



Weed density and species composition in rice-based cropping systems as affected by tillage and crop rotation

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ABSTRACT

Weeds in crop fields are largely influenced by crop rotations and management practices. A better understanding of response of various weed species to changing management practices is required to develop improved weed management systems. A study was conducted to assess the effect of different tillage intensities and crop rotations on the weed population dynamics in rice-based cropping systems. In this study, three tillage practices viz. conventional tillage (CT), reduced tillage (RT) and RT with 30% crop residues (RTR30) were evaluated in three different crop rotations, viz. rice-wheat, rice-lentil and rice-winter maize for their effect on weeds. Results show that weed density and species composition differed with tillage and crop rotation. Interaction between various tillage intensities and cropping systems had significant effect on density and dry weight of total, broadleaved, grasses and sedges. Irrespective of the tillage systems rice-wheat crop rotation favoured the prevalence of weeds (a total weed population of 1670/m² and weed dry biomass of 241.1 g/m²), whereas rice-winter maize rotation suppressed the weed growth (a total weed population of 403/m² and weed dry biomass of 213.4 g/m²) in summer (pre-Kharif) season. Reduced tillage with 30% residues retention (RTR30) favoured the infestation of horse purslane (*Trianthema portulacastrum* L.) in rice-wheat cropping system, but suppressed the weed growth in rice-lentil system. Contrary to this, RTR30 favoured the infestation of black nightshade (*Solanum nigrum* L.) in rice-winter maize cropping system, but suppressed the weed growth in rice-lentil and rice-wheat systems during winter season.

INTRODUCTION

Rice (*Oryza sativa* L.) is an important cereal crop in Asia, where about 90% of the global rice is produced and consumed. It is grown over a range of agro-ecosystems and management practices (Rao *et al.* 2007). The rice-wheat cropping system occupying nearly 14 million ha (10.5 m ha in India, 2.2 mha in Pakistan, 0.8 mha in Bangladesh and 0.5 m ha in Nepal) in Indo-Gangetic Plains (IGP) is the largest agricultural production system in South Asia. However, the productivity of this system is plateauing and total factor productivity is declining due to exhausted natural resource base (Ladha *et al.* 2003). Rice-rice (4.70 mha), rice-pulses (3.50 mha), rice-vegetables (1.40 mha) and rice-maize (0.53 mha) (Timsina *et al.* 2010) are the other rice-based cropping systems in different agro-ecological regions of India that help to produce food and feed, improve the soil health and livelihood. Presently, the conservation tillage practices, particularly no-tillage

and reduced tillage are being promoted in IGP to address the issues of shortage of man power, water and energy, soil health and climate change in rice-wheat cropping system (Kumar *et al.* 2013).

Weeds are one of the key threats to crop productivity, input-use efficiency and profitability in rice-based cropping systems. Continuous cultivation of rice-wheat cropping sequence favoured the intensification of grassy weeds (Bhatt *et al.* 2016). Tillage systems, crop rotations, choice of crop and management practices affect weed infestation by altering weed seed banks and species composition. Cultivation of crops having similar management practices favours certain weed species to become dominant in the system (Chauhan *et al.* 2012). For instance, conventional tillage (repeated soil tilling) in continuous cereal cropping of rice-wheat in IGP, favoured grassy weed littleseed canarygrass (*Phalaris minor* Retz.) in wheat and awn less barnyard grass [*Echinochloa colona* (L.) Link] in rice

(Malik *et al.* 2014). Therefore, it is necessary to rotate cereals with crops having different management requirements and crop duration. Crop diversification also changes weed spectrum (Singh *et al.* 2008) and makes soil conditions unfavourable for emergence and growth of certain weed species. Some weeds like *T. portulacastrum* and red sprangletop [*Leptochloa chinensis* (L.) Nees] in rice and *Solanum nigrum*, common vetch (*Vicia sativa* L.) and burclover (*Medicago denticulata* Willd.) in winter crops are becoming difficult to control by commonly used herbicides.

In India, conservation tillage practices such as no-tillage and reduced tillage are being promoted in rice-based cropping systems. Change in tillage system affects weed communities by direct killing of weeds or by redistributing weed seeds in varying soil depths, and by changing the soil environment and there by affecting weed seed germination and emergence (Nichols *et al.* 2015). Many weeds are crop specific. Therefore, diversification of the prevalent cropping system may help to reduce the infestation of a particular weed. Crop residues can affect weed seed germination by altering weed seed environment (light interception, physical barrier, soil moisture conservation and allelopathy) (Nichols *et al.* 2015). Much emphasis has been given on studying the effect of herbicides on weed control and crop yields in rice-wheat system, but very less effort has been made at managing weed populations by imposing diverse tillage sequences in cropping systems. The aim of the present study was to evaluate the density and composition of the weed population established after 4 years of crop rotations in 3 tillage systems.

MATERIALS AND METHODS

The present study was carried out during summer (pre-Kharif) and winter seasons of 2016 after completion of 4th year of a fixed field experiment from 2012-2016 at the Research farm, ICAR Research Complex for Eastern Region, Patna (25°30'N latitude 85°15'E longitude, and 52 m above mean sea level), Bihar, India. The soil of the experimental field was sandy clay loam soil (sand:55.5% silt:15.6% and clay 28.9%), low in available N (219 kg N/ha), medium in available P (19.3 kg P/ha) and K (190 kg K/ha) with pH 6.83 and EC 0.11 dS/m. The climate of the region is sub-tropical. Mean annual rainfall received during 2012 to 2016 at experimental site was 895.82 mm indicating a shortfall of 231.47 mm than the long-term normal rainfall (1127.29 mm). On an average, the highest

precipitation was received in the month of August and September in all the 4 years of experimentation. Mean monthly maximum temperature varied from 18.7°C (January) to 38.1°C (May) whereas, mean monthly minimum temperature ranged from 6.5°C (January) to 29.6 (August).

The treatments included three tillage practices *viz.* conventional tillage (CT), reduced tillage (RT) and RT with 30% crop residues (RTR30); and three different cropping systems *viz.* rice-wheat, rice-lentil and rice-winter maize. Tillage practices were assigned to the main plot and cropping systems to the sub-plot. Each sub-plot measured 4.5 x 10 m. Treatments were replicated thrice in a split-plot design. Rice was grown as puddled transplanted during rainy season, and treatments were imposed in following winter season. In CT and RT, rice was harvested manually from ground level leaving 5±2 cm anchored crop residue in the field, where as in RTR 30, about 30% anchored crop residues were left in the field by harvesting the crop 30±5 cm from the soil surface, and incorporated in the soil. After the harvesting the preceding rice crop, the field was prepared by two cultivations with tractor mounted cultivator followed by rotovator in CT. In RT/RTR30, the fields were prepared through reduced tillage practices involving one harrowing and one field levelling (using a wooden plank).

Data on weed count, for estimating weed density and their composition, and weed biomass were recorded (at 4-5 leaf stage) after completion of 4th year of field experiment during fallow period in early June (prior to planting rice crop) and 30 days after sowing of the succeeding crops, *viz.* wheat, maize and lentil (prior to application of post-emergence herbicide/manual weeding) with the help of quadrat (0.5 x 0.5 m) placed randomly at four spots in each plot. All the data on weed density and weed dry matter values were analyzed with 'Statistix 8.1' for analysis of variance (ANOVA). Data were square-root transformed before analysis to reduce heterogeneity of variance.

RESULTS AND DISCUSSION

Sixteen weed species including broad-leaved (BLW), grasses and sedges were identified from the weed density assessment during 1st week of June (pre-Kharif) and twelve weed species were observed during winter (*Rabi*) crop season. The field was dominated by broad-leaved weeds-BLWS (90%) followed by grasses (9%) and sedges (1%). Among BLWs, *T. portulacastrum* (72%), common purslane (*Portulaca oleracea* L.) 7% and prostrate knotweed

(*Polygonum aviculare* L.) 6% were major weeds during summer. In winter, *S. nigrum* (84%) was the dominant weed.

Density and dry matter of weeds during summer (pre-Kharif) season

Mean specific weed density (Table 1) and weed dry matter (Table 2) recorded during pre-Kharif season are presented to give an overview of weed densities and their dry matter in present study, and overall effect of the various tillage systems, crop rotations. The interaction of densities and dry weight of major weeds to various treatments is subsequently presented in Table 3. Conventional tillage in rice-maize crop rotation had the minimum total weed density (352/m²) whereas reduced tillage with 30% anchored crop residue in rice-wheat rotation had the maximum total density (2049/m²) and dry matter of weeds (270.6 g/m²). The minimum total weed dry matter (187.6 g/m²) was recorded with RT +30% anchored crop residue in rice-maize rotation. Irrespective of the tillage systems, minimum total weed density (403/m²) and weed dry biomass (213.4 g/m²) was recorded in the rice-maize system followed by rice-lentil and rice-wheat systems. As compared to RT and RT30, CT system had reduced the total weed density and weed biomass in rice-wheat system, but promoted the weed infestation in rice-lentil rotation (Table 5). Tillage changes vertical distribution of weed seeds in soil profile and soil physical properties, and affects emergence and seed survival of weeds through changes in soil conditions (Chauhan et al. 2006) and determines weed seedling

emergence and species composition (Sosnoskie et al. 2006, Murphy et al. 2006).

Maximum density and dry weight of broadleaved weed *T. portulacastrum* were recorded under CT than the other tillage practices. Among the crop rotations, maximum density and dry biomass of this weed were recorded in rice-wheat system followed by rice-lentil and rice-maize systems. Regarding interactive effects, density of *T. portulacastrum* was the highest in rice-wheat rotation under RT30 than other rotations and tillage systems (Table 3). However, rice-lentil rotation under RT30 and rice-maize rotation under RT helped to reduce the weed density than the other systems. In spite of the highest density of *T. portulacastrum* in rice-wheat system under RT30, its dry biomass was the lowest. Similarly, other crop rotations in combination with RT30 recorded the lowest dry biomass of this weed. The lowest weed dry biomass of *T. portulacastrum* was recorded in rice maize rotation under RT30. Crop residues have an impact on weed ecology (Chauhan et al. 2012). Presence of crop residues can influence weed emergence by altering soil moisture, light transmission or through allelopathic effects (Chauhan et al. 2012). Rice-wheat rotation probably created favourable conditions for germination and seedling emergence of the dominant broad-leaved weed *T. portulacastrum* as compared to rice-lentil and rice-maize rotations. In present study, compared to CT, reduced tillage with 30% crop residues (RT30) stimulated the emergence of *T. portulacastrum* in rice-wheat system, but suppressed its emergence in rice-lentil system.

Table 1. Weed density (no./m²) in summer (pre-Kharif) season as influenced by tillage practices and cropping systems

Treatment	Broad-leaved weeds							Sedge	Grasses				Others	
	TP	PA	PO	EA	AV	AP	SN		CA	CR	BR	CD		EC
<i>Tillage practice</i>														
CT	26.50 (702)	8.80 (77)	8.28 (68)	1.87 (3)	1.87 (3)	3.34 (10)	3.25 (5)	1.22 (1)	3.53 (12)	6.67 (44)	2.12 (4)	3.39 (11)	1.22 (1)	3.25 (5)
RT	25.11 (630)	8.03 (64)	8.09 (65)	2.92 (8)	2.78 (7)	4.85 (23)	2.91 (8)	1.58 (2)	2.35 (5)	8.03 (64)	4.53 (20)	2.91 (8)	1.22 (1)	1.58 (2)
RT30	26.33 (693)	6.36 (40)	8.22 (67)	2.35 (5)	2.12 (4)	3.08 (9)	5.05 (25)	1.58 (2)	2.74 (7)	7.65 (58)	4.42 (19)	2.74 (7)	3.39 (11)	2.55 (6)
LSD (p=0.05)	1.16	0.35	NS	0.23	0.16	0.14	0.23	0.07	0.26	0.40	0.15	0.18	0.09	0.10
<i>Cropping system</i>														
Rice-Wheat	39.52 (1561)	3.24 (10)	2.74 (7)	2.12 (4)	0.71 (0)	1.22 (1)	3.67 (13)	1.22 (1)	1.58 (2)	7.91 (62)	1.87 (3)	0.71 (0)	0.71 (0)	2.74 (7)
Rice-Lentil	20.06 (402)	11.89 (141)	4.85 (23)	2.35 (5)	1.22 (1)	0.71 (0)	3.39 (11)	1.58 (2)	4.53 (20)	8.63 (74)	5.96 (35)	2.35 (5)	3.39 (11)	1.87 (3)
Rice-Maize	7.84 (61)	5.52 (30)	13.09 (171)	2.55 (6)	3.81 (14)	6.52 (42)	3.54 (12)	1.58 (2)	1.87 (3)	5.52 (30)	2.12 (4)	4.74 (22)	1.22 (1)	1.87 (3)
LSD (p=0.05)	1.55	0.34	0.42	0.14	0.11	0.12	0.NS	0.05	0.14	0.37	0.09	0.10	0.08	0.07

Data subjected to square root transformation $\sqrt{x+0.5}$. Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

TP- *T. portulacastrum*; PA- *P. aviculare*; PO- *P. oleracea*; EA- *E. alba*; AV- *A. viridis*; AP- *A. pungens*; SN- *S. nigrum*; CA- *C. album*; CR- *C. rotundus*; BR- *B. ramose*; CD- *C. dactylon*; EC- *E. colona*; DS- *D. sanguinalis*

Density of *P. aviculare* was the highest under CT (Table 1), but the dry biomass was higher under RT than the other tillage systems (Table 2). Among crop rotations, maximum density and dry biomass of this weed were recorded in rice-lentil rotation than the other rice-based cropping systems (Table 3 and 4). *P. aviculare* was the most prevalent in rice-lentil rotation with CT and rice-maize rotation with RT compared with the other systems (Table 3). In contrast to these, rice-wheat rotation had minimum density and dry weight of this weed (Table 3).

Tillage systems did not show significant influence the density of *P. oleracea* (Table 1). The dry biomass of *P. oleracea* was, however significantly higher in CT than the other tillage systems (Table 2). Among crop rotations, maximum density and dry weight were recorded in rice-maize rotation followed by rice-lentil and rice-wheat rotations. *P. oleracea* was more prevalent in rice-maize system with RT and RT30 than the CT system. However in rice-lentil rotation, CT system favoured this weed compared to other tillage systems.

Table 2. Weed dry matter (g/m²) in summer (pre-Kharif) season as influenced by tillage practices and cropping systems

Treatment	Broad-leaved weeds								Sedge	Grasses				Others
	TP	PA	PO	EA	AV	AP	SN	CA		CR	BR	CD	EC	
<i>Tillage practice</i>														
CT	10.24 (104.4)	3.87 (14.5)	7.09 (49.8)	2.00 (3.5)	1.58 (2.0)	2.72 (6.9)	3.06 (8.9)	0.95 (0.4)	3.37 (10.9)	3.91 (14.8)	1.91 (3.15)	2.57 (6.1)	1.14 (0.8)	2.43 (5.4)
RT	9.65 (92.6)	5.41 (28.8)	4.63 (20.9)	3.00 (8.5)	2.12 (4.0)	3.18 (9.6)	4.12 (16.5)	1.52 (1.7)	2.26 (4.6)	4.65 (21.1)	3.56 (12.2)	1.87 (3.0)	1.18 (0.9)	1.63 (2.16)
RT30	8.18 (66.5)	3.42 (11.2)	5.54 (30.2)	2.26 (4.6)	1.79 (2.7)	2.70 (6.8)	6.65 (43.7)	1.30 (1.19)	2.51 (5.8)	4.12 (16.5)	3.48 (11.6)	1.81 (2.8)	4.00 (15.5)	2.33 (4.92)
LSD (p=0.05)	0.52	0.25	0.37	0.23	0.12	0.12	0.31	0.07	0.12	0.29	0.16	0.14	0.18	0.11
<i>Cropping system</i>														
Rice-Wheat	13.11 (171.5)	3.15 (9.4)	2.81 (7.4)	2.21 (4.4)	0.71 (0)	1.09 (0.7)	4.86 (23.1)	1.00 (0.5)	1.31 (1.21)	4.32 (18.2)	1.67 (2.3)	0.71 (0)	0.71 (0)	2.57 (6.1)
Rice-Lentil	7.76 (59.7)	5.48 (29.5)	5.12 (25.7)	2.43 (5.4)	0.89 (0.3)	0.71 (0)	4.58 (20.0)	1.41 (1.5)	4.28 (17.8)	5.13 (25.7)	4.66 (21.2)	1.52 (1.7)	4.00 (15.5)	1.89 (3.1)
Rice-Maize	5.72 (32.2)	3.99 (15.4)	8.26 (67.8)	2.68 (6.7)	2.98 (8.4)	4.81 (22.6)	5.15 (26.0)	1.38 (1.4)	1.67 (2.3)	2.98 (8.4)	2.00 (3.5)	3.29 (10.3)	1.52 (1.7)	1.95 (3.3)
LSD (p=0.05)	0.55	0.20	0.27	0.14	0.09	0.09	0.23	0.04	0.11	0.22	0.14	0.10	0.18	0.10

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

TP- *T. portulacastrum*; PA- *P. aviculare*; PO- *P. oleracea*; EA- *E. alba*; AV- *A. viridis*; AP- *A. pungens*; SN- *S. nigrum*; CA- *C. album*; CR- *C. rotundus*; BR- *B. ramosa*; CD- *C. dactylon*; EC- *E. colona*; DS- *D. sanguinalis*

Table 3. Interaction effect of tillage and cropping systems on density and dry weight of major weeds in pre-Kharif season

Treatments	<i>T. portulacastrum</i>			<i>P. aviculare</i>			<i>P. oleracea</i>			Total		
	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize
<i>Weed density (no./m²)</i>												
CT	37.14 (1379)	25.40 (645)	9.03 (81)	3.58 (12)	14.67 (215)	1.87 (3)	2.12 (4)	7.15 (51)	12.24 (149)	38.07 (1449)	32.18 (1035)	18.77 (352)
RT	37.48 (1404)	21.36 (456)	5.47 (30)	3.98 (15)	9.80 (96)	9.04 (82)	1.08 (1)	3.72 (13)	13.50 (182)	38.88 (1511)	27.43 (752)	21.47 (461)
RT + 30% crop residues	43.58 (1899)	10.33 (106)	8.63 (74)	1.22 (1)	10.63 (113)	2.55 (6)	4.06 (16)	2.41 (5)	13.48 (181)	45.27 (2049)	20.33 (413)	19.91 (396)
LSD (p=0.05)	T x CS 2.47	CS x T 2.80	T x CS 0.59	CS x T 0.63	T x CS 0.80	CS x T 0.80	T x CS 2.86	CS x T 3.13	T x CS 3.13	CS x T 3.13	T x CS 3.13	CS x T 3.13
<i>Weed dry weight (g/m²)</i>												
CT	13.54 (183.1)	9.27 (85.5)	6.72 (44.70)	2.86 (7.7)	5.86 (33.9)	1.61 (2.1)	2.75 (7.1)	6.34 (39.8)	10.16 (102.7)	15.03 (225.7)	15.20 (230.7)	15.56 (241.8)
RT	13.55 (183.1)	8.17 (66.2)	5.38 (28.5)	3.02 (8.6)	6.18 (37.7)	6.39 (40.3)	0.74 (0.1)	5.72 (32.2)	5.56 (30.5)	15.47 (239.0)	15.42 (237.3)	14.42 (207.7)
RT + 30% crop residues	12.2 (148.3)	5.30 (27.6)	4.90 (23.5)	3.53 (12.0)	4.19 (17.10)	2.26 (4.6)	3.97 (15.2)	2.40 (5.3)	8.40 (70.20)	16.46 (270.6)	14.66 (214.5)	13.71 (187.6)
LSD (p=0.05)	T x CS 0.93	CS x T 1.01	T x CS 0.38	CS x T 0.38	T x CS 0.53	CS x T 0.52	T x CS 1.10	CS x T 1.05	T x CS 1.05	CS x T 1.05	T x CS 1.05	CS x T 1.05

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

Maximum dry matter of this weed was recorded with rice-maize rotation under CT system. Rice-wheat system with RT almost completely suppressed this weed (Table 3). Similarly, rice-lentil system with RT30 and rice-maize system with RT recorded the lowest dry weight of *P. oleracea*.

Rice-maize rotation and RT favoured the density of false daisy [*Eclipta alba* (L.) Hassk.], slender amaranth (*Amaranthus viridis* L.) and khaki weed (*Alternanthera pungens* Kunth.) compared to other rotations and tillage systems (Table 1). Density of *S. nigrum* was significantly higher with RT30 compared to CT and RT. Purple nutsedge (*Cyperus rotundus* L.) was the only sedge recorded during summer season. Its density was maximum in CT compared to RT and RT30 (Table 1). Among crop rotations, maximum density of this weed was recorded in rice-lentil rotation. Rice-wheat and rice-maize rotations suppressed the density of *C. rotundus* to a great extent. Browntop millet [*Brachiaria ramosa* (L.) Stapf.], bermudagrass [*Cynodon dactylon* (L.) Pers.], Awnless barnyard grass [*Echinochloa colona* (L.) Link.] and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] were the major grassy weeds in the experimental field. Density and dry weight of *B. ramosa* and *C. dactylon* were significantly higher under RT and RT30 as compared to CT system (Table 1 and 2). Higher emergence of *C. dactylon* in RT and RT30 was probably due to lower soil disturbance compared to CT, resulting in an increase in its density (Gruber and Claupein 2009). Among crop rotations, rice-lentil system favoured these two weeds as compared to other rotations. Density and dry weight of *E. colona* were in the order of CT>RT>RT30, and maximum density and dry biomass were recorded with rice-maize rotation (Table 3 and 4). Similarly, the density and dry biomass of *D. sanguinalis* were higher in RT30 and rice-lentil rotation compared to other tillage systems and crop rotations.

Density and dry matter of weeds during winter season

Mean specific weed density and weed dry biomass recorded during winter season are presented in Tables 4 and 5 to give an overall effect of the various tillage systems, crop rotations and their interactions on densities and dry weight of major weeds. *S. nigrum*, common lambsquarters (*Chenopodium album* L.), beach launea (*Launaea pinnatifida* Cass.), strawberry clover (*Trifolium fragiferum* L.) (among broad-leaved weeds), *C. rotundus* (among sedges) and *B. ramosa* (among grasses) were the dominant weed species in the experimental plot (Table 4). Irrespective of the tillage systems, minimum total weed density and dry biomass was recorded with rice-wheat crop rotation followed by rice-lentil and rice-maize rotations. The lowest total weed density and dry weight was recorded with CT followed by RT and RT30 systems (Table 6). The minimum total weed density (118/m²) was recorded with RT30 in rice-wheat rotation, whereas the minimum total weed dry matter (6.32 g/m²) was recorded with CT system in rice-maize rotation. As compared to RT and RT30, CT system had reduced the total weed density and weed dry biomass in rice-maize system, but promoted the weed infestation in rice-wheat rotation.

Maximum density (Table 4) and dry weight (Table 5) of broadleaved weed *S. nigrum* were recorded under RT30 followed by RT and CT systems. Increase in density of *S. nigrum* under RTR30 was 471 and 119 per cent higher over CT and RT, respectively. Among the crop rotations, maximum density and dry biomass of this weed were recorded in rice-maize rotation followed by rice-wheat and rice-lentil systems. Regarding interactive effects, density and dry weight of *S. nigrum* were the highest in rice-maize rotation under RT30 than other rotations and tillage systems (Table 6). However, RT in rice-lentil and rice-wheat rotations helped to reduce

Table 4. Weed density (no./m²) as influenced by different tillage and cropping systems in winter (Rabi) season

Treatments	<i>S. nigrum</i>	<i>C. album</i>	<i>L. pinnatifida</i>	<i>T. fragiferum</i>	<i>C. rotundus</i>	<i>B. ramosa</i>	Others
<i>Tillage practice</i>							
CT	11.73(137)	4.18(17)	1.87(3)	1.22(1)	1.58(2)	2.74(7)	5.43(29)
RT	18.88(356)	3.81(14)	0.71(0)	0.71(0)	1.22(1)	5.61(31)	6.67(44)
RT30	27.97(782)	3.24(10)	4.85(23)	0.71(0)	1.58(2)	3.67(13)	6.74(45)
LSD (p=0.05)	1.08	0.16	0.10	0.07	0.04	0.32	0.65
<i>Cropping system</i>							
Rice-wheat	11.64(135)	1.87(3)	2.00(4)	1.22(1)	0.71(0)	4.43(19)	2.74(7)
Rice-lentil	7.71(59)	5.79(33)	4.64(21)	0.71(0)	2.34(5)	1.58(2)	10.51(110)
Rice-maize	32.90(1082)	2.55(6)	0.71(0)	0.71(0)	0.71(0)	5.52(30)	2.12(4)
LSD (p=0.05)	0.84	0.18	0.08	0.06	0.06	0.17	0.38

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

the weed density than the other systems. Higher weed density and dry weight of *S. nigrum* in rice-maize rotation under RT30 and RT system compared to CT system is probably attributed to greater soil moisture that promoted germination and reduced the resistance of soil to seedling emergence (Morton and Buchele 1960).

Density and dry biomass of *C. album* were the highest under CT (Table 4 and 5). This may be due to the effect of CT on the vertical distribution of weed seed bank in a silt loam soil. Association of *C. album* with CT in many crops has also been reported (Swanton *et al.* 1999, Shrestha *et al.* 2002). *C. album* was the most prevalent in rice-lentil rotation with RT and rice-maize rotation with CT compared with the other systems (Table 6). The *C. album* seeds may have been brought up to the surface under CT, but the lesser competitiveness of lentil compared to wheat

and winter maize might have increased its population in rice-lentil system. In contrast to these, rice-wheat rotation had minimum density and dry weight of *C. album* (Table 4 and 5). Density and dry biomass of *L. pinnatifida* were the highest in rice-lentil rotation under RT30 than the other rotations and tillage systems (Table 6). Population of *C. rotundus* was very less and observed only in rice-lentil system. Rice-maize rotation and RT favoured the density of *B. ramosa* compared to other rotations and tillage systems. Rice-lentil rotation and CT suppressed the growth of *B. Ramosa*. Population density of perennial weed *C. rotundus* increased in CT compared to other tillage systems. *C. rotundus* multiplies rapidly through tubers which can be greatly accelerated by conventional tillage.

Tillage systems and crop rotations had significant influence on weed infestation and species

Table 5. Weed dry weight (g/m²) as influenced by different tillage and cropping systems in winter (Rabi) season

Treatments	<i>S. nigrum</i>	<i>C. album</i>	<i>L. pinnatifida</i>	<i>T. fragiferum</i>	<i>C. rotundus</i>	<i>B. ramosa</i>	Others
<i>Tillage practice</i>							
CT	2.22(4.43)	1.20(0.97)	1.14(0.80)	0.82(0.20)	0.79(0.13)	1.06(0.63)	0.95(0.41)
RT	4.02(15.70)	1.15(0.97)	0.71(0)	0.71(0)	0.88(0.27)	1.56(1.93)	1.57(1.97)
RT30	4.79(23.03)	1.01(0.53)	2.25(4.58)	0.83(0.20)	0.82(0.20)	1.03(0.57)	1.39(1.43)
LSD (p=0.05)	0.20	0.05	0.11	0.06	0.04	0.32	0.13
<i>Cropping system</i>							
Rice-wheat	2.72(6.90)	0.84(0.20)	1.19(0.93)	0.83(0.20)	0.71(0)	1.37(1.37)	0.93(0.37)
Rice-lentil	1.69(2.37)	1.45(1.60)	2.22(4.43)	0.83(0.20)	1.02(0.53)	0.92(0.37)	1.86(2.97)
Rice-maize	5.87(33.90)	1.08(0.67)	0.71(0)	0.71(0)	0.71(0)	1.37(1.40)	0.98(0.47)
LSD (p=0.05)	0.16	0.05	0.04	0.04	0.03	0.05	0.07

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues

Table 6. Interaction effect of tillage and cropping systems on density and dry weight of major weeds in winter (Rabi) season

Treatment	<i>S. nigrum</i>			<i>C. album</i>			<i>L. pinnatifolia</i>			Total		
	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize	Rice-Wheat	Rice-Lentil	Rice-Maize
<i>Weed density (no./m²)</i>												
CT	13.70 (187)	9.30 (86)	11.80 (139)	2.93 (8)	5.87 (34)	3.23 (10)	2.97 (8)	0.71 (0)	0.71 (0)	14.53 (211)	14.73 (217)	12.78 (162)
RT	10.20 (104)	5.07 (25)	30.67 (939)	0.70 (0)	6.37 (40)	1.57 (2)	0.71 (0)	0.71 (0)	1.58 (2)	13.07 (170)	13.53 (183)	31.40 (987)
RT 30	10.67 (113)	8.10 (65)	46.57 (2167)	0.70 (0)	4.97 (24)	2.73 (7)	2.37 (5)	7.97 (63)	0.71 (0)	10.90 (118)	16.93 (286)	47.10 (2219)
	T x CS	CS x T		T x CS	CS x T		T x CS	CS x T		T x CS	CS x T	
LSD (p=0.05)	1.59	1.60		0.29	0.32		0.15	0.15		2.01	1.99	
<i>Weed dry matter (g/m²)</i>												
CT	2.53 (5.90)	1.82 (2.80)	2.66 (4.60)	1.05 (0.60)	1.41 (1.50)	1.14 (0.80)	1.70 (2.40)	0.71 (0)	0.70 (0)	3.22 (9.90)	2.64 (6.50)	2.61 (6.32)
RT	2.81 (7.40)	1.41 (1.50)	6.22 (38.20)	0.71 (0)	1.63 (2.10)	1.14 (0.80)	0.71 (0)	0.71 (0)	0.82 (0.60)	3.56 (12.20)	2.95 (8.20)	6.57 (42.70)
RT 30	2.81 (7.40)	1.82 (2.80)	7.71 (58.90)	0.71 (0)	1.30 (1.20)	0.95 (0.40)	0.95 (0.40)	3.71 (13.30)	0.71 (0)	2.88 (7.80)	4.81 (22.70)	7.85 (61.10)
	T x CS	CS x T		T x CS	CS x T		T x CS	CS x T		T x CS	CS x T	
LSD (p=0.05)	0.31	0.30		0.09	0.08		0.08	0.08		2.07	2.01	

Data subjected to square root transformation $\sqrt{x+0.5}$, Values in parentheses are original, CT=Conventional tillage, RT=Reduced tillage, RT30= RT + 30% crop residues, T=Tillage, CS=Cropping system

composition in rice-based cropping systems. The effect of crop rotation was more pronounced than the tillage system. The present study revealed that rice-wheat cropping system encourages the weed problems whereas rice-winter maize rotation reduces the weed growth. Reduced tillage with 30% residues retention (RTR30) favoured the infestation of dominant broadleaved weed *T. portulacastrum* in rice-wheat cropping system, whereas rice-winter maize system had strong suppressive effect against this weed in different tillage systems. But rice-maize rotation favoured the infestation of *P. oleracea* and *S. nigrum*. These findings suggest that both tillage system and crop rotation strategies are significant considerations while developing sustainable and eco-friendly weed management strategies.

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