is serious menace in zero till *toria*. Manual weeding is costly and cumbersome in such situation. There is a need to find out suitable herbicides for managing weeds effectively.

Keeping these points in view, an investigation was undertaken to develop appropriate crop-management practice to improve the productivity and profitability of rice-zero till *toria* cropping system in rice–fallows.

MATERIALS AND METHODS

The field experiment was conducted during 2013–14 and 2014–15 at Agronomy Main Research Farm, Odisha University of Agriculture and Technology, Bhubaneswar. During rainy (*kharif*) season, 7 management practices in rice, viz. C_1, Farmers' practice (broadcasting of seeds + *beushaning-khelua* + manual weeding 35 days after sowing; C_2, Dry direct seeded rice in lines (DSRL) + mechanical weeding at 21 and 35 DAS; C_3, DSRL + application of pendimethalin @ 1.0 kg/ha as pre-emergence spray + bispyribac Na @ 0.02 kg/ha at 21 DAS; C_4, DSRL + pendimethalin @ 1.0 kg/ha as pre-emergence spray + manual weeding at 35 DAS; C_5, DSRL + bispyribac Na @ 0.02 kg/ha at 21 DAS; C_6, drum seeding + application of bispyribac Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS; C_7, transplanting + application of bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS, were tried in randomized block design with 3 replications. During the winter (*rabi*) season, zero-till *toria* crop was grown on residual soil-moisture conditions. *Beushaning* refers to cross-ploughing in standing crop of rice by narrow wooden country plough by impounding 10 cm rain water about 30 days after sowing. The practice is followed by laddering. The weeds in rice crop, predominantly grassy with C_4 photosynthetic cycle, are killed by maintenance of standing water and laddering. Rice plants with C_3 photosynthetic cycle come out of mud and water and stand erect. *Khelua* refers to uniform distribution of plants over the field by using a small hand-held tool made of iron with a wooden handle. The residual effects of 7 crop-establishment methods imposed in rice in *kharif* and 3 weed-management practices, viz. W_1, application of glyphosate 1.0 kg/ha (pre-planting desiccation); W_2, application of quizalofop ethyl 0.05 kg/ha (post-emergence), and W_3, application of glyphosate 1.0 kg/ha (pre-planting desiccation) followed by application of quizalofop ethyl 0.05 kg/ha (post-emergencve), were tried in split-plot design with 3 replications. Rice cv. 'Naveen' and *toria* cv. 'Sushree' were taken as test variety of the crops. Direct sowing of rice/ seed soaking for nursery sowing for transplanting was done on 30 June and 18 June in respective seasons. Seed soaking for sowing under drum seeding was done after receipt of sufficient precipitation that facilitated puddling. The crop was harvested on 8 November and 19 October in direct seeding, 18 November and 29 October in drum seeding and 13 November and 26 October in transplanting during 2013 and 2014, respectively. The succeeding *toria* was sown on 4 December in 2013 and 15 November in 2014 and harvested on 20 February in 2014 and 2 February in 2015. Excess rainfall in October 2013 coinciding with harvesting of rice delayed *toria* sowing beyond the normal time of sowing. The soil of the experimental site was sandy loam with acidic pH of 5.4, medium organic carbon of 0.51%, medium available N 251.3 kg/ha, low available P 10.3 kg/ha and low available K 111.3 kg/ha.

The weed index (WI) was calculated based on the rice grain/ seed yield obtained from treatments using formula.

$$WI\ (\%) = \frac{(X-Y)}{X} \times 100$$

where X, grain yield from treatment with the maximum yield/ minimum weed competition, Y, grain yield from treatment for which weed index is to be worked out.

RESULTS AND DISCUSSION

Weedflora and biomass

The weedflora of rice comprised 4 grasses, 2 sedges and 4 broad-leaf weeds. The major grasses were: *Echinochloa colona* (L.) link., *Digitaria sanguinalis* (L.) Scop., *Elusine indica* (L.) Gaertn. and *Leptochloa chinensis* (L.) nees and the important sedges were *Cyperus difformis* (L.) and *Cyperus iria* (L.). Among broad-leaf weeds, *Alternanthera philoxeroides* (Mart.) Griseb. and *Marsilea quadrifoliata* (L.) were perennial and *Eclipta alba* (L.) Hassk. and *Ludwigia perennis* L.; syn. L. *parviflora* Roxb. were annual

Among crop-management practices in rice in *kharif*, Farmers' practice of broadcasting of seeds + *beushaning-khelua* + manual weeding 35 days after sowing proved to be the least efficient in managing the weeds. Other 6 integrated crop-management practices recorded significantly less dry-matter production by weeds (Table 1). Crop-management practices involving efficient herbicides helped in successful management of weeds. Pendimethalin, a herbicide of dinitroaniline group, inhibits cell-division in weeds by interacting with the microtubular system. The herbicide was applied as pre-emergence spray in dry direct-seeded rice for managing weeds in combination with bispyribac sodium as post-emergence spray or manual weeding. Bispyribac sodium, a herbicide of pyrimidinyl oxybenzoic acid group, inhibits acetolactate synthase (ALS) enzyme responsible for synthesis of branched chain amino acids and controlled annual and perennial grasses, broad-leaf weeds and sedges. Bispyribac sodium managed weeds successfully in transplanted and drum-seeded rice.

Zero-till *toria* grown under residual soil-moisture conditions after transplanted rice was subjected to the least weed competition. Weed flora included 1 grass, 1 sedge and 3 broad-leaf weeds. *Leptochloa chinensis* was the dominant grass and *Cyperus iria* L. was the dominant sedge. All the 3 broad-leaf weeds, viz. *Ageratum conyzoides* L., *Gnaphalium indicum* ambiguous synonym for *Helichrysum indicum* (L.) Grierson and *Blainvillea acmella* (l.) Philipson; syn. *Spilanthes acmella* (L.) Murray were from 1 family, i.e. Asteraceae. Among the weed-management practices in *toria*, sequential application of glyphosate as pre- planting desciccation (PPD) of ratoon rice and emerged weeds and quizalofop ethyl as post-emergence spray proved to be the best in managing the weeds. Glyphosate inhibits enzyme 5-enolpyruvyl shikimate-3-phosphate synthase (EPSP synthase) which obstructs production of aromatic amino acids as phenylalanine, tryp-

Table 1. Effect of crop management in rice and weed management in *toria* on biomass of weeds

Treatment	Biomass of weeds (g/m^2) in rice at harvesting		Biomass of weeds (g/m^2) in *toria* at harvesting	
	2013	2014	2013–14	2014–15
Crop-management practices in rice				
C_1, Farmers' practice	10.8*(115.6)	10.3 (105.1)	4.7 (21.5)	4.0 (15.2)
C_2, DSRL+ MW	8.1 (68.1)	7.6 (57.4)	4.5 (19.5)	3.8 (14.0)
C_3, DSRL+ Pre+PoE	8.6 (72.6)	6.6 (43.6)	4.1 (16.7)	3.6 (12.3)
C_4, DSRL+ Pre +HW	7.9 (61.8)	7.4 (54.9)	4.0 (15.4)	3.5 (11.5)
C_5, DSRL+ PoE	9.8 (96.5)	9.6 (92.4)	4.3 (18.1)	3.7 (13.0)
C_6, Drum seeding + PoE + MW	8.3 (69.0)	8.0 (63.9)	3.7 (13.0)	3.3 (10.6)
C_7, TP + PoE + MW	6.9 (47.6)	6.5 (41.6)	3.4 (11.2)	3.2 (9.9)
SEm±	0.1	0.2	0.04	0.04
CD (P=0.05)	0.3	0.6	0.1	0.1
Weed management in toria				
W_1, Glyphosate			4.2(17.2)	3.6 (12.1)
W_2, Quizalofop ethyl			4.4(18.9)	3.7 (13.5)
W_3, Glyphosate + quizalofop ethyl			3.7(12.9)	3.4 (11.3)
SEm±			0.04	0.04
CD (P=0.05)			0.1	0.1

*$\sqrt{x+0.5}$ transformed values of data on dry-matter production by weeds and original values are given in parentheses
Details of treatments are given under Materials and Methods

tophan, and tyrosine. Quizalofop ethyl, an aryloxyphenoxy propionates (AOPP) herbicide, inhibits synthesis of Acetyl-CoA-carboxylase (Accase) which is essential for biosynthesis of lipids and fatty acids. It controls grassy weeds effectively in dicot crops. Glyphosate 1.0 kg/ha alone or quizalofop ethyl 0.05 kg/ha alone recorded significantly higher weed biomass at harvesting of *toria*.

Grain and straw yield of rice

In rice, transplanted rice with post-emergence application of bispyribac sodium followed by mechanical weeding resulted in the maximum yield of rice (4,640 kg/ha), while farmers practice of broadcasting + *beushaning-khelua* + manual weeding 35 days after sowing recorded the minimum grain yield 2,965 kg/ha (Table 2). The higher yield in transplanting-based crop management was due to better weed control by puddling, adequate plant stand and efficacy of the herbicide. The lower yield in broadcasting + *beushaning-khelua* + manual weeding 35 days after sowing was due to inadequate plant population, uneven plant stand and poor weed control (Singh *et al.,* 2004). Puddling in transplanting and drum seeding provided clean weed control during initial period of crop establishment, whereas row-seeded rice with different types of weed management could not provide weed-free environment to the crop as transplanted rice during early part of crop establishment (Chauhan and Yadav, 2013). Drum seeding with post-emergence application of bispyribac sodium followed by mechanical weeding ranked the second for yield of grain. Dry direct-seeded rice in line (DSRL)-based crop management resulted in comparatively less grain yield than transplanting and drum seeding. This is in agreement with the findings of Brar and Bhullar (2013) and Khare *et al.* (2014). Pooled over years, transplanting in rice with application of bispyribac Na @ 0.02 kg/ha followed by mechanical weeding recorded the maximum straw yield (5,563 kg/ha) and proved superior to all the other crop-management practices in rice. Drum seeding with post-emergence application of bispyribac sodium followed by mechanical weeding and DSRL + pendimethalin @ 1.0 kg/ha as pre-emergence spray + manual weeding at 35 DAS with weed index values of 13.7 and 15.4**%**, respectively, proved more efficient than the other treatments in managing the weeds.

Seed yield of toria

Toria, sown after direct-seeded rice in lines with mechanical weeding, gave mean yield of 506 kg/ha (Table 3). The 2 crop-establishment methods such as transplanting and drum seeding with post-emergence application of bispyribac sodium 0.02 kg/ha followed by mechanical weeding gave lower seed yield and reduced seed yield by 37.8 and 23.2% compared to DSRL. Soil was subjected to intense ploughing and puddling both under transplanting and drum seeding. The poor root development and crop growth and lower seed yield in *toria* was due to deterioration of soil properties, as bulk density and water stable aggregates (Bajpai *et al.*, 2000; Gangwar *et al*., 2008). Kirchoff *et al.* (2000) and Mohanty *et al*. (2006) reported poor performance of post rice soybean and wheat, respectively, due to puddling in rice. Among the weed-management practices, weed management by sequential application of glyphosate 1.0 kg/ha followed by application of quizalofop ethyl as post-emergence spray recorded the maximum seed yeld of 472 kg/ha owing to satisfactory weed control throughout the crop life-cycle. Application of glyphosate 1.0 kg/ha recorded weed index of 4.2% as against 26.7% in case of quizalofop ethyl as post-emergence spray, indicating higher efficacy of the former.

Interaction effects of crop management in rice and weed management in *toria* were significant on seed yield of *toria.* Dry direct-seeded rice in lines (DSRL) + mechanical weeding at 21 and 35 DAS and sequential application of glyphosate 1.0 kg/ha (PPD) and quizalofop ethyl 0.05 kg/

Table 2. Effect of crop-management practices in rice on yield (pooled over 2013 and 2014)

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	Weed index
C_1, Farmers' practice	2,965	3,657	36.0
C_2, DSRL+ MW	3,044	3,728	34.4
C_3, DSRL+ Pre+PoE	3,515	4,181	24.3
C_4, DSRL+ Pre +HW	3,925	4,711	15.4
C_5, DSRL+ PoE	2,990	3,708	35.6
C_6, Drum seeding + PoE + MW	4,004	4,826	13.7
C_7, TP + PoE + MW	4,640	5,563	0
SEm±	149	232	–
CD (P=0.05)	412	643	–

DSRL, Dry direct-seeded rice in lines; TP, transplanting; Pre, pre-emergence application of pendimethalin @1.0 kg/ha; PoE, post-emergence application of bispyribac Na @ 0.02 kg/ha at 21 DAS; MW, mechanical weeding; HW, hand-weeding ha as post-emergence spray recorded the maximum seed yield of 536 kg/ha. Dry direct-seeded rice in lines (DSRL) + mechanical weeding at 21 and 35 DAS and application of glyphosate 1.0 kg/ha (PPD) alone in *toria* remained at par with the seed yield of 527 kg/ha.

Rice-equivalent yield of rice-zero till toria cropping system

Pooled over seasons, transplanting + bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS resulted in the maximum rice-equivalent yield (REY) of 5062 kg/ha and all the other crop-management practices recorded significantly less rice-equivalent yield. In case of weed-management practices, sequential application of glyphosate 1.0 kg/ha and quizalofop ethyl 0.05 kg/ha resulted in the maximum REY of 4,892 kg/ha and proved superior to the other 2 weed-management practices.

Interaction effects of crop management in rice and weed management in *toria* were found significant on yield of rice–*toria* system as rice-equivalent yield. Transplanting in rice + bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS and sequential application of glyphosate 1.0 kg/ha (pre-planting desiccation) + quizalofop ethyl 0.05 kg/ha as post-emergence in *toria* recorded the maximum system REY of 5,792 kg/ha. The treatment combinations, viz. transplanting in rice with bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS and glyphosate 1.0 kg/ha as PPD alone or quizalofop ethyl 0.05 kg/ha as post-emergence in *toria* recorded statistically similar system rice-equivalent yield.

Production economics of rice

In rice, transplanting recorded the maximum gross returns of ₹67,771/ha and proved significantly superior to all the other treatments (Table 4). Transplanting recorded the maximum net returns of 37,104/ha and both drum seeding + bispyribac Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS and dry direct-seeded rice in lines with pendimethalin @ 1.0 kg/ha as pre-emergence spray followed by manual weeding at 35 DAS remained at par. The DSRL with pre-emergence application of pendimethalin followed by hand-weeding gave the maximum return per rupee investment of 2.42 and drum seeding + bispyribac Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS was at par with return per rupee investment of 2.38 due to decrease in cost of cultivation as compared to transplanting. The results are in conformity with the findings of Yadav and Singh (2006) and Singh and Singh (2010).

Net return from toria

Dry direct seeded rice in lines (DSRL) + mechanical weeding at 21 and 35 DAS recorded the maximum net return of ₹11,733/ha and proved significantly superior to all other crop management practices (Table 5). Among weed management practices, application of glyphosate 1.0 kg/ha (PPD) recorded the maximum net return of ₹10,674/ha and proved superior to other two weed management practices. Interaction effects of crop management in rice and weed management in *toria* were found significant on net return from *toria*. Dry direct seeded rice in lines + mechanical weeding at 21 and 35 DAS and application of

Table 3. Effect of crop management in rice and weed management in residual *toria* on seed yield of *toria* and rice-equivalent yield of rice–*toria* cropping system (pooled over 2013 and 2014)

Treatment	Crop management practices in rice (C)							Mean	Weed index (%)
	C_1	C_2	C_3	C_4	C_5	C_6	C_7		
Weed management (W)	*Seed yield of* toria *(kg/ha)*								
W_1	492	527	424	439	453	417	407	452	4.2
W_2	407	456	293	319	385	286	278	346	26.7
W_3	505	536	460	471	478	438	415	472	-
Mean	468	506	392	410	438	380	367	423	
SEm±	C=11, W=3, C×W=10, W×C=8								
CD (P=0.05)	C=32, W=9, C×W=30, W×C=24								
	Rice-equivalent yield of rice-zero till toria *cropping system (kg/ha)*								
W_1	4,331	4,508	4,691	5,144	4,245	5,163	5,771	4,836	
W_2	4,097	4,314	4,332	4,815	4,061	4,802	5,416	4,548	
W_3	4,366	4,532	4,791	5,231	4,313	5,221	5,792	4,892	
Mean	4,265	4,452	4,605	5,064	4,207	5,062	5,660	4,759	
SEm±	C=207, W=8, C×W=137, W×C =22								
CD (P=0.05)	C=637, W=25, C×W=422, W×C =65								

CW, **C** at same or different levels of W; WC, W at same level of **C**
Details of treatments are given under Materials and Methods

glyphosate 1.0 kg/ha in *toria* recorded the maximum net return of ₹13,502/ha and proved significantly superior to all the other treatment combinations.

Net return from rice-zero till toria cropping system

Pooled over seasons, residual effects of transplanting in rice + bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS recorded the maximum net returns of ₹37,787/ha and DSRL + pendimethalin @ 1.0 kg/ha as pre-emergence spray + manual weeding at 35 DAS, drum seeding + bispyribac Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS and DSRL + pendimethalin @ 1.0 kg/ha as pre-emergence spray + bispyribac Na @ 0.02 kg/ha at 21 DAS were statistically at par with net returns of ₹29,663, ₹36,822 and ₹35,969 respectively. Among the weed-management practices, glyphosate 1.0 kg/ha recorded the maximum system net returns of ₹32,951/ha and the other 2 weed-management practices proved to be significantly inferior to it.

Interaction effects of crop management in rice and weed management in *toria* were found significant on system net return. Transplanting in rice + bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS and glyphosate 1.0 kg/ha in *toria* gave the maximum system net

Table 4. Production economics under crop management in rice (pooled over 2013 and 2014)

Treatment	Gross returns (₹/ha)	Net returns (₹/ha)	Returns/rupee investment
C_1, Farmers' practice	43,600	14,962	1.52
C_2, DSRL+ MW	44,702	21,368	1.91
C_3, DSRL+ Pre+PoE	51,482	26,679	2.08
C_4, DSRL+ Pre +HW	57,436	33,686	2.42
C_5, DSRL+ PoE	44,031	20,603	1.88
C_6, Drum seeding + PoE + MW	58,577	33,996	2.38
C_7, TP + PoE + MW	67,771	37,104	2.21
SEm±	2,168	2,206	0.09
CD (P=0.05)	6,009	6,113	0.25

Table 5. Effects of crop management in rice and weed-management in *toria* on economics (pooled over 2013 and 2014)

Treatment	Crop-management practices in rice (C)							Mean
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	
Weed management (W)				*Net returns (₹/ha) from* toria				
W_1	12,185	13,502	9,646	10,224	10,699	9,415	9,049	10,674
W_2	7,996	9,858	3,807	4,793	7,205	3,551	3,244	5,779
W_3	10,681	11,840	8,994	9,395	9,631	8,196	7,340	9,440
Mean	10,287	11,733	7,482	8,137	9,178	7,054	6,544	8,631
SEm±	C=397, W=143, C×W=436, W×C= 377							
CD (P=0.05)	C=1,224, W=413, C×W=1,312, W×C= 1,093							
				*Net returns (₹/ha) from rice-*toria *cropping system*				
W_1	23,148	30,839	31,827	38,909	27,213	38,330	40,392	32,951
W_2	18,960	27,195	25,989	33,478	23,720	32,466	34,587	28,056
W_3	21,644	29,178	31,175	38,081	26,145	37,112	38,682	31,717
Mean	21,251	29,071	29,663	36,822	25,693	35,969	37,887	30,908
SEm±	C=2,795, W=143, C×W=1,863, W×C=377							
CD (P=0.05)	C=8,614, W=414, C×W=5,737, W×C=1,093							
				*Return/rupee investment of rice-*toria *cropping system*				
W_1	1.66	2.05	2.03	2.31	1.92	2.24	2.09	2.04
W_2	1.53	1.89	1.81	2.08	1.78	2.02	1.91	1.86
W_3	1.59	1.93	1.93	2.19	1.83	2.13	1.99	1.95
Mean	1.59	1.96	1.93	2.19	1.84	2.13	2.00	1.95
SEm±	C=0.09, W=0.01, C×W=0.06, W×C=0.02							
CD (P=0.05)	C=0.28, W=0.03, C×W=NS, W×C=NS							

Details of treatments are given under Materials and Methods

returns of ₹40,392/ha and treatment combinations involving DSRL+ Pre + HW and drum seeding in rice and glyphosate 1.0 kg/ha (PPD) and glyphosate 1.0 kg/ha (PPD) + quizalofop p-ethyl 0.05 kg/ha (post-emergence) in *toria* and transplanting + bispyribac-Na @ 0.02 kg/ha at 21 DAS + mechanical weeding at 35 DAS in rice and glyphosate 1.0 kg/ha (PPD) + quizalofop ethyl 0.05 kg/ha (post-emergence) in *toria* were at par.

Returns per rupee investment from the system

Among the crop-management practices, DSRL + pendimethalin @1.0 kg/ha as pre-emergence spray + manual weeding at 35 DAS showed the maximum returns per rupee investment of 2.19 (Table 5). All the other crop-management practices except farmers' practice and DSRL + bispyribac Na @ 0.02 kg/ha at 21 DAS remained at par. Among the weed-management practices, glyphosate 1.0 kg/ha recorded the maximum returns per rupee investment of 2.04 and proved superior to the other 2 weed-management practices. Interaction effects of crop management in rice and weed management in *toria* were found non-significant on returns per rupee investment from the system. However, DSRL + pendimethalin @ 1.0 kg/ha as pre-emergence spray + manual weeding at 35 DAS and glyphosate 1.0 kg/ha in *toria* gave the maximum returns per rupee investment of 2.31.

Line sowing in direct-seeded rice in lines with pendimethalin as pre-emergence spray followed by hand-weeding at 35 days after sowing or transplanting rice with bispyribac-Na @ 0.02 kg/ha as post-emergence spray at 21 days after sowing + mechanical weeding at 35 days after sowing and use of glyphosate 1.0 kg/ha as pre-planting desiccation of ratoon rice and established weeds in *toria* may be recommended for maximizing rice-*toria* system yield, net returns and returns/rupee investment.

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