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Effect of conservation agriculture and weed management on weeds, soil microbial activity and wheat (*Triticum aestivum*) productivity under a rice (*Oryza sativa*)-wheat cropping system

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ABSTRACT

Field experiment was carried out during the winter seasons of 2012-13 and 2013-14 to evaluate the effects of conservation agriculture (CA) and weed management practices on weeds, soil microbial activity and wheat productivity under a CA-based three-year old rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L. emend Fiori & Paol.) rotation. The design was a split plot with CA practices adopted in main plots and weed control measures in sub-plots with three replications. Results showed that zero till wheat (ZTW) encountered comparatively lower weed infestations compared to conventional till wheat (CTW). The ZTW with rice residue under (DSR) + mungbean residue (MR) – ZTW + rice residue (RR) – zero till summer mungbean (ZTSMB) + wheat residue (WR) recorded 58.8% and 61.9% higher soil dehydrogenase activity (DHA) and 48.2% and 53.8% more microbial biomass carbon (MBC) during 2012-13 and 2013-14, respectively than CTW under TPR-CTW, but weed control/ herbicides applications did not significantly influence microbial activity. Wheat crop yield was higher in ZTW than CTW. Among the CA treatments, the direct-seeded rice (DSR) + mungbean residue (MR) – ZTW + rice residue (RR) – zero till summer mungbean (ZTSMB) + wheat residue (WR), and DSR – ZTW – ZTSMB resulted in higher values of yield attributes (spike no./m^2, grain/ spike) and yield of wheat. The increase in wheat yield due to the DSR + MR – ZTW + RR –ZTSMB + WR was 17.9 and 18.4%, respectively in 2012-13 and 2013-14 over that in TPR–CTW. The sequential applications of pre-emergence pendimethalin 1.0 kg/ha at 2 days after sowing (DAS) and post-emergence sulfosulfuron 25 g/ha at 30 DAS resulted in an effective control of weeds, irrespective of zero till (ZT) and conventional till (CT) conditions and gave significantly higher yield attributes and yield of wheat. This study provides information on better soil microbial health and higher wheat productivity under CA practices compared to CT conditions through effective weed control in rice-wheat cropping system. The recommendation may be adopted in the Indo-Gangetic plains of India with similar climatic and edaphic conditions.

Key words: Conservation agriculture, Conventional tillage, Microbial activity, Wheat, Weeds, Zero tillage

Rice (*Oryza sativs* L.)-wheat (*Triticum aestivum* L.) cropping system is the most important cropping system in India and the backbone of food security in South-east Asia. It spreads over 26 million ha (m ha) in South-east Asia and in 13.5 m ha area in the Indo-Gangetic plains (IGP) (Gupta and Seth 2007). It covers around 10.5 m ha in the IGPs of India. The rice-wheat cropping system feeds around 8% of the world's population (Saharawat *et al.* 2010). But, recently, gradual resource degradation, increasing cost of cultivation, and declining factor productivity question about the sustainability of this system. In conventional tillage, usual delay in sowing of wheat results in yield losses and subject to disease infestation. Zero till wheat (ZTW) with rice residue retention could be alternate conservation agriculture (CA)-based option for conventionally till wheat in the rice-wheat system. Zero tillage skips field preparation for sowing and reduces the cost of tillage operations for wheat. It increases crop productivity and resource-use efficiency, provides time for early sowing and subsequently increases crop yield (Das *et al*. 2014a). But, weeds are most important constraint under both CT and ZT conditions, which can reduce wheat yield up to 60.5% under CT and 70% under ZT conditions (Jain *et al.* 2007). Weeds as hosts harbour pests and increase the cost of weed control. The CA practices can result in weed species diversity and dynamics (Das and Yaduraju 2012, Tuti and Das 2011). Weed management, however, has received least attentions under CA systems.

Herbicide application is the major option for weed control under ZT conditions (Nath *et al.* 2016). Herbicides

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use may pose non-target and residual toxicities, health hazards and environmental risks (Susha *et al.* 2018). Continuous use of herbicides leads to resistance development in weeds, for example, *Phalaris minor* developed resistance to isoproturon and cross-resistance to clodinafop-propargyl, fenoxaprop-ethyl, diclofop-methyl etc in India (Das *et al.* 2014b). Herbicides and tillage systems offer great impact on soil micro-flora and fauna. The physico-chemical condition of soil under CA differs from the conventional systems. While minimum tillage/no tillage favours better microbial activity (Pankhurst *et al.* 2002), soil disturbance and herbicides offer negative impacts on soil micro-flora and fauna and reduce their activity (Das *et al*. 2010). Soil micro-organisms are the bio-indicator of sustainable system, play a vital role in nutrient cycling, improve soil health and maintain ecosystems functions. Therefore, this experiment was undertaken to provide effective weed management options in wheat without jeopardizing the soil microbial activity under a CA-based rice-wheat system.

MATERIALS AND METHODS

The experiments were conducted at the Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi (28°35′ N latitude, 77°12′ E longitude and at an altitude of 228.6 m above mean sea level) during 2012-13 and 2013-14. The objectives were to evaluate the effects of CA and weed management practices on weed interference, microbial activity and wheat crop productivity in a three-year old CA-based rice–wheat system. Soil belonged to order Inceptisols with sandy clay loam texture in upper 30 cm layer. Water table remained below 3.5 m deep from the ground surface during crop-growing period. The soil was low in available N (170.6 kg/ha), and medium in available P (18.6 kg/ha) and organic carbon (0.6%). The experiment was laid out in a split plot design with CA practices adopted in main plots and weed control measures in sub-plots with three replications. The main and sub-plot sizes were 42.0 m × 4.0 m and 4.2 m × 4.0 m, respectively. Crop cultivars were PRH 10 (for rice); HD 2894 (for wheat); and SML 668 (for summer mungbean). In main plots, eight 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- summer mungbean (ZTSMB), DSR + mungbean residue (MR) - ZTW + RR - ZTSMB + wheat residue (WR), transplanted puddled rice (TPR) - ZTW and TPR - CTW. Three weed control options assigned to the sub-plots were: single application of pre-emergence pendimethalin @ 1.0 kg/ha at 2 DAS; pre-emergence pendimethalin @ 1.0 kg/ha at 2 DAS followed by (*fb*) post-emergence sulfosulfuron @ 25 g/ha at 30 DAS; and unweeded control (UWC). Weeds were allowed to grow throughout crop-growing season under the UWC. Wheat was directly drilled into soil in the respective plots with or without residue retention using a Happy Seeder. In conventional tillage after rice, field was ploughed with disk plough followed by cultivator and planking. Summer mungbean was grown only in two treatments under zero till conditions with and without wheat residue using a happy seeder. Nitrogen, P and K were applied to wheat as per recommendations.

The observations on weed populations and dry matter accumulations were made at 70 DAS. A quadrat (0.25 m^2) was randomly placed in each plot and individual weed species were counted, collected, sun-dried for 2 days and kept in an oven at 70±5^{0}C for 48 h for recording dry weights. Weed control efficiency (WCE), which determines a treatment's efficiency for reducing the density of weeds was determined using equation 1 (Das *et al.* 2010).

$$WCE\ (\%) = [\{(WPc - WPt) \times 100\} \ / \ WPc] \quad (1)$$

where, WP_c and WP_t are weed density (no. m^{-2}) at UWC and treated plots, respectively.

Weed index (WI), differently known as yield losses (%) across the treatments compared with that in weed-free control was calculated using equation 2 (Das *et al.* 2010).

$$\mathrm{WI}\ (\%) = [\{(\mathrm{Ywf} - \mathrm{Yt}) * 100\} \ / \ \mathrm{Ywf}] \quad (2)$$

where, Y_{wf} and Y_t are wheat yields in weed-free control and treatment, respectively.

Microbial biomass carbon (MBC) and soil dehydrogenase activity (DHA) were studied at 70 DAS as per Paul *et al.* (2009). For this, five 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 sieve and DHA was determined. MBC was determined using chloroform fumigation extraction method.

Data on weed density and weed dry matter was transformed through square-root ($\sqrt{x+0.5}$) method. Data on crop and weeds were analyzed in a split plot design. The significance was tested by the variance ratio (F-value) at 5% level (Gomez and Gomez, 1984). Standard error (SE) and critical difference (CD) were worked out for comparing treatment means of the studied variables of crop and weeds.

RESULTS AND DISCUSSION

Effects on composite weeds

The major weed flora in experimental wheat field comprised of grasses, namely *Phalaris minor* Retz., *Cynodon dactylon* (L.) Pers.; sedge, namely, *Cyperus rotundus* L.; and broad-leaved weeds, namely, *Chenopodium album* L., *Coronopus didymus* (L.) Smith, *Melilotus indica* (L.) All., *Circium arvense* (L.) Scop, *Spergula arvensis* L., and *Anagallis arvensis* L. Broad-leaved weeds were more dominant than grassy and sedge weeds in wheat (Dodamani and Das 2013). CA practices influenced weeds spectrum and distribution. During the second year (2013-14), the density of grassy and broad-leaved weeds were lower (Table 1) compared to that in first year (2012-13). The densities of grassy and broad-leaved weeds as well as total weed were significantly higher in wheat under the conventional rice-wheat cropping system (i.e. TPR - CTW/ZTW plots), where previous rice was grown in transplanted puddled conditions (Tables 1 and 2). Singh *et al.* (2012) reported

Table 1 Category-wise weed density at 70 DAS in wheat as influenced by conservation agriculture and weed control practices

Treatment	Grassy weed (no./m^2)*		Broad-leaved weed (no./m^2)*		Sedge (no./m^2)*	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CA practices						
DSR-ZTW	3.2 (10.9)	2.0 (4.1)	3.6 (14.1)	2.5 (6.6)	1.0 (0.7)	1.2 (1.0)
DSR-ZTW+RR	2.2 (5.2)	1.9 (3.3)	3.2 (10.9)	2.2 (4.8)	1.0 (0.8)	1.1 (0.7)
DSR+BM-ZTW	3.1 (11.1)	2.0 (3.8)	3.5 (13.8)	2.4 (5.9)	0.8 (0.2)	0.8 (0.2)
DSR+BM-ZTW+RR	2.3(6.1)	1.6 (2.3)	2.9 (9.7)	2.0 (4.2)	0.9 (0.3)	0.9 (0.4)
DSR-ZTW-ZTSMB	3.0 (10.0)	2.2 (4.8)	3.2 (11.0)	2.3 (5.2)	1.5 (2.1)	1.5 (2.1)
DSR+MR-ZTW+RR-ZTSMB+WR	2.6 (7.3)	2.1 (4.3)	2.5 (7.3)	2.1 (4.4)	1.5 (2.0)	1.6 (2.3)
TPR-ZTW	3.3 (11.4)	2.3 (5.0)	3.7 (14.0)	3.1 (10.2)	0.9 (0.3)	1.0 (0.7)
TPR-CTW	3.5(12.4)	2.2 (4.7)	4.6 (23.0)	3.3 (11.2)	0.9 (0.3)	1.0 (0.7)
SEm±	0.2	0.1	0.2	0.1	0.1	0.1
CD (P=0.05)	0.6	0.4	0.7	0.3	0.2	0.4
Weed control (WC) practices						
UWC	4.0 (16.2)	2.7 (6.8)	4.6 (21.6)	3.4 (11.8)	1.4 (1.8)	1.4 (1.8)
Pendimethalin	3.0 (9.0)	2.0 (3.8)	3.7 (14.0)	2.5 (5.2)	1.0 (0.5)	1.1 (0.8)
Pendimethalin fb$^+$ sulfosulfuron	1.7 (2.8)	1.4 (1.6)	1.9 (3.3)	1.6 (2.1)	0.8 (0.3)	0.9 (0.4)
SEm±	0.1	0.1	0.1	0.1	0.1	0.1
CD (P=0.05)	0.3	0.2	0.3	0.2	0.2	0.2
CA × WC						
SEm±	0.3	0.2	0.3	0.2	0.2	0.2
CD (P=0.05)	NS	NS	NS	NS	NS	NS

*Data were transformed through square-root ($\sqrt{x+0.5}$) method. Original values are in the parentheses. + fb; followed by

that CT conditions considerably influenced the emergence of weeds, and after puddled rice, weed emergence was more in CTW. Malik *et al.* (2002) reported that, under ZT conditions, weed infestation was less due to minimum soil disturbance. Sedge population was significantly higher in triple cropping system-based ZTW, irrespective of the residue and no residue conditions (i.e., DSR + MR – ZTW + RR –ZTSMB + WR and DSR – ZTW – ZTSMB), where mungbean was grown during summer under ZT conditions. Summer mungbean favoured the infestation of perennial weeds like *Cyperus* spp. during hot summer months, mainly, through providing shed and moisture for their survival and proliferation. Rice residue retentions reduced the emergence of weeds in respective ZTW plots (Table 1). The DSR – ZTW + RR resulted in lower grassy weed density in first year, but the DSR + BM – ZTW + RR recorded lower grassy weeds in second year. The DSR + BM – ZTW + RR also recorded significantly lower broad-leaved weed density in both year, but the treatment DSR +MR – ZTW + RR– ZTSMB +WR was comparable. Again, the category-wise (Table 1) and total weed (Table 2) densities were significantly lower in the residue-retained plots. Susha *et al.* (2018) reported similar results in maize-wheat system. Residue retentions on the surface provided a physical barrier for the emergence of weeds, which suppressed weed infestations. Also, allelochemicals released from the surface-laden residues could play roles on the reduction in weed growth (Weston 1996).

In general, the UWC resulted in significantly higher infestations of grassy, broad- leaved and sedge weeds as well as total weed in both years (Das and Yaduraju 2011). Among the weed control treatments, the pre-emergence pendimethalin followed by (fb) post-emergence sulfosulfuron resulted in significantly lower populations of grassy, broad-leaved and sedge weeds compared to UWC and single application of pendimethalin. Single application of pendimethalin controlled emerging weeds and reduced crop their interference at the early stage, but not at latter stages, which culminated into higher weed population in this treatment. But, the pre-emergence pendimethalin fb post-emergence sulfosulfuron effectively controlled weeds throughout the crop-growing period, and resulted in lower densities of grassy and broad-leaved weeds and higher weed control efficiency (Chhokar and Malik 2002). Interaction between CA and weed control practices was non-significant for category-wise weed densities as well as total weed densities. But, in second year 2013-14, interaction was significant in case of total weed density. The weed control efficiency (WCE) provides per cent control of weeds, and weed index (WI) shows per cent yield losses due to weeds.

Table 2 Total weed density, weed control efficiency (WCE) at 70 DAS and weed index (WI) in wheat as influenced by conservation agriculture and weed control practices

Treatment	Total weed density (no./m^2)*		Weed control efficiency (%)		Weed index (%)‡	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CA practices						
DSR-ZTW	4.8(25.7)	3.3(11.7)	28.2	31.1	6.6	7.9
DSR-ZTW+RR	3.9(16.9)	3.0(8.8)	29.5	21.1	6.5	7.8
DSR+BM-ZTW	4.7(25.1)	3.1(9.9)	28.4	24.4	7.5	8.0
DSR+BM-ZTW+RR	3.7(16.1)	2.6(7.0)	30.3	28.8	6.6	8.4
DSR-ZTW-ZTSMB	4.6(23.1)	3.4(12.1)	28.4	28.8	7.1	7.5
DSR+MR-ZTW+RR-ZTSMB+WR	3.9(16.7)	3.2(11.1)	29.7	28.9	7.1	6.9
TPR-ZTW	4.9(25.8)	3.9(15.9)	21.3	25.5	7.4	8.4
TPR-CTW	5.7(35.8)	3.9(16.6)	24.5	26.8	8.7	8.9
SEm±	0.2	0.1	3.1	2.9	0.6	0.6
CD (P=0.05)	0.7	0.4	NS	NS	NS	NS
Weed control (WC) practices						
UWC	6.3(39.5)	4.5(20.3)	0.0	0.0	17.0	18.7
Pendimethalin	4.8(23.5)	3.3(10.4)	22.4	27.2	4.7	5.2
Pendimethalin fb sulfosulfuron	2.5(6.4)	2.1(4.2)	60.2	53.6	0.0	0.0
SEm±	0.1	0.1	1.7	1.4	0.4	0.4
CD (P=0.05)	0.3	0.2	4.9	4.0	1.1	1.1
CA × WC						
SEm±	0.3	0.2	4.8	3.9	1.1	1.1
CD (P=0.05)	NS	0.5	NS	NS	NS	NS

*Data were transformed through square-root ($\sqrt{x+0.5}$) method. Original values are in the parentheses. ‡For calculation of WI pendimethalin fb sulfosulfuron was taken as weed free check. Although it was not weed free check but it was as good as weed-free check.

The CA treatments did not differ significantly with respect to WCE and WI, but the weed control options differed significantly (Table 2). The pre-emergence pendimethalin fb post-emergence sulfosulfuron provided higher WCE and, in turn, lower WI compared to pendimethalin alone in both years (Nath *et al*. 2016). Considering the pre-emergence pendimethalin fb post-emergence sulfosulfuron as control for determining WI, wheat yield losses were 17 and 18.7% due to UWC, and 4.7 and 5.2% due to single application of pendimethalin, respectively in 2012-13 and 2013-14. These yield losses were significantly higher from that of the pre-emergence pendimethalin fb post-emergence sulfosulfuron treatment.

Soil microbial activities

In wheat, microbial biomass carbon (MBC) and dehydrogenase activity (DHA) were significantly influenced by tillage operations and residue retentions (Table 3). The values of MBC and DHA were higher in ZTW practices than that in CTW. Significantly higher DHA and MBC were recorded with the DSR + MR – ZTW + RR –ZTSMB + WR, followed by the DSR – ZTW – ZTSMB. But, the soil MBC and DHA were significantly lower with TPR – CTW/ ZTW than in other CA treatments. Sharma *et al.* (2012) reported that soil DHA and MBC were higher under no-till conditions. Among CA practices, compared to no residue plots, residue retained plots (i.e., DSR + MR – ZTW + RR –ZTSMB + WR, DSR + BM – ZTW + RR and DSR – ZTW + RR) resulted in significantly higher values of MBC and DHA. Residue retention on the surface, which moderates soil temperature and provides adequate moisture in soil for longer period, could influence microbial activity. It also provides steady source of carbon and energy to microbes (Pankhurst *et al.* 2002).

Among the weed control measures, UWC resulted in slightly higher values of MBC and DHA than those obtained in pendimethalin alone, and pendimethalin fb sulfosulfuron treatments, but the values were not significantly different from that in herbicide treated plots. Initially herbicide applications inhibit microbes and their activity, but at latter stage, increase the activity of microbes (Balasubramanian and Sankaran 2001). UWC had higher weed density and root biomass, which resulted in slight increment in microbial activity (Wardle *et al.* 1999).

Wheat yield attributes and yield

In general, all CA-based treatments showed improvement in yield attributes and yield over conventional practices (Table 4). ZTW performed better than CTW during both 2012-13 and 2013-14 (Susha *et al.* 2018). Wheat yield

Table 3 Microbial biomass carbon (MBC) and dehydrogenase activity (DHA) at 70 DAS as influenced by conservation agriculture and weed control practices

Treatment	MBC (µg C/g soil)		DHA (µg TPF* /g soil/h)	
	2012-13	2013-14	2012-13	2013-14
CA practices				
DSR-ZTW	168.3	194.0	70.6	72.2
DSR-ZTW+RR	181.0	215.2	77.4	86.0
DSR+BM-ZTW	169.5	205.3	71.2	78.8
DSR+BM-ZTW+RR	206.9	238.7	81.7	87.9
DSR-ZTW-ZTSMB	211.5	252.3	87.9	94.7
DSR+MR-ZTW+RR-ZTSMB+WR	217.6	260.1	90.2	99.1
TPR-ZTW	162.3	176.0	65.6	67.7
TPR-CTW	146.8	169.1	56.8	61.2
SEm±	3.3	5.0	2.6	3.8
CD (P=0.05)	10.1	15.3	8.0	11.6
Weed control (WC) practices				
UWC	188.3	216.7	78.2	86.1
Pendimethalin	182.4	213.0	74.2	80.1
Pendimethalin fb sulfosulfuron	178.2	211.8	73.1	76.6
SEm±	3.5	3.2	2.1	2.9
CD (P=0.05)	NS	NS	NS	NS
CA × WC				
SEm±	9.9	8.9	5.8	8.2
CD (P=0.05)	NS	NS	NS	NS

* TPF-Triphenylformazan

attributes (namely, spike no./m^2 and grains/spike) and yields (grain and straw yields) were higher in ZTW practices than in CT conditions. However, 1000-grain weight of wheat was not affected by tillage, residue retention and weed control practices. Residue retention further increased wheat yield under ZT conditions (Table 4). Treatments with residue retention (i.e. DSR + MR – ZTW + RR –ZTSMB + WR, DSR + BM – ZTW + RR and DSR – ZTW + RR) resulted in higher yield attributes and yields compared with their respective treatments without residues. Govaerts *et al.* (2005) reported increment in crop yield due to residue retention/ incorporation. Residue retention reduced weed emergence and their competitions, which resulted in higher wheat yield (Tables 1, 2 and 4). Besides, ZT and rice residue retentions had favourable effects on wheat crop growth and development. Cumulative addition of summer mungbean residue in rice and rice residue in wheat led to favourable residual effects on wheat, which significantly influenced wheat yield (Singh *et al.* 2003). Significantly lower wheat yield was recorded in TPR – CTW/ZTW, where previous rice crop was grown under puddled condition. Poor field conditions in TPR – CTW/ZTW, which was cloddy even after 2 ploughings and 2 harrowings after puddled rice and quickly drying surface soil led to poor wheat crop stand and resulted in lower crop yield (Erenstein and Laxmi 2008). The increase in yield due to the DSR + MR – ZTW + RR –ZTSMB + WR was 17.9 and 18.4%, respectively in 2012-13 and year 2013-14 over that in TPR–CTW.

Wheat grain and straw yields differed significantly between the weed control treatments in both years. The sequential application of pendimethalin fb sulfosulfuron, through better weed control (i.e. grassy and broad-leaved weeds control) resulted in higher wheat yield over single pendimethalin application and UWC treatments (Chhokar and Malik 2002).On the contrary, higher weed interference in UWC from the beginning of crop emergence, and at the later stages in the pendimethalin alone treatment, reduced wheat yields. More reduction in weed interference compared to that in first year (2012-13) led to better growth and higher yield of wheat in second year (2013-14) (Tables 1, 2 and 4). The pendimethalin fb sulfosulfuron increased wheat grain yield by 20 and 23% over that in UWC in 2012-13 and 2013-14, respectively. The findings of Nath *et al.* (2016) corroborated our results.

Regression analysis

The spike (no./m^2) and grain yield of wheat were negatively correlated with weed dry matter in both years (Fig 1a, 1b, 1c and 1d). Higher the weed biomass, greater were the reductions in number of spike and grain yield and *vice-versa* (Dodamani and Das 2013). However, the number of spike was positively correlated with grain yield (Fig 1e and 1f).

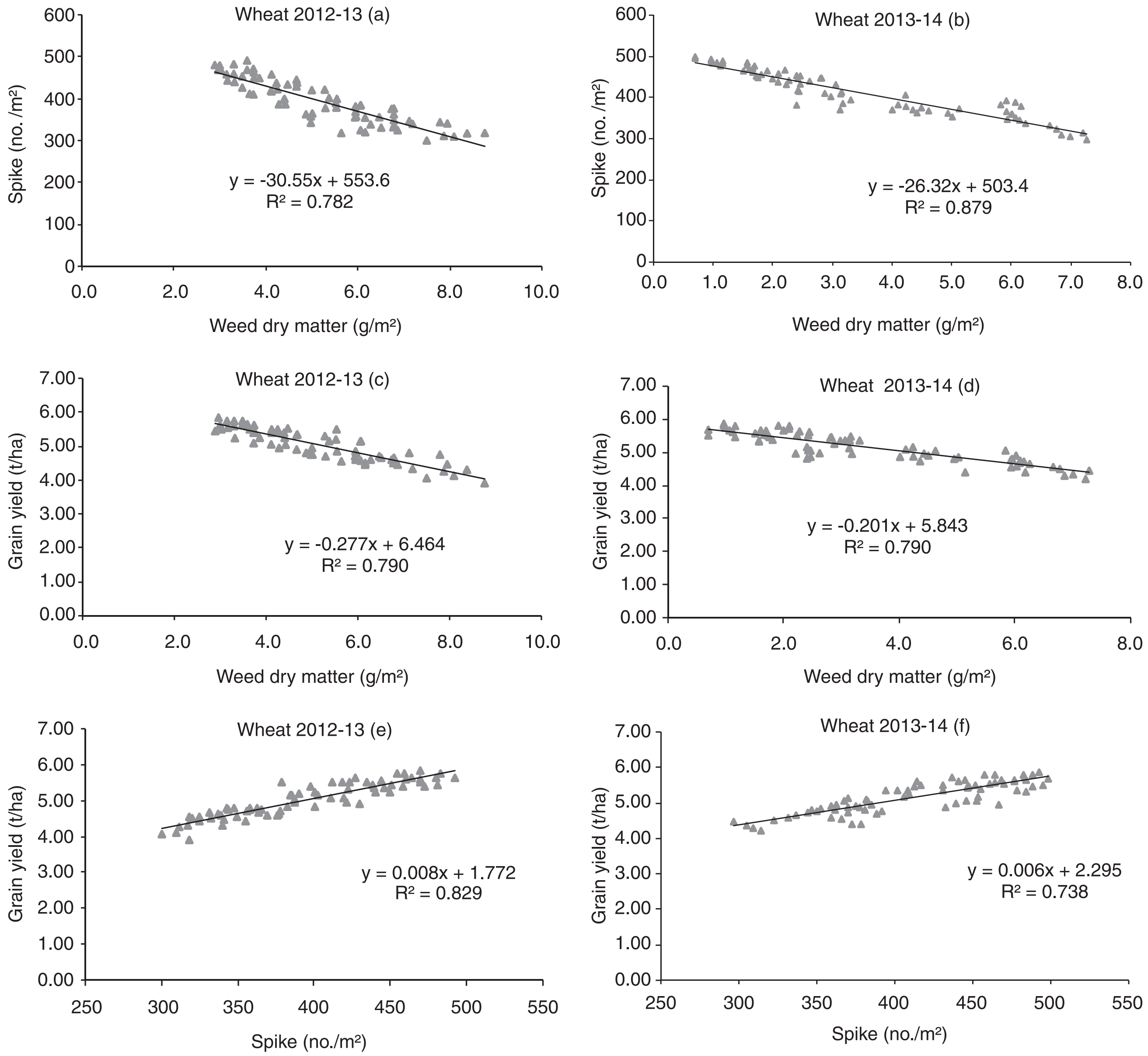

Fig 1 Relationship between weed dry matter and spikes no./m^2 in 2012-13 (a) and 2013-14 (b); weed dry matter and wheat grain yield in 2012-13 (c) and 2013-14 (d); and spikes no./m^2 and wheat grain yield in 2012-13 (e) and 2013-14 (f) as influenced by conservation agriculture and weed control practices (based on 72 observations). Weed dry matter were transformed through square-root ($\sqrt{x+0.5}$) method.

Table 4 Yield attributes and yield of wheat as influenced by conservation agriculture and weed control practices

Treatment	Spike (no./m^2)		Grains/ spike (no.)		1000-grains weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
CA practices										
DSR-ZTW	395.2	402.9	58.7	59.3	42.3	43.7	5.14	5.17	7.22	7.26
DSR-ZTW+RR	385.1	418.0	58.1	59.7	42.2	43.8	4.95	5.27	7.05	7.34
DSR+BM-ZTW	387.4	410.1	58.3	59.1	42.2	43.5	5.07	5.19	7.12	7.21
DSR+BM-ZTW+RR	408.5	430.3	59.7	60.9	42.7	43.4	5.17	5.36	7.41	7.48
DSR-ZTW-ZTSMB	418.8	437.8	62.2	62.2	43.4	43.7	5.25	5.43	7.48	7.56
DSR+MR-ZTW+RR-ZTSMB+WR	429.0	441.4	62.7	62.4	43.7	43.8	5.36	5.48	7.53	7.59

Contd.

Table 4 (*Concluded*)

Treatment	Spike (no./m^2)		Grains/ spike (no.)		1000-grains weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
TPR-ZTW	367.0	386.1	53.4	56.0	41.5	42.8	4.71	4.75	6.86	6.96
TPR-CTW	359.0	374.6	52.9	55.6	41.2	42.7	4.58	4.63	6.60	6.72
SEm±	3.6	3.0	2.1	1.4	0.6	0.6	0.04	0.03	0.04	0.03
CD (P=0.05)	10.9	9.1	6.5	4.1	NS	NS	0.13	0.1	0.1	0.1
Weed control (WC) practices										
UWC	336.2	351.2	57.2	58.8	42.1	43.2	4.50	4.56	6.84	6.73
Pendimethalin	395.0	416.5	58.4	59.5	42.3	43.5	5.17	5.32	7.21	7.35
Pendimethalin fb sulfosulfuron	450.0	470.3	59.1	60.0	42.8	43.6	5.42	5.61	7.42	7.71
SEm±	1.9	1.8	0.8	0.9	0.3	0.3	0.02	0.02	0.02	0.02
CD (P=0.05)	5.3	5.2	NS	NS	NS	NS	0.06	0.1	0.1	0.1
CA × WC										
SEm±	5.2	5.1	2.2	2.5	1.0	0.9	0.1	0.1	0.1	0.1
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	0.2	0.2

This implied that the number of spike was the determining factor for yield. The wheat grain yield reductions, whatever have resulted in this study over the years, were through significant reductions in number of spikes/m^2, which was, again, due to higher weed interference.

The studies showed that zero tillage was more beneficial than conventional tillage towards reduction in weed interference. The effect was further improved with the retention of residue in zero till conditions. Microbial parameters (MBC and DHA) were considerably improved due to residue retention in ZTW. A CA-based direct-seeded rice + mungbean residue – zero till wheat + rice residue–zero-till summer mungbean + wheat residue resulted in significantly higher yield attributes and yields of wheat. The sequential application of pendimethalin @ 1.0 kg/ha as pre-emergence fb sulfosulfuron @ 25 g/ha as post-emergence was more effective against grassy, broad-leaved and total weeds compared to single pendimethalin application. Therefore, the CA-based direct-seeded rice + mungbean residue – zero till wheat + rice residue–zero-till summer mungbean + wheat residue combined with pendimethalin fb sulfosulfuron may be recommended for better weed suppression and higher wheat yield in the North-western IGPs of India.

REFERENCES

Balasubramanian K and Sankaran S. 2001. Effect of pendimethalin on soil microorganisms. *Indian Agriculturist* **45**(1-2): 93–8.

Chhokar R S and Malik R K. 2002. Isoproturon resistant *Phalaris minor* and its response to alternate herbicides. *Weed Technology* **16**: 116–23.

Das T K and Yaduraju N T. 2011. Effects of missing-row sowing supplemented with row spacing and nitrogen on weed competition and growth and yield of wheat. *Crop and Pasture Science* **62**(1): 48–57.

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): 311–20.

Das T K, Ahlawat I P S and Yaduraju N T. 2014b. Littleseed canarygrass (*Phalaris minor*) resistance to clodinafop-propargyl in wheat fields in north-western India: Appraisal and management. *Weed Biology and Management* **14**(1): 11–20.

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): 315–25.

Das T K, Bhattacharyya R, Sudhishri S, Sharma A R, Saharawat Y S, Bandyopadhyay K K, Sepat S, Bana R S, Aggarwal P, Sharma R K, Bhatia A, Singh G, Kar A, Singh Billu, Singh P, Pathak H, Vyas A K and Jat M L. 2014a. Conservation agriculture in an irrigated cotton-wheat system of the western Indo-Gangetic Plains: crop and water productivity and economic profitability. *Field Crops Research* **158**: 24–33.

Dodamani B M and Das T K. 2013. Density and nitrogen effects on interference and economic threshold of common lambsquarters in wheat. *Journal of Pest Science* **86**: 611–9.

Erenstein O and Laxmi V. 2008. Zero tillage impacts in India's rice–wheat systems: A review. *Soil and Tillage Research* **100**: 1–14.

Gomez K A and Gomez A A. 1984. *Statistical Procedures for Agricultural Research,* 2nd ed. Pp 591. Johns and Sons, New York.

Govaerts B, Sayre K D and Deckers J. 2005. Stable high yields with zero tillage and permanent bed planting? *Field Crops Research* **94**: 33–42.

Gupta R and Seth A. 2007. A review of resource conserving technologies for sustainable management of the rice-wheat cropping systems of the Indo-Gangetic plains (IGP). *Crop Protection* **26** (3): 436−47.

Jain N, Jain V, Mishra J S and Kewat M L. 2007. Effect of tillage packages and herbicides on energy and economics of wheat in transplanted rice (*Oryza sativa*)-wheat (*Triticum* *aestivum*) system. *Indian Journal of Agricultural Sciences* **77**(3): 174–6.

Malik R K, Yadav A, Singh S, Malik R S, Balyan R S, Banga R S, Sardana P K, Jaipal S, Hobbs P R, Gill G, Singh S, Gupta R K, Bellinder R. 2002. *Herbicide Resistance Management and Evolution of Zero-tillage—A Success Story.* Research Bulletin, CCSHAU, Hisar, India, 43pp.

Nath C P, Das T K and Rana K S. 2016. Effects of herbicides and tillage practices on weeds and summer mungbean (*Vigna radiata*) in wheat (*Triticum aestivum*)-mungbean cropping sequence *Indian Journal of Agricultural Sciences* **86**(7): 860–4.

Pankhurst C E, Mc Donald H J, Hawke B G and Kirkby C A. 2002. Effect of tillage and stubble management on chemical and microbiological properties and the development of suppression towards cereal root disease in soils from two sites in NSW, Australia. *Soil Biology and Biochemistry* **34**: 833–40.

Paul S, Prasanna R, Lata and Wattal Dhar D. 2009. *A Manual for Agricultural Microbiologists*. Division of microbiology, Indian Agricultural Research Instituite, New Delhi, pp 27–8

Saharawat Y S, Singh B, Malik R K, Ladha J K, Gathala M, Jat M L and Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. *Field Crops Research* **116**: 260–7.

Sharma M P, Gupta S, Sharma S K and Vyas A K. 2012. Effect of tillage and crop sequences on Arbuscular Mycorrhizal symbiosis and soil enzyme activities in soybean (*Glycine max*) rhizosphere. *Indian Journal of Agricultural Science*s **82**(1): 25–30.

Singh A, Kaur R, Kang J S and Singh G. 2012. Weed dynamics in rice–wheat cropping system. *Global Journal Biology and Agricultural Health Science* **1**: 7–16.

Singh G, Singh Y, Singh V P, Singh R K, Singh P, Johnson D E, Mortimer M and Orr A. 2003. Direct seeding as an alternative to transplanted rice for the rice–wheat system of the Indo-Gangetic plains: sustainability issues related to weed management, Proceedings of the BCPC Conference -*Weeds* **2** pp 1035–40.

Susha V S, Das T K, Nath C P, Pandey R, Paul S and Ghosh S. 2018. Impacts of tillage and herbicide mixture on weed interference, agronomic productivity and profitability of a maize – wheat system in the North-western Indo-Gangetic Plains. *Field Crops Research* **219**: 180–91.

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): 121–6.

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): 1707–20.

Weston L A. 1996. Utilization of allelopathy for weed management in agro ecosystems. *Agronomy Journal* **88**: 860–6.