Indian Journal of Agronomy **63** (2): 129–136 (June 2018)

Research Paper

Effect of weed control on weed competition, soil microbial activity and rice productivity in conservation agriculture-based direct-seeded rice (*Oryza sativa*)–wheat (*Triticum aestivum*) cropping system

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Received : January 2017; Revised accepted : April 2018

ABSTRACT

A field experiment was carried out during 2012–13 and 2013–14 at New Delhi, to evaluate the effects of weed-control options on weed interference, microbial activity and direct-seeded rice (DSR) productivity in a conservation agriculture (CA)-based rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend. Fiori et Paol) cropping system. The CA practices such as brown manuring, mungbean [*Vigna radiata* (L.) R. Wilczek] residue (MR) and rice-residue (RR) retention, zero tillage (ZT) significantly influenced weed density, microbial activity and crop yield. Grassy weeds were more dominant among the weeds. The DSR practices encountered more weed infestations than transplanted rice (TPR). The sequential applications of pendimethalin @ 1.5 kg/ha as pre-emergence, and bispyribac-Na @ 25 g/ha at 25 days after sowing/ transplanting (DAS/ DAT) as post-emergence resulted in better control of weeds and higher weed-control efficiency (WCE), but this combination plus 1 hand-weeding (HW) at 45 DAS was the best weed-control option in DSR. Higher WCE of 50% and 52% obtained from this treatment respectively, in 2012 and 2013. These herbicides applications slightly reduced microbial activity at 40 DAS. Soil microbial activity positively responded to CA practices. Soil-dehydrogenase activity (DHA) and microbial biomass carbon (MBC) were significantly higher in DSR than TPR. The rice yields were comparable between the TPR – ZTW and DSR + MR – ZTW + RR – SMB + wheat residue (WR) systems, but higher than in other CA-based DSR-wheat systems. Treatment DSR + MR – ZTW + RR – SMB + WR provided higher grain yield 4.41 t/ha and 4.53 t/ha in 2012 and 2013, respectively.

Key words : Conservation agriculture, Dehydrogenase activity, Direct-seeded rice, Microbial biomass carbon, Weed, Yield

Conservation agriculture (CA) is a resource-saving crop production concept that has potential to rectify the negative consequences encountered in global agriculture, threatening the sustainability and productivity of crop production systems. The CA can improve soil health, stabilize soil moisture and temperature, improve soil aggregate stability, increase soil organic matter (Chauhan *et al.,* 2002), nullify threats to environment and increase productivity of cropping system. The rice–wheat cropping system covers 13.5 million ha area in the Indo-Gangetic plains (IGPs), out of that around 10.5 million ha area is in the IGPs of India. Substantial rice yield losses under direct-seeded conditions due to severe weed infestation is a most important anxiety and a major reason for disinclination of farmers towards adoption of direct-seeded rice (DSR). The physico-chemical conditions of soil under CA differ vastly from the conventional systems. Soil disturbance has negative effects on soil microbes and microbial biomass (Unger *et al.,* 2009). Herbicides, particularly the sequential applications of herbicides, herbicide mixtures (Das and Yaduraju, 2012; Susha *et al.,* 2014) would be more effective to control diverse weed flora. They might have initial temporary negative impact on soil micro-organisms and their activities, but the micro-organisms recover soon from the initial setbacks (Das *et al.,* 2010). Herbicides can also affect succeeding crops and weeds due to carry-over effects (Tuti and Das, 2011). Usually, the productivity of DSR is lower than that in TPR, but with CA and proper weed management, higher productivity of DSR could be achieved (Bhattacharyya *et al.,* 2015). Hence, this experiment was planned in a CA-based DSR under a 2-year old

Based on a part of Ph.D. Thesis of the first author, submitted to ICAR-Indian Agricultural Research, Institute, New Delhi, 2017 (Unpublished)

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CA-based rice–wheat cropping system with a superimposition of the weed-control treatments, to evaluate the impacts of CA and weed-control measures on weed interference, microbial activity and rice crop performance in rice–wheat cropping system.

MATERIALS AND METHODS

The experiment was conducted during the rainy, winter and summer seasons in 2012–13 and 2013–14 at the ICAR-Indian Agricultural Research Institute, New Delhi (28°35' N, 77°12' E; 228.6 m above mean sea-level). Soil was Inceptisol with sandy clay loam texture in upper 30 cm layer and loam below. Water-table remained below 3.5 m deep from ground surface during crop-growth period. The soil was low in available N and medium in available P and organic carbon.

The experiment was laid out in a split-plot design, keeping CA practices in main plots and weed-control options in subplots, with 3 replications. The plot size for main plot was 42.0 m × 4.0 m and that of sub-plot was 4.2 m × 4.0 m. Rice crop cultivar chosen for the experiment was 'PRH 10'. Eight main plot treatments were: direct-seeded rice (DSR) – zero till wheat (ZTW), DSR – ZTW + rice residue (RR), DSR + brown manuring (BM) – ZTW, DSR + BM – ZTW + RR, DSR – ZTW – ZT summer mungbean (ZTSMB), DSR + mungbean residue (MR) – ZTW + RR – ZTSMB + wheat residue (WR), transplanted puddled rice (TPR) – ZTW and TPR – CTW. The subplots treatments in rice were: unweeded control (UWC), the application of pre-emergence pendimethalin @ 1.5 kg/ha + post-emergence bispyribac-Na @ 25 g/ha at 25 DAS/ DAT; and the pre-emergence pendimethalin @ 1.5 kg/ha + post-emergence bispyribac-Na at 25 g/ha at 25 DAS/ DAT + 1 hand-weeding (HW) at 45 DAS. The DSR was conventionally-tilled and the plots were ploughed once with a disc plow, followed by harrowing and planking twice. Nursery was sown at the time of sowing of DSR for TPR. The TPR plots were conventionally-tilled as DSR and then were puddled for smooth transplanting of rice seedlings. Recommended dose of fertilizer was applied to rice.

Soil microbial biomass carbon (MBC) and soil dehydrogenase activity (DHA) were studied at 70 DAS of rice. For this, 4 to 5 soil cores from the top soil (0–15 cm depth) were collected from each plot. The soil samples were air-dried and sieved through a 2.0 mm mesh. The DHA was determined as per Paul *et al.* (2009). Microbial biomass carbon (MBC) was analyzed following chloroform fumigation extraction method as described by Paul *et al.* (2009). Observations on weeds were recorded at 70 DAS and data were transformed through square-root [$\sqrt{(x + 0.5)}$ method. A quadrat of 0.25 m^2 was thrown randomly in each subplot and weeds were collected from the quadrat area and counted. The species-wise weed density was expressed in number/m^2. Data on weeds, microbes and rice crop were analyzed in split-plot design. The significance was tested by the variance ratio (~F-value) at 5% level (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Weeds

Weed flora in the experimental DSR field comprised *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Dactyloctenium aegyptium* (L.) P. Beauv., *Leptochloa chinensis* (L.) Nees., *Cyperus rotundus* L., *Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop., *Elusine indica* (L.) Gaertn, *Commelina benghalensis* L. and *Eclipta alba* Hassak. The CA practices significantly influenced weed density in both the years of experimentation in DSR (Table 1), which resulted in higher densities of weeds than TPR (under TPR – ZTW/CTW systems). Grassy weeds were more pre-dominant than broad-leaf and sedge weeds in both DSR and TPR. The triple cropping system-based DSRs with and without residues of the respective crops (i.e. DSR + MR – ZTW + RR – ZTSMB + WR and DSR – ZTW – ZTSMB) resulted in lower densities of grassy weeds than the other DSR treatments. The DSR in these 2 cropping systems also recorded lower densities of broad-leaf weeds in the first year (2012), but the brown manuring treatments (i.e. DSR + BM – ZTW + RR and DSR + BM – ZTW) under double cropping systems caused the highest reduction in broad-leaf weed densities in the second year (2013). The densities of sedges, mainly, *Cyperus rotundus* were relatively higher in the triple cropping systems-based DSR with and without residue (i.e. DSR + MR – ZTW – ZTSMB and DSR + MR – ZTW + RR – ZTSMB + WR). The DSR – ZTW and DSR – ZTW + RR resulted in the highest total weed density, whereas the TPR – ZTW/CTW recorded significantly lower total weed densities compared to all the DSR treatments, except DSR + MR – ZTW + RR - ZTSMB + WR, which was comparable with them (Table 2). Pendimethalin + bispyribac + HW resulted in significantly lower total weed populations. Interactions revealed that CA-based DSR practices, excepting DSR – ZTW and DSR – ZTW + RR and TPR – ZTW/CTW resulted in total weed densities that were comparable between pendimethalin + bispyribac and pendimethalin + bispyribac + HW in 2012. But in 2013, all CA-based DSR treatments and TPR resulted in significantly lower total weed density in pendimethalin + bispyribac + HW than in pendimethalin + bispyribac. This indicates that in the first year, pendimethalin + bispyribac treatment was as good as the pendimethalin + bispyribac + HW treatment, but in the second year, hand-weeding with pendimethalin + bispyribac proved more effective, mainly due to slightly higher infestation of *Cyperus rotundus* (Table 1). Besides, frequent and higher rainfall in the second year made herbicide treatments less effective and promoted more weed infestations.

Tillage and puddling were responsible for better weed control in TPR (Mishra and Singh, 2012). Buhler *et al.* (1994) reported that, reduced tillage in DSR caused heavy weed infestations, which subsequently increased dry matter of weed. Brown manuring could suppress weeds, particularly broad-leaf ones at the early stage. The weed-management option, pendimethalin + bispyribac + HW was more effective against weeds than UWC and pendimethalin + bispyribac treatments, and the occurrence of frequent rainfall made herbicides less effective. Singh *et al.* (2006) reported effective weed control in DSR by using the pre-emergence pendimethalin and post-emergence bispyribac. In our study, sedges were present in DSR crop; therefore, pendimethalin + bispyribac supplemented with hand-weeding proved more effective. Sedges, namely *Cyperus rotundus,* shows tolerance to both the herbicides, particularly pendimethalin. Bispyribac could suppress this weed to a little extent. Owing to higher total weed densities in UWC and much higher reductions in total weed densities by the herbicide treatments (i.e. pendimethalin + bispyribac + HW, and pendimethalin + bispyribac), the DSR – ZTW and DSR – ZTW + RR resulted in higher weed-control efficiency (WCE) than the other DSR treatments (Table 3), although they had higher total weed density (Table 2), which resulted in higher weed index/ yield losses. This indicates that the WCE could not be a better estimate of the weed interference in DSR (Das, 2008). The DSR – ZTW – ZTSMB recorded the lowest WCE during both the years (Table 3). Among the weed-control treatments, the application of pendimethalin + bispyribac + HW provided higher WCE than pendimethalin + bispyribac. Weed index (WI) provides information about per cent yield loss due to weed interference. It was higher due to DSR – ZTW. The reasons have been discussed earlier. Much higher weed density in UWC was mainly responsible for higher yield losses under this treatment. On the contrary, the TPR – ZTW with lowest weed interference resulted in lower yield losses/ WIs. The interaction between CA and weed control was not significant for WCE, but it was significant for WI.

Microbial activity

In general, higher values of microbial biomass carbon (MBC) and dehydrogenase activity (DHA) were recorded in DSR than TPR (Table 4). Puddling and flooding condi-

Table 1. Category-wise weed density at 70 days after sowing in rice as influenced by conservation agriculture and weed-control practices

Treatment	Grassy weeds (Nos./m^2)*		Broad-leaf weeds (Nos./m^2)*		Sedges (Nos./m^2)*	
	2012	2013	2012	2013	2012	2013
CA practice (CA)						
DSR – ZTW	4.7 (23.7)	4.6 (23.4)	1.6 (2.7)	1.8 (3.3)	1.3 (1.4)	1.6 (2.6)
DSR – ZTW + RR	4.2 (19.1)	4.0 (17.9)	1.3 (1.4)	1.6 (2.7)	1.1 (1.0)	1.5 (2.3)
DSR + BM – ZTW	3.7 (14.6)	3.0 (10.4)	1.2 (1.2)	1.2 (1.2)	1.0 (0.7)	1.3 (1.6)
DSR + BM – ZTW + RR	3.6 (13.3)	2.8 (8.8)	1.3 (0.6)	1.2 (1.2)	1.0 (0.7)	1.3 (1.3)
DSR – ZTW – ZTSMB	3.0 (9.7)	2.9 (9.7)	1.0 (0.7)	1.4 (2.0)	3.2 (9.7)	2.2 (10.8)
DSR + MR – ZTW + RR –ZTSMB + WR	2.8 (8.2)	2.5 (7.4)	1.0 (0.1)	1.4 (1.9)	3.2 (10.2)	1.8 (12.1)
TPR – ZTW	2.6 (6.7)	2.9 (8.6)	0.8 (0.2)	1.0 (0.6)	0.7 (0.0)	0.7 (0.0)
TPR – CTW	2.8 (8.1)	3.1 (9.8)	0.8 (0.2)	0.9 (0.3)	0.7 (0.0)	0.7 (0.0)
SEm±	0.2	0.2	0.1	0.2	0.1	0.2
CD (P=0.05)	0.5	0.6	0.4	0.6	0.3	0.6
Weed control (WC)						
UWC	4.7 (22.6)	4.6 (21.3)	1.5 (2.0)	1.8 (3.3)	1.8 (4.2)	1.9 (5.8)
Pendimethalin + bispyribac	3.3 (11.2)	3.4 (11.4)	1.1 (0.9)	1.2 (1.1)	1.5 (3.0)	1.3 (3.3)
Pendimethalin + bispyribac + HW	2.2 (4.9)	1.8 (3.3)	0.8 (0.3)	0.9 (0.6)	1.3 (1.8)	1.0 (2.4)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1
CD (P=0.05)	0.2	0.2	0.3	0.3	0.2	0.2
CA × WC						
SEm±	0.2	0.2	0.2	0.3	0.2	0.2
CD (P=0.05)	0.7	0.7	NS	NS	0.5	NS

Details of treatments are given under Materials and Methods. DSR, Direct-seeded rice; ZTW, zero till wheat; RR, rice residue; BM, brown manuring; SMB, summer mungbean; MR, mungbean residue; WR, wheat residue, TPR, transplanted puddled rice; UWC, unweeded control. *Data were transformed through square-root ($\sqrt{x+0.05}$) method. Original values are in the parentheses tions had detrimental effects on micro-organisms, which could reduce the activities of micro-organisms (Unger *et al.*, 2009). Among the DSR treatments, the treatments – DSR + MR – ZTW + RR – ZTSMB + WR and DSR-ZTW – ZTSMB – resulted in significantly higher values of MBC and DHA in both the years. The lowest values of soil MBC and DHA were observed in DSR under the DSR – ZTW system. The brown manuring (i.e. DSR + BM –

Table 2. Interaction between conservation agriculture and weed-control practices on total weed density at 70 days after sowing

Treatment	Total weed density (Nos./m^2)*2012				Total weed density (Nos./m^2)* 2013			
Weed control (WC)	UWC	Pendimethalin + bispyribac	Pendimethalin + bispyribac + HW	Mean	UWC	Pendimethalin + bispyribac	Pendimethain + lbispyribac + HW	Mean
CA practice (CA)								
DSR – ZTW	7.2 (51.0)	4.8 (22.3)	3.2 (10.0)	5.0	7.6 (57.7)	4.8 (22.3)	3.3 (10.3)	5.2
DSR – ZTW + RR	6.3 (39.7)	4.4 (18.7)	2.6 (6.3)	4.4	6.6 (43.0)	4.5 (20.3)	2.5 (6.0)	4.6
DSR + BM – ZTW	5.4 (29.0)	3.8 (14.0)	2.5 (6.3)	3.9	4.9 (23.7)	3.8 (14.3)	1.8 (3.0)	3.5
DSR + BM – ZTW + RR	5.1 (26.0)	3.8 (14.0)	2.6 (6.3)	3.8	4.5 (20.0)	3.6 (13.0)	2.0 (3.7)	3.3
DSR – ZTW – ZTSMB	5.4 (28.7)	4.6 (20.3)	3.3 (10.7)	4.4	5.9 (34.0)	4.6 (21.7)	3.4 (11.0)	4.6
DSR + MR – ZTW + RR– ZTSMB + WR	5.4 (29.0)	4.3 (18.3)	3.2 (10.0)	4.3	5.9 (34.7)	4.5 (19.7)	3.3 (11.0)	4.6
TPR – ZTW	3.6 (12.7)	2.3 (5.0)	1.7 (2.7)	2.6	4.1 (16.7)	3.1 (9.0)	1.9 (3.0)	3.0
TPR – CTW	3.8 (14.3)	2.8 (7.7)	1.9 (3.0)	2.8	4.2 (17.3)	3.2 (10.0)	2.5 (5.7)	3.3
Mean	5.3	3.8	2.6		5.5	4.0	2.6	
	CA	*WC*	*CA × WC*		*CA*	*WC*	*CA × WC*	
SEm±	0.2	0.2	0.5		0.2	0.1	0.2	
CD (P=0.05)	0.6	0.5	1.4		0.5	0.2	0.7	

Details of treatments are given under Materials and Methods. DSR, Direct-seeded rice; ZTW, zero till wheat; RR, rice residue; BM, brown manuring; SMB, summer mungbean; MR, mungbean residue; WR, wheat residue, TPR, transplanted puddled rice; UWC, unweeded control. *Data were transformed through square-root ($\sqrt{x + 0.5}$) method. Original values are in the parentheses

Table 3. Weed-control efficiency and weed index (~per cent yield loss) in rice at 70 days after sowing as influenced by conservation agriculture and weed-control practices

Treatment	Weed control efficiency (%) 2012	Weed control efficiency (%) 2013	Weed index (%) 2012	Weed index (%) 2013
CA practice (CA)				
DSR – ZTW	29.6	31.3	30.4	29.4
DSR – ZTW + RR	29.9	30.7	29.5	29.0
DSR + BM – ZTW	28.4	27.5	25.9	25.4
DSR + BM – ZTW + RR	25.0	25.7	25.8	24.6
DSR – ZTW – ZTSMB	17.5	21.3	13.5	13.8
DSR + MR – ZTW + RR –ZTSMB + WR	20.5	22.7	13.9	12.7
TPR – ZTW	36.0	26.6	12.1	11.9
TPR – CTW	25.5	22.0	12.3	12.0
SEm±	2.3	2.7	0.6	0.5
CD (P=0.05)	6.8	NS	1.9	1.6
Weed control (WC)				
UWC	0.0	0.0	57.8	56.4
Pendimethalin + bispyribac	29.6	25.4	3.5	3.0
Pendimethalin + bispyribac + HW	50.0	52.5	0.0	0.0
SEm±	1.8	1.5	0.5	0.4
CD (P=0.05)	5.1	4.4	1.5	1.2
CA ×WC				
SEm±	5.0	4.4	1.5	1.2
CD (P=0.05)	NS	NS	4.3	3.4

Details of treatments are given under Materials and Methods. DSR, Direct-seeded rice; ZTW, zero till wheat; RR, rice residue; BM, brown manuring; SMB, summer mungbean; MR, mungbean residue; WR, wheat residue, TPR, transplanted puddled rice; UWC, unweeded control. *Weed-control efficiency and weed index were worked out on square-root ($\sqrt{x + 0.5}$) transformed data.

ZTW + RR; DSR + BM – ZTW) was intermediate in improving soil MBC and DHA. Among the weed-control options, the UWC recorded significantly higher values of MBC and DHA than that in pendimethalin + bispyribac and pendimethalin + bispyribac + HW treatments. Sebiomo *et al.* (2011) reported that, herbicides could reduce MBC and DHA. Herbicides initially affect microorganisms and reduce their population and specific enzyme activity, but the effect is short-lived/temporary (Das *et al.,* 2010). The UWC resulted in higher MBC and DHA due to a larger rhizosphere in presence of higher weed density and root biomass that caused higher increment in microbial activity (Wardle *et al.,* 1999).

Rice crop productivity

Rice grain, straw and total biological yields were significantly influenced by CA and weed-control practices during both the years (Table 5). The TPR, irrespective of the TPR–ZTW/CTW systems, resulted in significantly higher values of these yields than DSR treatments (Gill *et al.,* 2006), but the DSR + MR – ZTW + RR – ZTSMB + WR was comparable with it in respect of grain yield. This DSR practice recorded slightly higher harvest index, although not significantly different from that of the TPR. However, it recorded significantly higher net benefit: cost ratio than that in all other DSR and TPR treatments. Better weed management in TPR and water availability improved the yield attributes and enhanced rice yield (Kumar and Ladha, 2011). Incorporation of summer mungbean residue in the DSR + MR – ZTW + RR – ZTSMB + WR improved soil fertility through, mainly, N supply and enhanced rice yield in both the years. Besides, it improved soil physico-chemical properties, helping better microbial activities. Brown manuring (i.e. DSR + BM – ZTW + RR; DSR + BM – ZTW) in DSR was also helpful in reducing crop-weed competition, which subsequently resulted in higher crop yield than without brown manuring plots (Table 5). The grain yield, straw yield and total biological yield were lower in DSR – ZTW, DSR – ZTW + RR and DSR + BM – ZTW, mainly, because of heavy weed infestations in these plots, resulted in poor plant population and crop growth, and subsequently reduced crop yield (Kumar and Ladha, 2011).

Weed-management options also differed significantly on these straw, grain and total biological yields (Table 5). The pendimethalin + bispyribac + HW treatment resulted in significantly higher grain, straw and total biological yields of rice than the other weed-control options in both the years owing to better weed control. The pendimethalin + bispyribac treatment, however, followed it closely in

Table 4. Microbial biomass carbon (MBC) and dehydrogenase activity (DHA) at 70 days after sowing as influenced by conservation agriculture and weed-control practices

Treatment	MBC (µg C/g soil)		DHA (µg TPF* /g soil/h)	
	2012	2013	2012	2013
CA practice (CA)				
DSR – ZTW	182.9	233.8	182.9	233.8
DSR – ZTW + RR	193.4	243.0	193.4	243.0
DSR + BM – ZTW	245.5	292.9	245.5	292.9
DSR + BM – ZTW + RR	251.7	300.8	251.7	300.8
DSR – ZTW – ZTSMB	261.2	317.2	261.2	317.2
DSR + MR – ZTW + RR –ZTSMB + WR	274.8	323.9	274.8	323.9
TPR – ZTW	164.0	200.7	164.0	200.7
TPR – CTW	160.7	190.3	160.7	190.3
SEm±	7.0	6.1	7.0	6.1
CD (P=0.05)	21.2	18.5	21.2	18.5
Weed control (WC)				
UWC	232.0	272.9	232.0	272.9
Pendimethalin + bispyribac	212.1	256.3	212.1	256.3
Pendimethalin + bispyribac + HW	206.3	259.3	206.3	259.3
SEm±	4.3	4.6	4.3	4.6
CD (P=0.05)	12.3	13.3	12.3	13.3
CA × WC				
SEm±	12.1	13.0	12.1	13.0
CD (P=0.05)	NS	NS	NS	NS

Details of treatments are given under Materials and Methods. DSR, Direct-seeded rice; ZTW, zero till wheat; RR, rice residue; BM, brown manuring; SMB, summer mungbean; MR, mungbean residue; WR, wheat residue, TPR, transplanted puddled rice; UWC, unweeded control. *TPF-Triphenylformazan

Table 5. Crop productivity of rice as influenced by conservation agriculture and weed-control practices

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Total biological yield (t/ha)		Harvest index (%)		Net benefit : cost	
	2012	2013	2012	2013	2012	2012	2013	2012	2013	2012
CA practice (CA)										
DSR – ZTW	3.14	3.17	5.02	5.12	8.16	8.29	38.5	38.6	0.48	0.53
DSR – ZTW + RR	3.23	3.29	5.11	5.20	8.34	8.49	39.6	38.9	0.52	0.58
DSR + BM – ZTW	3.43	3.50	5.37	5.49	8.80	8.99	39.4	39.2	0.55	0.62
DSR + BM – ZTW + RR	3.46	3.56	5.49	5.58	8.96	9.14	38.3	39.2	0.57	0.65
DSR – ZTW – ZTSMB	4.26	4.40	6.69	6.81	10.95	11.21	38.7	39.1	1.21	1.69
DSR + MR – ZTW + RR– ZTSMB + WR	4.41	4.53	6.82	6.93	11.23	11.46	39.1	39.3	1.34	1.86
TPR – ZTW	4.59	4.67	7.24	7.32	11.82	11.99	38.7	38.8	0.50	0.56
TPR – CTW	4.49	4.55	7.11	7.19	11.61	11.75	38.5	38.6	0.47	0.52
SEm±	0.04	0.04	0.03	0.04	0.05	0.07	0.7	0.3	0.01	0.02
CD (P=0.05)	0.11	0.1	0.10	0.1	0.14	0.2	NS	NS	0.04	0.05
Weed control (WC)										
UWC	2.10	2.20	3.44	3.56	5.54	5.76	38.6	38.7	0.03	0.21
Pendimethalin + bispyribac	4.68	4.76	7.35	7.43	12.03	12.19	38.9	39.1	1.08	1.25
Pendimethalin + bispyribac + HW	4.84	4.91	7.54	7.63	12.38	12.54	39.1	39.2	1.01	1.17
SEm±	0.02	0.02	0.02	0.02	0.04	0.03	0.4	0.2	0.01	0.01
CD (P=0.05)	0.07	0.1	0.06	0.1	0.11	0.1	NS	NS	0.03	0.02
CA × WC										
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	1.3	0.5	0.03	0.0
CD (P=0.05)	0.2	0.1	0.2	0.2	0.3	0.3	NS	NS	0.1	0.1

Details of treatments are given under Materials and Methods. DSR, Direct-seeded rice; ZTW, zero till wheat; RR, rice residue; BM, brown manuring; SMB, summer mungbean; MR, mungbean residue; WR, wheat residue, TPR, transplanted puddled rice; UWC, unweeded control.

these regards. The grain yield was increased by 130% and 123% in 2012 and 2013, respectively, owing to the pendimethalin + bispyribac + HW treatment compared to UWC. The harvest index was non-significant, but the pendimethalin + bispyribac treatment gave significantly higher net benefit: cost than other weed-control options. This indicated that, although the pendimethalin + bispyribac + HW treatment was superior to pendimethalin + bispyribac treatment on yields, was inferior to the latter on net B : C. Unequal/ disproportionate increase in the returns due to higher rice yields in the former treatment to the higher cost required for hand-weeding caused the reduction in net benefit: cost. As mentioned earlier, the CA and weed-control options exhibited considerable differential impacts on weeds, and soil microbes and their activities (Bhattacharyya *et al.,* 2015), which were ultimately reflected in the yields of rice.

Regression analysis

The relationships of effective tillers and grain yield with weed dry matter were negatively correlated in both the years (Fig. 1a, b, c and d). Higher the weed biomass, lower were the grain yield and effective tillers and *vice-versa*. However, the effective tillers and grain yield were positively correlated (Fig. 1e, f). This implied that higher weed biomass caused significant reductions in the number of effective tillers, which, in turn, reduced rice grain yield significantly.

The DSR + MR-ZTW + RR – ZTSMB + WR resulted in comparable reduction in weed- population density and had comparably higher rice grain yield as that of the TPR. It recorded significantly higher net B:C and considerably improved the microbial biomass carbon and dehydrogenase activity than in other DSRs. It may be recommended as a CA-based DSR practice. Further, its combination with the pendimethalin + bispyribac, where natural weed infestation without *Cyperus rotundus* is present, is worth-recommending. However, the pendimethalin + bispyribac + HW may be recommended along with this CA-based DSR practice, where *Cyperus rotundus* is predominant.

REFERENCES

Bhattacharyya, R., Das, T.K., Sudhishri, S., Dudwal, B., Sharma, A.R., Bhatia, A. and Singh, G. 2015. Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the west-

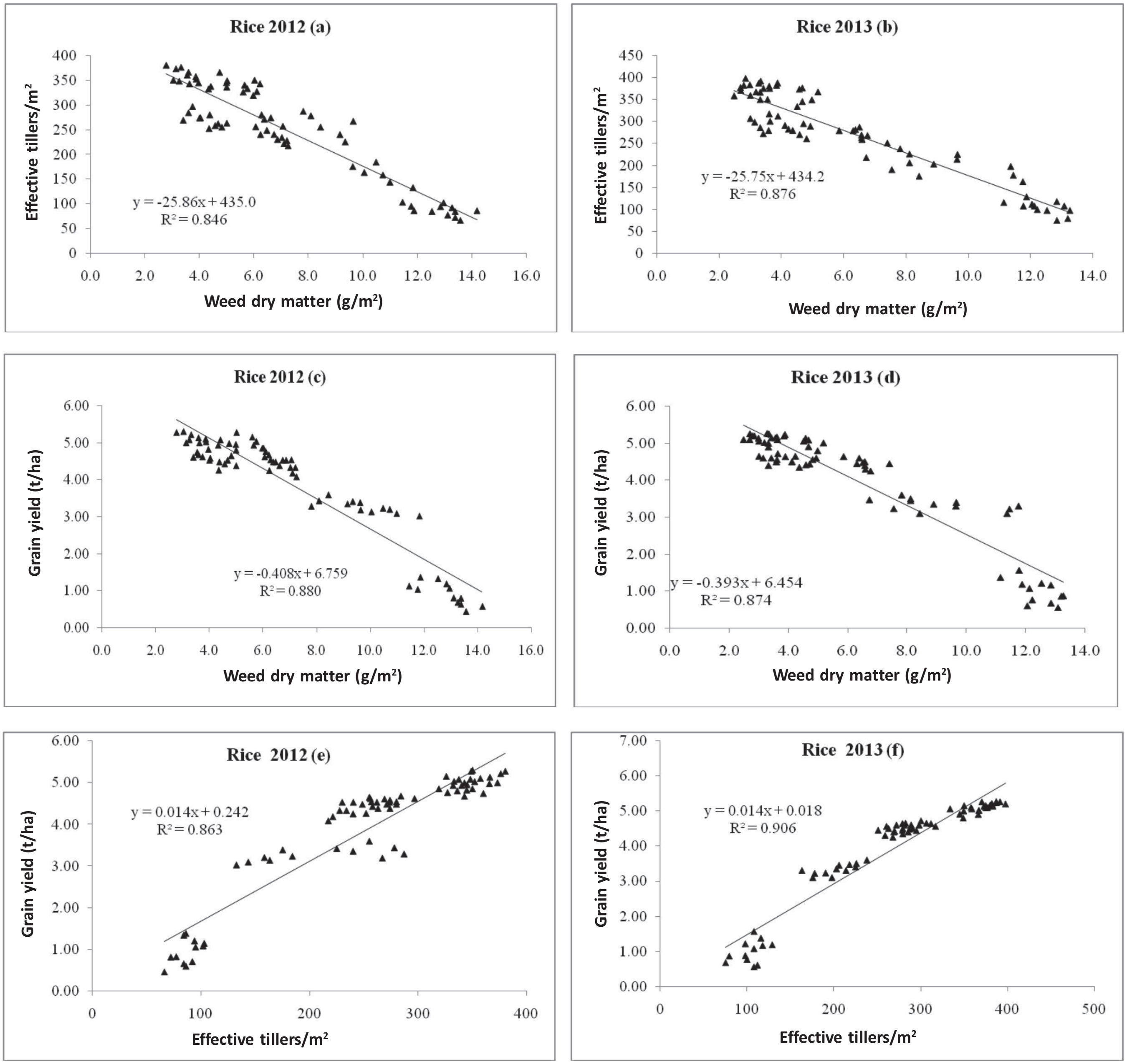

Fig. 1. Relationship between weed dry matter and effective tillers in 2012 (*a*) and 2013 (*b*); weed dry matter and rice grain yield in 2012 (*c*) and 2013 (*d*); and effective tillers and rice grain yield in 2012 (*e*) and 2013 (*f*) as influenced by conservation agriculture and weed-control practices (based on 72 observations). Weed dry-matter are transformed through square-root ($\sqrt{(x + 0.5)}$) method.

ern Indo-Gangetic Plains. *European Journal of Agronomy* **70**: 11–21.

Buhler, D.D., Stoltenberg, D.E., Becker, R.L. and Gunsolus, J.L. 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. *Weed Science* **42**: 205–209.

Chauhan, B.S., Yadav, A. and Malik, R.K. 2002. Zero tillage and its impact on soil properties: a brief review. (In) *Herbicide Resistance Management and Zero Tillage in Rice–Wheat System*. (Eds) Malik, R.K., Balyan, R.S., Yadav, A., Pahwa, S.K. 4–6 March, 2002. Chaudhary Charan Singh Haryana Agricultural University, Hisar, India, 109–114p.

Das, T.K. 2008. *Weed Science- Basics and Applications*, pp 901. Jain Brothers, New Delhi, India.

Das, T.K. and Yaduraju, N.T. 2012. The effects of combining modified sowing methods with herbicide mixtures on weed interference in wheat. *International Journal of Pest Management* **58**(4): 311–320.

Das, T.K., Sakhuja, P.K. and Zelleke, H. 2010. Herbicide efficacy and non-target toxicity in highland rainfed maize of Eastern Ethiopia. *International Journal of Pest Management* **56**(4): 315–325.

Gill, M.S., Kumar, A. and Kumar, P. 2006. Growth and yield of rice cultivars under various methods and time of sowing. *Indian Journal of Agronomy* **51**: 123–127.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research,* edn 2, pp. 591. Johns & Sons, New York.

Kumar, V. and Ladha, J.K. 2011. Direct-seeding of rice: recent developments and future research needs. *Advances in Agronomy* **111**: 297–413.

Mishra, J.S. and Singh, V.P. 2012. Tillage and weed control effects on productivity of a dry seeded rice–wheat system on a Vertisol in Central India. *Soil and Tillage Research* **12**: 11–20.

Paul, S., Prasanna, R., Lata and Wattal, Dhar D. 2009. *A Manual for Agricultural Microbiologists*. Division of Microbiology, Indian Agricultural Research Institute, New Delhi, 110 012, pp. 27–28.

Sebiomo, A., Ogundero V.W. and Bankole, S.A. 2011. Effect of four herbicides on microbial population, soil organic matter and dehydrogenase activity. *African Journal of Biotechnology* **10**(5): 770–778.

Singh, S., Bhushan., L., Ladha, J.K., Gupta, R.K., Rao, A.N. and Sivaprasad, B. 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated in the furrow-irrigated raised-bed planting system. *Crop Protection* **25**: 487–49.

Susha, V.S., Das, T.K., Sharma, A.R. and Nath, C.P. 2014. Carry-over effect of weed-management practices of maize (*Zea mays)* on weed dynamics and productivity of succeeding zero and conventional till wheat (*Triticum aestivum*). *Indian Journal of Agronomy* **59**(1): 41–47.

Tuti, M.D. and Das, T.K. 2011. Carry-over effect of metribuzin applied to soybean (*Glycine max*) on weeds and wheat (*Triticum aestivum*) under zero and conventional tillage. *Indian Journal of Agronomy* **56**(2): 121–126.

Unger, I.M., Kennedy, A.C. and Muzika, R.M. 2009. Flooding effects on soil microbial communities. *Applied Soil Ecology* **42**: 1–8.

Wardle, D.A., Yeates, G.W., Nicholson, K.S., Bonner, K.I. and Watson, R.N. 1999. Response of soil microbial biomass dynamics, activity and plant litter decomposition to agricultural intensification over a seven-year period. *Soil Biology and Biochemistry* **31**(12): 1,707–1,720.