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Effect of tillage sequence and weed management on weed dynamics and productivity of dry-seeded rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system

J.S. MISHRA[1] AND V.P. SINGH[2]

Directorate of Weed Science Research, Maharajpur, Jabalpur, Madhya Pradesh 482 004

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ABSTRACT

A field experiment was conducted during 2006-07 to 2008-09 at Jabalpur to study the effect of four tillage sequences [zero-till planting of both the crops (ZT-ZT), conventional planting in both the crops (CT-CT), and two rotational tillage sequences that altered between zero-till and conventional tillage (ZT-CT and CT-ZT)] and three weed control treatments (weedy check, herbicide alone, and herbicide + 1 hand weeding at 35 days after sowing) on weed dynamics, tillage economy and productivity of dry-seeded rice (*Oryza sativa* L.)-wheat [(*Triticum aestivum* (L.) emend Fiori & Paol)] system on a clay-loam soil. Results revealed that continuous zero tillage increased the population density of *Echinochloa colona* (L.) Link (jungle rice) and *Cyperus iria* L. (rice flat sedge), the most dominant weeds of rice. In subsequent wheat crop, zero tillage reduced the population of *Avena ludoviciana* (L.) Dur. (wild oats) and *Chenopodium album* L. (common lambsquarters) but increased the density of *Medicago hispida* Gaertn. (burclover) as compared to other tillage systems. Rotational tillage systems had variable effects on weed density in rice and wheat. Pendimethalin (1.0 kg/ha) *fb* 2, 4-D (0.50 kg/ha) significantly reduced the population density of *E. colona*, *C. iria* and *Alternanthera sessilis* (L.) D.C. (sessile joyweed) but failed to control *Caesulia axillaris* Roxb. (pink node flower) in rice. In subsequent wheat, clodinafop propargyl alone significantly reduced the population of *A. ludoviciana*, but *M. hispida* was unaffected even with integration of herbicide with 1 hand weeding. Continuous zero tillage yielded 25.1 and 15.4% higher grain yields of rice and wheat respectively, than that of conventional tillage regardless to weed control methods. Continuous zero tillage with recommended herbicide + 1 hand weeding recorded the maximum net returns (₹73.87 × 10^3/ha) and B: C ratio (3.81) in direct-seeded rice-wheat system.

***Key words*:** Economics, Herbicides, Rice-wheat system, Tillage, Weeds, Yield

In recent years, the major emphasis in the rice-wheat system has been on alternative resource conservation technologies for both rice and wheat to reduce the cost of cultivation and energy consumption, to sustain productivity, and to increase the profit margin of farmers (Singh *et al.*, 2006). Change in rice establishment method from traditional manual transplanting of seedlings to direct-seeding has occurred in many Asian countries in the last two decades in response to rising production costs, especially for labour and water (Chauhan and Johnson, 2009). Weed infestation, however continues to be a major bottleneck in dry-seeded rice. The weed problems may further be increased if dry seeding of rice is done with zero tillage. In India, zero tillage in wheat after rice has become a reality and is being followed on nearly 2.1 million ha area in IGP (Yadav *et al.*, 2009). As the direct-seeding of rice facilitates timely sowing of wheat, even a slight loss in rice productivity is compensated by increased wheat yields, implying no loss in system productivity. In fact, the tillage operations performed for growing rice should complement those practiced for growing wheat and *vice-versa*. It is the overall system productivity that should be considered while judging the suitability of a practice (Bhushan *et al.*, 2007).

The tillage sequence with in a crop rotation is often unrecognized as a rotational component, but like crop rotations, the sequence may reduce weeds and other pests in annual cropping systems if managed properly (Carter, 1994). Rotational tillage effects on weed populations have received very little attention, but could be used to reduce populations of troublesome species (Peachey *et al*., 2006). Less effort has been made at managing weed populations by imposing divers and designed tillage sequences within crop rotations. Hence, the present investigation was undertaken to find out the effect of tillage sequences and weed

[1]**Corresponding author Email:** jsmishra31@gmail.com
[1]Principal Scientist, Directorate of Sorghum Research, Hyderabad; [2]Principal Scientist

management on weed dynamics and productivity of direct-seeded rice-wheat cropping system.

MATERIALS AND METHODS

The experiment was conducted at Directorate of Weed Science Research, Jabalpur (23^0 90' N, 79^0 58' E, and 412 m above mean sea level), India, during 2006-2009. The soil at the study site had a clay loam texture (Typic chromusterts) with pH 7.3 and E.C. 0.22. The organic carbon and available nitrogen, phosphorus and potassium were 0.54%, 238, 38 and 342 kg/ha, respectively. The experiment was initiated in June 2006 with rice crop after the harvest of wheat. The experimental design was a split-split plot with three replications. Main plot treatments were the four tillage sequences (Table 1) viz., zero tillage (ZT) in both the crops (ZT-ZT), conventional tillage (CT) in both the crops (CT-CT), and two rotational tillage sequences that alternated between CT and ZT (ZT-CT and CT-ZT) and sub-plot treatments were three weed control methods (weedy check, recommended herbicide and herbicide + 1 hand weeding at 35 days after sowing (DAS). Each sub-plot measured 4.5 × 10 m. Crops were either direct-seeded without soil tillage (zero tillage) or conventionally planted after the soil was tilled (conventional tillage). Conventional tillage consisted of tillage once with mouldboard plough, disked once with disc harrow and rototilled once with a vertical tine tiller to prepare a fine seedbed before planting the crops. Conventional-till crops were planted using conventional-till ferti-seed drill. Zero-till crops were planted by direct seeding into dead residue of the previous crop without field preparation using zero-till ferti-seed drill having inverted T-type furrow openers. Glyphosate at 1.0 kg/ha was applied 1 week before seeding in all the zero-till plots to kill the existing vegetation. Recommended herbicides {(pendimethalin at 1.0 kg/ha as pre-emergence followed by 2, 4-D (ethyl easter) at 0.50 hg/ha at 25 DAS in rice and clodinafop propargyl at 0.06 kg/ha at 25 DAS followed by 2, 4-D at 0.50 kg/ha at 30 DAS in wheat)} were applied with 500 litre/ha of water with help of knapsack sprayer, fitted with flat-fan nozzle.

Direct seeding of rice cultivar 'Kranti' was done in the third week of June with 80 kg/ha seed. All the plots received 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. Full dose of phosphorus and potassium and 1/3 of nitrogen were placed at 10 cm depth using ferti-seed drill (zero/conventional) at the seeding. Remaining 2/3 nitrogen was applied in two equal splits at mid tillering (35 DAS) and panicle initiation (60 DAS). The crop was irrigated twice at reproductive stage due to withdrawal of monsoon. Rice was harvested manually with sickle at a height of 10-15 cm from ground level in the last week of October. The wheat cultivar 'WH 147' was seeded at 120 kg/ha during third week of November each year. The crop received 120 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha. Half dose of nitrogen and full dose of phosphorus and potassium were applied basally at 10-cm depth using seed-cum-fertilizer drill (zero/conventional) at the time of seeding and the remaining nitrogen was applied in 2 equal splits at crown root initiation (CRI), and maximum tillering stages. The wheat was grown under irrigated condition. Total 5 irrigations ($\pm$ 5 cm) were applied at 20, 40, 70, 90 and 110 DAS. Wheat crop was harvested manually with sickle at a height of 5-7 cm from ground surface in the last week of March each year. Weed density and weed dry matter were recorded at 60 DAS from 1m^2 area by placing a quadrat of 50 cm by 50 cm randomly at four places in each plot.

The cost of cultivation was calculated by taking into account the prevailing market prices of inputs. The returns were calculated by using minimum support price of rice (₹8.50/kg) and wheat (₹10.80/kg) for 2008-09. All the data on weed density and weed dry matter values, yield and yield parameters of rice and wheat, and economics were analyzed with Statistix 8.1 for analysis of variance (ANOVA). The significant differences between treatments were compared pare-wise by critical difference at 5% level of probability.

RESULTS AND DISCUSSION

Effect on weeds

Rice

The dominant weeds associated with rice were *Echinochloa colona* (L.) Link (jungle rice), *Cyperus iria* L. (rice flat sedge), *Caesulia axillaris* Roxb. (pink node flower) and *Alternanthera sessilis* (L.) D.C. (sessile joyweed). During 2008, due to prolonged initial water submergence *Ischaemum rugosum* Salisb. (wrinkle duck weed) and *Ammania baccifera* L. (blistering ammania) were observed as new weeds but in low density. At the conclusion of the experiment, the emergence of *E. colona* was greatly influenced ($P< 0.05$) by the tillage systems (Table 1). Continuous zero tillage (ZT-ZT) had greater maximum emergence than continuous conventional (CT-CT) and rotational tillage systems. Rotational tillage systems (ZT-CT and CT-ZT), however, had similar but significantly lower emergence than continuous ZT. Seedling emergence response of *C. iria* due to tillage systems was different between years. In 2006, ZT had lesser seedling emergence than CT while in 2008, the trend was reverse and continuous ZT had 141 % higher seedling emergence than continuous CT. Between two rotational tillage systems, CT in rice and ZT in wheat had 43% lower seedling emergence of *C. iria* than ZT in rice and CT in wheat, indicating that tilling land during rice season was more effective in reducing *C. iria* population than tilling during wheat season. Total weed population was also increased significantly under continuous ZT as compared to continuous CT. These results indicate that low-soil-disturbance systems are likely to leave a large portion of the weed seed rain on or near the soil surface, where light may stimulate seed germination, resulting in higher seedling emergence than high-soil-disturbance systems (Chauhan and Johnson, 2009). Pre-emergence application of pendimethalin (1.0 kg/ha) *fb* post-emergence application of 2, 4-D (0.50 kg/ha) significantly reduced the population density of *E. colona*, *C. iria* and *A. sessilis* than the weedy check. *C. axillaris* was however, not controlled by these herbicides. Pendimethalin was reported to give the best grass weed control (Singh *et al*., 2006) and found economical for dry-seeded rice.

Wheat

Weed population in wheat was recorded at 25 DAS (before applying weed control treatments) and at 60 DAS. The dominant weeds associated with wheat were *Avena ludoviciana* (L.) Dur. (wild oats), *Medicago hispida* Gaertn. (toothed burclover) and *Chenopodium album* L. (common lambsquarters). At 25 DAS, ZT wheat sowing (either continuous or rotated with conventional) significantly increased the population of *A. ludoviciana* than conventional (CT-CT or ZT-CT) tillage during 2006-07, but in subsequent years, continuous ZT reduced its population (Table 2). Tillage systems did not influence the emergence of *M. hispida* during 2006-07, while in subsequent years, rotational and continuous tillage systems significantly reduced its emergence than the continuous ZT system. Density of *C. album* was quite low as compared to other two weeds. Its seedling emergence declined significantly due to ZT wheat sowing in 2006-07. Mohler and Galford (1997) also reported lesser emergence of *C. album* in untilled soil than the tilled soil. In subsequent years, population of *C. album* was completely eliminated due to the increased density of *A. ludoviciana* in all the tillage systems. The initial (before applying weed control treatments) population of wild oat did not vary significantly during first year. It indicates that weed control treatments applied to preceding rice crop did not influence wild oats population in succeeding wheat crop. However in subsequent years, weed control either through herbicide alone or integrated with one hand weeding in previous wheat crop caused significant reduction in wild oats density as compared to weedy check (Table 2). This is mainly due to reduced wild oat seed rain in soil in herbicide treated plots. Medd (1990) also reported that input of new seed, not the carryover of seeds, is responsible for the marked fluxes in wild oats population. Application of herbicides alone or its integration with one hand weeding did

Table 1. Effect of tillage sequence and weed control on weed density (number/m^2) in dry-seeded rice at 60 days after sowing

Treatment	*Echinochloa colona*			*Caesulia axillaris*			*Cyperus iria*			*Alternanthera sessilis*			Total		
	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Tillage sequence															
ZT-ZT	6.1	10.5	43.3	27.3	6.9	6.6	28.3	8.7	70.3	16.7	10.4	0.92	78.4	36.5	131.1
ZT-CT	6.1	11.2	26.9	27.3	6.9	6.4	28.3	8.8	56.0	16.7	3.2	0.42	78.4	30.1	101.6
CT-ZT	5.3	7.4	12.8	31.7	3.2	9.8	44.1	5.2	31.7	20.3	3.0	0.92	101.4	18.8	60.8
CT-CT	5.3	8.8	5.3	31.7	3.2	6.2	44.1	9.1	28.5	20.3	2.1	0.42	101.4	23.2	43.5
SEm±	0.45	1.1	5.2	1.2	1.2	1.4	2.8	1.2	8.3	1.3	2.1	0.19	4.3	4.9	10.2
CD (P=0.05)	NS	3.4	15.5	3.8	3.5	NS	8.5	3.5	24.4	NS	6.4	NS	12.3	14.6	31.5
Weed control methods															
Recommended herbicide[a]	2.4	6.2	3.9	35.7	1.2	7.1	19.4	6.4	37.2	16.4	2.4	0.44	73.9	16.2	55.1
Herbicide + 1 HW at 35 DAS	3.4	2.1	1.9	15.6	12.4	9.4	22.2	9.6	33.9	22.8	0	1.25	64.0	24.1	53.6
Weedy check	12.9	27.2	60.4	40.1	3.2	5.2	74.8	7.4	68.8	31.3	15.2	0.31	159.1	53.0	144.2
SEm±	0.32	1.0	4.0	1.1	0.5	0.9	2.1	1.1	6.6	1.2	1.7	0.31	3.9	3.9	8.3
CD (P=0.05)	0.95	3.1	11.9	3.2	1.6	2.8	6.4	NS	19.9	3.6	5.4	NS	10.6	11.6	24.5

Pendimethalin 1.0 kg/ha as pre-em. *fb* 2,4-D 0.50 kg/ha; ZT: zero tillage; CT: conventional tillage not reduce the density of *M. hispida*. The higher population of *M. hispida* in herbicide + 1 hand weeding treatment might be due to the exposure of buried weed seeds to solar radiation due to hand weeding. The lowest population of *M. hispida* and *C. album* in weedy check was due to severe competition offered by increased density of *A. ludoviciana*.

At 60 DAS, the population of *A. ludoviciana* was significantly lower in continuous ZT than that of continuous CT system during initial year (Table 3). However in subsequent years, tillage systems did not have significant influence on its density. Tillage systems did not affect the population of *M. hispida* during first year. However, at the completion of the experiment, rotational tillage and continuous tilling significantly reduced its population than ZT-ZT system, indicating that rotational tillage could be an alternative to continuous tillage system to control *M. hispida* population. Application of recommended herbicide (clodinafop propargyl *fb* 2, 4-D) alone significantly reduced the population of *A. ludoviciana*, indicating that additional hand weeding is not required to manage its population. Scursoni *et al*. (2011) also reported effective control of wild oat in wheat with clodinafop. However, application of herbicide alone or its integration with one hand weeding did not control *M. hispida*.

Table 2. Effect of tillage sequence and weed control on weed density (number/m^2) in wheat before applying weed control treatment (25 DAS)

Treatment	*Avena ludoviciana*			*Medicago hispida*			*Chenopodium album*			Total		
	2006-07	2007-08	2008-09	2006-07	2007-08	2008-09	2006-07	2007-08	2008-09	2006-07	2007-08	2008-09
Tillage sequence												
ZT-ZT	159	330	397	95	191	324	3	0	0	257	521	721
ZT-CT	109	589	414	100	81	64	13	0	0	222	670	478
CT-ZT	184	467	420	92	77	92	2	0	0	278	544	512
CT-CT	114	602	459	87	125	69	6	0	0	207	727	528
SEm±	16	48	45	9	19	22	0.5			16	51	55
CD (P=0.05)	47	142	NS	NS	57	66	1.6			47	152	164
Weed control methods												
Recommended herbicide[a]	149	379	209	79	137	220	10	0	0	238	516	429
Herbicide + 1 HW at 35 DAS	150	386	111	115	177	127	6	0	0	271	563	238
Weedy check	124	743	948	85	50	64	3	0	0	212	793	1012
SEm±	10	37	41	7	7	16	0.5			12	46	43
CD (P=0.05)	NS	115	124	21	21	48	60			37	135	128

[a]clodinafop propargyl 0.06 kg/ha at 25 DAS *fb* 2,4-D at 0.50 kg/ha at 30 DAS
ZT: zero tillage; CT: conventional tillage

Table 3. Effect of tillage sequence and weed control on weed density (number/m^2) in wheat at 60 DAS

Treatment	*Avena ludoviciana*			*Medicago hispida*			Total		
	2006-07	2007-08	2008-09	2006-07	2007-08	2008-09	2006-07	2007-08	2008-09
Tillage sequence									
ZT-ZT	59	97	173	50	7.4	40	109	104	213
ZT-CT	72	95	112	55	4.8	13	127	100	125
CT-ZT	80	120	138	44	9.2	22	124	129	160
CT-CT	92	91	143	59	8.3	12	151	99	155
SEm±	5	10	24	5	1.1	5.1	10	9	26
CD (P=0.05)	15	31	72	NS	3.2	15.7	29	27	77
Weed control methods									
Recommended herbicide[a]	69	64	17	56	13.4	43	125	77	60
Herbicide + 1 HW at 35 DAS	64	43	10	56	18.3	9	120	61	19
Weedy check	93	198	398	44	0	13	137	198	411
SEm±	4	6	17	4	1.2	4.1			
CD (P=0.05)	13	18	49	NS	3.5	12.1	22		53

[a]clodinafop propargyl 0.06 kg/ha at 25 DAS *fb* 2,4-D at 0.50 kg/ha at 30 DAS
ZT: zero tillage; CT: conventional tillage

Effect on yield

Rice

The various tillage sequences and weed control methods had a significant effect on rice yield in all the three years (Table 4). Initially (2006 and 2007) conventional tillage was more promising and gave 23.3% and 18.6% higher rice yield than the zero tillage, whereas at the completion of the experiment (2008), zero tillage yielded 25.1% more than the conventional tillage regardless to weed control methods. This might be due to improved soil conditions over the years in ZT. Post-flowering drought during 2006 caused greater yield reduction mainly due to lower panicle number (data not shown). Lu *et al*. (2001) reported that moisture stress at panicle initiation and flowering stages could lead to yield loss because of reduction in number of grains per panicle and spikelet sterility. However during 2007 and 2008, the drought at panicle initiation stage was managed with supplemental irrigations. Application of recommended herbicide (pendimethalin at 1.0 kg/ha as pre-emergence followed by 2, 4- D at 0.50 kg/ha at 25 DAS) alone did not improve the rice yield over weedy check during first year due to poor control of dominant weed *C. axillaris*. Integration of herbicides with one hand weeding improved the rice yields by 28.41, 16.62 and 25.82% over herbicide alone and 31.92, 105 and 38.5% over weedy check in different years.

Wheat

In 2006-07, wheat grown in ZT (either continuous or rotated with conventional) yielded significantly higher than CT. During 2007-08, tillage sequences had no effect on wheat yield. However, at the completion of the experiment, continuous ZT gave 15.4% higher yields than continuous CT. Higher wheat yields in ZT was also reported by Erenstein and Laxmi (2008). Rotational tillage system was at par with CT but significantly lower than ZT. Application of recommended herbicides (clodinafop 60 g followed by 2, 4-D at 0.50 kg/ha) alone or integration with one hand weeding significantly increased the wheat yields than weedy check. Similar results are also reported by Punia *et al*. (2006). Integration of herbicides with one hand weeding improved the wheat yields by 13.18, 12.03% over herbicide alone during 2006-07 and 2007-08, respectively, however, during 2008-09, the effect of hand weeding was not visible. Weed competition throughout the growth period reduced wheat yields by 65.4, 46.7 and 64.3 % in different years.

Wheat equivalent yield (WEY)

In 2006-07, the WEYs under continuous ZT (3.56 t/ha) or CT rotated with ZT (3.40 t/ha) were at par but significantly superior than ZT rotated with CT (2.69 t/ha) or continuous CT (2.94 t/ha). At the completion of the experiment (2008-09), WEY under continuous ZT (6.77t/ha) was significantly higher than those in either continuous CT (5.71 t/ha) or rotational tillage systems (5.25-5.67 t/ha) regardless of weed control methods (Table 4). Irrespective of the tillage system, maximum WEY (7.29 t/ha) was recorded in herbicide + 1 hand weeding treatment followed by herbicide alone and weedy check.

Economics

Irrespective of the weed control methods, continuous zero tillage recorded maximum net returns and benefit: cost ratio (Table 5). Continuous zero tillage with recommended herbicide + 1 hand weeding recorded the maxi-

Table 4. Yield of rice and wheat with different tillage and weed control treatments.

Treatment	Grain yield (t/ha)											
	Rice				Wheat				Wheat equivalent yield			
	2006	2007	2008	Mean	2006-07	2007-08	2008-09	Mean	2006-07	2007-08	2008-09	Mean
Tillage methods												
ZT-ZT	1.06	1.84	2.94	1.95	2.73	3.72	4.45	3.63	3.56	5.17	6.77	5.17
ZT-CT	1.06	2.16	2.59	1.94	1.85	3.92	3.62	3.13	2.69	5.62	5.67	4.66
CT-ZT	1.31	2.10	2.47	1.96	2.37	3.98	3.31	3.22	3.40	5.64	5.25	4.77
CT-CT	1.31	2.26	2.35	1.97	1.91	3.80	3.86	3.13	2.94	5.58	5.71	4.74
SEm±	0.08	0.14	0.22		0.09	0.09	0.02		0.15	0.17	0.17	
CD (P=0.05)	0.24	0.40	0.65		0.26	NS	0.55		0.47	NS	0.51	
Weed control methods												
Recommended herbicide[a]	1.09	2.29	2.45	1.95	2.63	4.26	4.84	3.91	3.49	6.06	6.77	5.44
Herbicide + 1 HW at 35 DAS	1.40	2.67	3.09	2.33	2.98	4.77	4.86	4.20	4.08	6.87	7.29	6.08
Weedy check	1.06	1.30	2.23	1.53	1.03	2.54	1.73	1.77	1.87	3.57	3.49	2.97
SEm ±	0.06	0.12	0.12		0.11	0.07	0.25		0.13	0.19	0.15	
CD (P=0.05)	0.18	0.35	0.36		0.33	0.20	0.73		0.41	0.56	0.45	

[a]Pendimethalin 1.0 kg/ha as pre-em. *fb* 2,4-D 0.50 kg/ha, in rice and clodinafop propargyl 0.06 kg/ha at 25 DAS *fb* 2,4-D at 0.50 kg/ha at 30 DAS in wheat; ZT: zero tillage; CT: conventional tillage

Table 5. Tillage sequence and weed management-wise total variable cost, net income and B:C ratio under different tillage sequences

Treatment	ZT-ZT			ZT-CT			CT-ZT			CT-CT		
	Total variable cost (×10³₹/ha)	Net income (×10³ ₹/ha)	B:C ratio	Total variable cost (×10³₹/ha)	Net income (×10³ ₹/ha)	B:C ratio	Total variable cost (×10³₹/ha)	Net income (×10³ ₹/ha)	B:C ratio	Total variable cost (×10³₹/ha)	Net income (×10³ ₹/ha)	B:C ratio
Recommended herbicide[a]	23.88	57.53	3.41	25.68	46.08	2.79	24.27	36.90	2.52	25.99	51.31	2.97
Herbicide + 1 HW at 35 DAS	26.26	73.87	3.81	28.13	44.15	2.57	26.67	47.42	2.78	28.37	39.92	2.41
Weedy check	22.39	15.32	1.68	24.15	15.13	1.63	22.76	11.52	1.51	24.48	14.90	1.61
Mean	24.18	48.91	2.97	25.99	35.12	2.33	24.57	31.95	2.27	26.28	35.38	2.33

[a]Pendimethalin 1.0 kg/ha as pre-em. *fb* 2,4-D 0.50 kg/ha in rice and clodinafop propargyl 0.06 kg/ha at 25 DAS *fb* 2,4-D at 0.50 kg/ha at 30 DAS in wheat; ZT: zero tillage; CT: conventional tillage

mum net returns (73,867/ha) and B: C ratio (3.81) in direct-seeded rice-wheat system. Among the rotational tillage systems, ZT-CT was more economical with the use of recommended herbicide and CT-ZT, with herbicide + 1 hand weeding. Under continuous conventional tillage system, use of herbicide alone was more beneficial than that of herbicide + 1 hand weeding.

The study suggests that continuous zero tillage and effective weed control using recommended herbicide followed by 1 hand weeding appeared to be the most productive and remunerative approach in direct-seeded rice-wheat system in vertisols.

REFERENCES

Bhushan, L., Ladha, J.K., Gupta, R.K., Singh, S., Tirol-Padre, A., Saharawat, Y.S., Gathala, M. and Pathak, H. 2007. Saving of water and labour in a rice-wheat system with no-tillage and direct-seeding technologies. *Agronomy Journal* **99**: 1288–96.

Carter, M.R. 1994. Strategies to overcome impediments of adoption of conservation tillage. In: *Conservation Tillage in Temperate Agro ecosystems*. Carter, M.R. (Ed.), Boca Raton, FL: Lewis. 3–19 pp.

Chauhan, B.S. and Johnson, D.E. 2009.Influence of tillage systems on weed seedling emergence pattern in rainfed rice. *Soil & Tillage Research* **106**: 15–21.

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

Lu, J., Hirasawa, T. and Lu, J. 2001. Study on intermittent irrigation for paddy rice. I. Water use efficiency. *Pedosphere* **11**: 49–56.

Medd, R.W. 1990. Seed bank dynamics of wild oat (*Avena fatua*) populations in wheat. In: *Proceedings of the 9th Australian Weeds Conference*, Adelaide, South Australia, August, 6-10, 1990.

Mohler, C.L. and Galford, A.E. 1997. Weed seedling emergence and seed survival, separating the effects of seed position and soil modification by tillage. *Weed Research* **37**: 147–55.

Peachey, B.E., William, R.D. and Mallory-Smith, C. 2006. Effect of spring tillage sequence on summer annual weeds in vegetable row crop rotations. *Weed Technology* **20**: 204–14.

Punia, S.S., Singh, S., Malik, R.K. and Yadav, D. 2006. Studies on herbicide mixtures in wheat. *Indian Journal of Weed Science* **38**: 1–4.

Scursoni, J.A., Martin, A., Catanzaro. M.P., Quiroga, J. and Goldar, F. 2011. Evaluation of post-emergence herbicides for the control of wild oat (*Avena fatua* L.) in wheat and barley in Argentina. *Crop Protection* **30**: 18–23.

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**: 487–95.

Yadav Ashok, Malik R K, Malik R S, Kadian V S, Kumar V, Phogat V K, Kukreja K, Dabur K R, Kumar Ramesh and Mehta Anil. 2009. Productivity and sustainability of long-term zero tillage in non-rice-wheat cropping systems in Haryana, India. In: *Proceedings (Abstracts) of 4th World Congress on Conservation Agriculture*, 4-7 February 2009, New Delhi, pp.121–22.