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Research Paper

Effect of herbicides and their combinations on weeds and productivity of direct-seeded rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2014 and 2015 at the Bidhan Chandra Krishi Viswavidyalaya (BCKV), West Bengal, to evaluate the effect of different herbicides and their combinations on growth of composite weed flora and productivity of direct-seeded rice (DSR) (*Oryza sativa* L.). The experiment was laid out in a randomized block design with 3 replications. The experiment comprised 8 weed-control treatments, viz. T_1, pyrazosulfuron ethyl @ 30 g/ha as post-emergence (PoE); T_2, pretilachlor @ 0.75 kg/ha as pre emergence (PE); T_3, pyrazosulfuron ethyl 0.75% + pretilachlor 30% WG (pre-mix) @ 1.50 kg/ha (commercial product) as PoE; T_4, pyrazosulfuron ethyl 0.75% + pretilachlor 30% WG (pre-mix) @ 1.75 kg/ha (commercial product) as PoE; T_5, pyrazosulfuron ethyl 0.75% + pretilachlor 30% WG (pre-mix) @ 3.50 kg/ha (commercial product) as PoE; T_6, Almix @ 20 g/ha (commercial product) as PoE; T_7, bispyribac-sodium @ 25 g/ha as PoE + 1 hand weeding (HW) at 40 days (farmers' practice); and T_8, unweeded control (season-long weedy condition). All weed-control options significantly influenced the weed growth and crop yield. Monocot weeds, particularly sedges, were the most dominant among all the species. Grain yield losses due to weeds would amount to 59.0–65.6%, if weed-control measures were not undertaken. Combined applications of ready-mix herbicides provided better weed control with higher weed-control index (WCI) in DSR than those observed with sole application of herbicides. Post-emergence application of pyrazosulfuron ethyl + pretilachlor as ready-mix (3.5 kg/ha) resulted in significantly lower weed density and dry matter with higher WCI (77.25%) at 30 days after application (DAA) than the other sole and combined applications of herbicides. Application of herbicides initially reduced microbial activity slightly up to 3 DAA, but recovered well at subsequent stages owing to improved crop growth. A significant negative correlation was found between weed growth (density and biomass) and yield of rice. Ready-mix application of pyrazosulfuron ethyl + pretilachlor (3.50 kg/ha) being at par with pyrazosulfuron ethyl + pretilachlor @ 1.75 kg/ha (ready-mix) and bispyribac-sodium (25 g/ha) + 1 hand weeding (farmers' practice) resulted in the highest grain (2.99 t/ha) and straw yield (4.29 t/ha) of rice. This weed-control treatment resulted in a mean grain yield increase of 190.3% compared to uncontrolled weed growth.

Key words: Direct-seeded rice, Herbicide, Pretilachlor, Pyrazosulfuron ethyl, Ready/pre-mix, Rice, Weed, Yield

The sustainability of puddled transplanted rice system is under jeopardy due to several production-related constraints, viz. water, labour and energy scarcity, during peak period of demand and growing environmental concerns. Direct-seeded rice (DSR) is being considered as the suitable alternative resource-conserving technology in the face of looming scarcity of agricultural resources. Depending on the types of DSR, it can save up to 12–33% water and ~60% labour requirement compared to transplanted rice (Kumar and Ladha, 2011). Moreover, DSR matures 7–10 days earlier than transplanted rice, thereby facilitating timely sowing of succeeding winter season (*rabi*) crops (Farooq *et al*., 2011; Mahajan *et al*., 2013). However, weeds, the major biological constraint in DSR (Rao *et al*., 2007), often limit its successful cultivation, as it is subjected to much higher weed pressure than transplanted rice (Chauhan, 2012; Baghel *et al*., 2018). The situation is aggravated if the initial flushes of weeds are left uncontrolled. Aerobic soil condition in DSR is congenial for weed growth causing yield losses around 80% (Mahajan

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et al., 2009; Sen *et al*., 2018). Thus, success of DSR largely depends on timely and effective control of weeds. Herbicides (pre- and post-emergence) offer selective, timely, effective and cost-efficient control of weeds than manual weeding, giving the crop a competitive superiority over weeds. However, it is very difficult to control the complex weed flora observed in DSR with application of single pre- or post-emergence herbicide (Mahajan *et al*., 2013). Moreover, application of pre-emergence (PE) herbicides may be difficult at times due to anomalous soil moisture and weather conditions. Continuous use of a single herbicide or herbicides with similar mode of action leads to difficult-to-control herbicide-resistant weeds. Currently available herbicides for rice have a limited range of activity and their efficacy is limited when used alone. Therefore, combined post-emergence (PoE) application of more than 1 herbicide with different mode of actions may be useful for effective and broad-spectrum weed-control in DSR and thus delaying the development of herbicide resistance. Keeping this in view, the present work was undertaken to evaluate the bio-efficacy of various pre-mix post-emergence herbicides in managing weeds in DSR.

MATERIALS AND METHODS

The experiment was conducted during rainy (*kharif*) season of 2014 and 2015 at farmers' field in Nadia district (22°57' E, 88°20' N; 9.75 m above mean sea-level) of West Bengal (lower Gangetic alluvial plains). The well-drained alluvial soil of the experimental site had sandy loam texture with a *p*H of 6.81. The soil was low in available N (238.6 kg/ha), medium in available P_2O_5 (26.8 kg/ha) and K_2O (228.2 kg/ha), as well as organic carbon (0.57%).

Plot size of each experimental unit was 5 m × 4 m. All the pre- and post-emergence herbicides were applied at 1 and 20 days after sowing (DAS) respectively. Rice cultivar 'IET-4786' was directly sown in the field using a seed rate of 25 kg/ha and at 20 cm row spacing. The seeds were treated with *Trichoderma viridi* @ 4 g/kg seed before sowing. The crop was managed uniformly except for weed control. The herbicides were applied using a knapsack sprayer calibrated to deliver a spray volume of ~500 litres/ha through flat-fan nozzle at a spray pressure of 140 kPa.

Observations on weeds were recorded at 10 and 30 days after applying herbicides (DAA) by placing a quadrate (0.25 m^2) randomly at 2 places in each plot, and weed density (no./m^2) and dry matter accumulation (g/m^2) were calculated. For dry matter, samples were sun dried for 24 h and then oven dried at 65 ± 5°C until constant dry weight was obtained. Visual scoring of phytotoxicity symptoms (i.e. chlorosis, necrosis, leaf epinasty, hyponasty, wilting or vein clearing) in rice was carried out from 1 DAA to 30 DAA of herbicides. A 10-point scale was used, where, 0 stands for no phytotoxicity and 10 signified complete death of plant (Rao, 2000). For microbial study, soil samples (0–15 cm) were collected form inter-row spaces from each plot before and after sowing (at 3, 7, 15 and 30 DAA and at harvesting). Enumeration of microbial population was done on agar plate containing appropriate media following serial dilution technique and pour plate method (Pramer and Schmidt, 1964). Plates were incubated at 30°C and counts were taken on the 3rd day of incubation. All data were analysed through analysis of variance (ANOVA) using standard variance techniques, as suggested by Gomez and Gomez (1984). Weed data were subjected to square-root transformation [$\sqrt{(x + 1)}$] before statistical analyses to improve the homogeneity of variance. Treatment means were separated using the critical difference (CD) at 5% level of significance ($P \leq 0.05$).

To compare the efficacy of different herbicidal treatments, herbicide-efficiency index (HEI) was calculated, as suggested by Krishnamurthy *et al*. (1975).

$$HEI = [(Y_T - Y_C)/Y_T] \div (WDM_T / WDM_C)$$

Similarly, weed-control efficiency (WCE) and weed-control index (WCI) were calculated as per Mani *et al*. (1973) and Das (2008).

$$WCE\ (\%) = [(WD_C - WD_T) \div WD_C] \times 100$$

$$WCI\ (\%) = [(WDM_C - WDM_T) \div WDM_C] \times 100$$

Likewise, weed persistence index (WPI), weed management index (WMI), agronomic management index (AMI) and integrated weed management index (IWMI) were worked out as suggested by Mishra and Misra (1997) using the following formulae.

$$WPI = [WD_C \div WD_T] \times [WDM_T \div WDM_C]$$

$$WMI = [Y_T/Y_C] \div [(WDM_C - WDM_T) \div WDM_C]$$

$$AMI = [(Y_T/Y_C) - \{(WDM_C - WDM_T)/WDM_C\}] \div [(WDM_C - WDM_T)/WDM_C]$$

$$IWMI = (WMI + AMI) \div 2$$

where Y_T and Y_C, yield in treated and unweeded control plot respectively; WD_T and WD_C, weed density (no./m^2) in treated and unweeded control plot respectively; WDM_T and WDM_C, weed dry weight (g/m^2) in treated and unweeded control plot respectively.

RESULTS AND DISCUSSION

Weed flora

The dominant weed flora in the DSR field comprised *Echinochloa colona* and *Leersia hexandra* (grassy weeds), *Cyperus rotundus* and *Cyperus difformis* (sedges); while *Ammania baccifera* was dominant among broad-leaf weeds (BLWs). Weed density under unweeded control (UWC) situation showed that monocot weeds (grasses and sedges) were more pre-dominant than BLWs, particularly sedges which constituted 39.9% and 43.5% of total weed density at 10 DAA and 30 DAA respectively. Among individual weeds species, *A. baccifera* was most dominant and alone constituted 34% of total weed density at 10 DAA followed by *C. rotundus* (29.9%). However, at 30 DAA, *C. rotundus* became the major weed constituting 32.4% of total weed density followed by *Ammania baccifera* (31.7%).

Weed density and weed dry weight

All the weed-control treatments significantly reduced the weed density and dry matter compared to UWC (Tables 1, 2). Highest density and dry matter accumulation by weeds were recorded in UWC attributable to uncontrolled weed growth. Among the herbicides, application of ready-mix of pyrazosulfuron ethyl + pretilachlor @ 3.5 kg/ha significantly reduced the total weed density and dry weight at 10 and 30 DAA than rest of the treatments. This combination effectively reduced the growth of *E. colona*, *A. braccifera*, *C. rotundus* and *C. difformis* along with other monocots and dicots during both the years of experiment. This treatment reduced the overall weed density by 49.25% and 41.28% (WCE), and weed dry weight by 78.34% and 77.25% (WCI) at 10 and 30 DAA respectively (Table 3). Application of pyrazosulfuron ethyl + pretilachlor @ 1.75 kg/ha ranked second in terms of providing better weed control with 45.95% and 37.51% WCE, and 76.57% and 75.49% WCI at 10 and 30 DAA respectively. The results of this study are in conformity with the findings of Sen *et al*. (2018), who stated that sequential application of herbicides involving post-emergence application of a pre-mix herbicide (penoxsulam + cyhalofop butyl) could reduce the weed density and dry weight significantly in DSR with higher WCE. Among the combined application of herbicides, pyrazosulfuron ethyl + pretilachlor (1.50 kg/ha) and Almix (20 g/ha) resulted in significantly higher density and dry weight by weeds than

Table 1. Effect of weed-control treatments on density (no./m^2) of major weed species in direct-seeded rice (pooled over 2 years)

Treatment	*Echinochloa* spp		*Cyperus rotundus*		*Cyperus difformis*		*Ammania baccifera*		Total density (no./m^2)	
	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA
T_1	2.05 (3.2)	2.08 (3.3)	4.59 (20.1)	5.75 (32.1)	2.14 (3.6)	2.26 (4.1)	4.40 (18.3)	5.15 (25.6)	7.44 (54.4)	8.93 (78.8)
T_2	2.13 (3.6)	2.26 (4.1)	4.74 (21.4)	5.93 (34.2)	2.43 (4.9)	2.54 (5.4)	4.53 (19.6)	5.47 (28.9)	7.81 (60.0)	9.45 (88.4)
T_3	2.26 (4.1)	2.28 (4.2)	4.72 (21.3)	5.89 (33.8)	2.21 (3.9)	2.69 (6.2)	4.53 (19.6)	5.41 (28.3)	7.62 (57.1)	9.41 (87.7)
T_4	1.92 (2.7)	2.00 (3.0)	4.48 (19.1)	5.70 (31.6)	1.97 (2.9)	2.21 (3.9)	4.32 (17.7)	5.08 (24.8)	6.96 (47.6)	8.76 (75.9)
T_5	1.79 (2.2)	1.89 (2.6)	4.42 (18.6)	5.61 (30.4)	1.85 (2.4)	2.11 (3.4)	4.25 (17.1)	4.94 (23.4)	6.76 (44.7)	8.50 (71.3)
T_6	2.21 (3.9)	2.56 (5.6)	4.53 (19.5)	6.13 (36.6)	2.24 (4.0)	2.38 (4.7)	4.83 (22.3)	5.60 (30.4)	8.00 (63.1)	9.78 (94.8)
T_7	2.24 (4.0)	2.40 (4.8)	4.89 (22.9)	5.79 (32.6)	2.69 (6.2)	2.49 (5.2)	5.16 (25.7)	5.36 (27.8)	8.45 (70.5)	9.28 (85.1)
T_8	2.73 (6.4)	2.81 (6.9)	5.23 (26.3)	6.35 (39.3)	3.13 (8.8)	3.81 (13.6)	5.56 (29.9)	6.28 (38.4)	9.43 (88.0)	11.06 (121.5)
SEm±	0.011	0.012	0.02	0.025	0.013	0.017	0.021	0.024	0.037	0.044
CD (P=0.05)	0.033	0.035	0.061	0.076	0.040	0.052	0.064	0.073	0.113	0.132

Data in parentheses are original values while transformed [$\sqrt{(x + 1)}$] values were used for statistical analysis. T_1, pyrazosulfuron ethyl @ 30 g/ha (PoE); T_2, pretilachlor @ 0.75 kg/ha (PE); T_3, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.50 kg/ha (PoE); T_4, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.75 kg/ha (PoE); T_5, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (PoE); T_6, Almix @ 20 g/ha (PoE); T_7, bispyribac-Na @ 25 g/ha (PoE) *fb* HW; T_8, unweeded control; DAA, days after application.

Table 2. Effect of weed-control treatments on dry weight (g/m^2) of major weed species in direct-seeded rice (pooled over 2 years)

Treatment	*Echinochloa* spp		*Cyperus rotundus*		*Cyperus difformis*		*Ammania baccifera*		Total dry-weight (g/m^2)	
	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA	10 DAA	30 DAA
T_1	2.21 (3.9)	2.29 (4.3)	4.98 (23.8)	5.23 (26.4)	2.06 (3.3)	2.71 (6.3)	3.51 (11.3)	4.59 (20.1)	7.20 (51.0)	8.27 (67.5)
T_2	2.40 (4.8)	2.50 (5.3)	5.11 (25.1)	5.39 (28.1)	2.24 (4.0)	2.91 (7.5)	3.80 (13.4)	4.88 (22.9)	7.77 (59.4)	8.78 (76.2)
T_3	2.29 (4.2)	2.58 (5.7)	5.32 (27.4)	5.33 (27.5)	2.29 (4.3)	2.58 (5.7)	3.71 (12.8)	4.71 (21.3)	7.76 (59.3)	8.43 (70.2)
T_4	1.99 (3.0)	2.05 (3.2)	4.68 (20.9)	5.04 (24.4)	1.65 (1.7)	2.42 (4.9)	3.23 (9.4)	4.17 (16.4)	6.56 (42.1)	7.39 (53.6)
T_5	1.93 (2.7)	2.01 (3.0)	4.55 (19.7)	4.91 (23.1)	1.56 (1.6)	2.28 (4.2)	3.06 (8.4)	4.03 (15.3)	6.31 (38.9)	7.12 (49.8)
T_6	2.50 (5.2)	2.75 (6.6)	5.28 (26.9)	5.42 (28.4)	2.62 (5.8)	2.92 (7.6)	3.97 (14.8)	4.70 (21.1)	8.31 (68.1)	8.69 (74.7)
T_7	2.61 (5.8)	2.90 (7.4)	5.03 (24.4)	5.43 (28.5)	2.42 (4.9)	2.89 (7.4)	3.87 (14.0)	4.86 (22.7)	7.95 (62.3)	8.92 (78.7)
T_8	3.65 (12.4)	3.77 (13.3)	7.37 (53.4)	7.89 (61.2)	4.23 (6.9)	5.31 (27.2)	7.56 (56.2)	8.55 (72.2)	13.43 (179.5)	14.82 (218.8)
SEm±	0.016	0.017	0.030	0.031	0.023	0.025	0.037	0.039	0.061	0.066
CD (P=0.05)	0.049	0.053	0.091	0.095	0.070	0.077	0.113	0.119	0.185	0.201

Data in parentheses are original values while transformed [$\sqrt{(x + 1)}$] values were used for statistical analysis. T_1, pyrazosulfuron ethyl @ 30 g/ha (PoE); T_2, pretilachlor @ 0.75 kg/ha (PE); T_3, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.50 kg/ha (PoE); T_4, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.75 kg/ha (PoE); T_5, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (PoE); T_6, Almix @ 20 g/ha (PoE); T_7, bispyribac-Na @ 25 g/ha (PoE) *fb* HW; T_8, unweeded control; DAA, days after application.

the other treatments. Sole application of pyrazosulfuron ethyl, pretilachlor or bispyribac-Na + HW was less effective in reducing the weed growth compared to application of herbicides mixture. This could be due to the broad-spectrum control of weeds provided by combined application of herbicides (pyrazosulfuron ethyl + pretilachlor) with different mode of action. These results are in conformity with Singh *et al*. (2018), who reported that single applications of pyrazosulfuron, pretilachlor, bispyribac-Na and penoxsulam is less effective in reducing the weed growth compared to combined application of herbicides (tank-mix or sequence).

Impact assessment indices

The highest herbicide-efficiency index (2.94) and relatively higher values of weed-management index (3.73), agronomic management index (2.73) and integrated weed-management index (3.23) were recorded with the post-emergence application of pyrazosulfuron ethyl + pretilachlor (3.50 kg/ha) as ready-mix (Table 3). Besides, the lowest weed-persistence index (0.40) was obtained with this combination of herbicides, the highest being in UWC (1.0). Treatments with higher values of these indices indicate relatively better control of weeds than those with lower values. Similar findings were also reported by Mondal *et al*. (2018) in transplanted rice under system of rice intensification (SRI).

Both pyrazosulfuron ethyl and pretilachlor are systemic and selective herbicides, and effectively control annual grasses, sedges and BLWs in rice (both DSR and transplanted rice). Pyrazosulfuron ethyl after absorption shows chlorosis followed by necrosis in weeds. Pretilachlor kills the germinating weed species by inhibiting cell division and/or protein synthesis. When these 2 herbicides with different mode of actions are applied in a combination, they provide a significant inhibitory effect on composite weed flora in DSR.

Yield attributes and yield of direct-seeded rice

All weed-control treatments showed significantly higher values of yield components compared to UWC (Table 4) mainly due to effective suppression of weeds that resulted in improved uptake of inputs like nutrients, light, moisture and other resources by crop. Significantly higher values of yield attributes like number of effective tillers/m^2 and filled grains/panicle were recorded with combined application of pyrazosulfuron ethyl + pretilachlor (3.50 kg/ha) and was statistically at par with bispyribac-Na (25 g/ha) + HW. Similar results were also observed by Teja *et al*. (2016). The 1,000-grain weight did not vary significantly across the treatments. Grain yield losses would have been up to 59.0–65.6% due to weed competition, if weed-control treatments were not adopted. Similar yield reduction in rice due to uncontrolled weed growth was also reported by Mondal *et al*. (2017) in SRI and Mahajan *et al*. (2009) in aerobic rice. The treatment pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha being at par with bispyribac-Na + HW resulted in significantly higher grain (2.99 t/ha) and straw yield (4.29 t/ha) of rice than rest of the weed-control treatments in both the years owing to better control of weeds. Harvest index of rice was not significantly influenced by the weed-control treatments. All the weed-control treatments increased the rice productivity by 143.7–190.3% compared to season-long weedy condition (UWC), the highest being in pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (190.3%). These findings are in conformity with the findings of Mondal *et al.* (2018), who reported that effective and timely weed management under these treatments reduced the density and dry weight of weeds which facili-

Table 3. Impact assessment indices of various weed-control treatments (mean of 2 years)

Treatment	WCE (%)		WCI (%)		HEI	WPI	WMI	AMI	IWMI
	10 DAA	30 DAA	10 DAA	30 DAA					
T_1	38.14	35.13	71.62	69.17	2.11	0.47	3.83	2.83	3.33
T_2	31.82	27.19	66.90	65.17	1.73	0.48	3.69	2.69	3.19
T_3	35.10	27.82	66.95	67.93	1.90	0.47	3.88	2.88	3.38
T_4	45.95	37.51	76.57	75.49	2.68	0.41	3.69	2.69	3.19
T_5	49.25	41.28	78.34	77.25	2.94	0.40	3.73	2.73	3.23
T_6	28.33	21.96	62.08	65.87	1.72	0.48	4.06	3.06	3.56
T_7	19.94	29.91	65.31	64.01	1.84	0.48	4.43	3.43	3.93
T_8	-	-	-	-	0	1.00	-	-	-

WCE, Weed-control efficiency; WCI, weed-control index; HEI, herbicide-efficiency index; WPI, weed-persistence index; WMI, weed-management index; AMI, agronomic management index; IWMI, integrated weed-management index; T_1, pyrazosulfuron ethyl @ 30 g/ha (PoE); T_2, pretilachlor @ 0.75 kg/ha (PE); T_3, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.50 kg/ha (PoE); T_4, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 1.75 kg/ha (PoE); T_5, pre-mix of pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (PoE); T_6, Almix @ 20 g/ha (PoE); T_7, bispyribac-Na @ 25 g/ha (PoE) *fb* HW; T_8, unweeded control; DAA, days after application.

tated the crop with sufficient space, light, nutrients and moisture, and hence improved yield attributes and yield of rice.

Phytotoxicity

The herbicides applied in DSR did not show any phytotoxic symptoms i.e. chlorosis, necrosis, leaf epinasty, hyponasty, wilting or vein clearing during both the years of investigation.

Soil microbial activity

Population of rhizosphere microorganisms (i.e., total bacteria, fungi and actinomycetes) did not differ much (Fig. 1) during initial stages (in soil samples collected before sowing). However, their populations varied to a greater degree after application of herbicides across treated and non-treated plots. Among the treatments, UWC recorded higher microbial populations in soil up to 30 DAA in case of total bacteria and actinomycetes, and 15 DAA for fungi. This might be owing to higher rhizosphere activity owing to larger root density by weeds. Herbicides initially reduced the abundance, activity and diversity of microorganisms due to their toxic effects. But, it recovered during subsequent growth stages owing to higher rhizosphere activity attributable to improved crop growth provided by better control of weeds. Hence, higher activities of these microorganisms were noticed in plots that received pyrazosulfuron ethyl and combination of pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (at 30 DAA and later). Toxic effects of herbicides are temporary and usually pronounced immediately after application, when its concentration is higher. Subsequently, microorganisms are able to degrade the organic herbicide molecules and utilize carbon substrate for their own physiological processes (Mondal *et al.*, 2018). Thus, the higher rhizosphere activity put forth by improved crop growth coupled with reduced concentra-

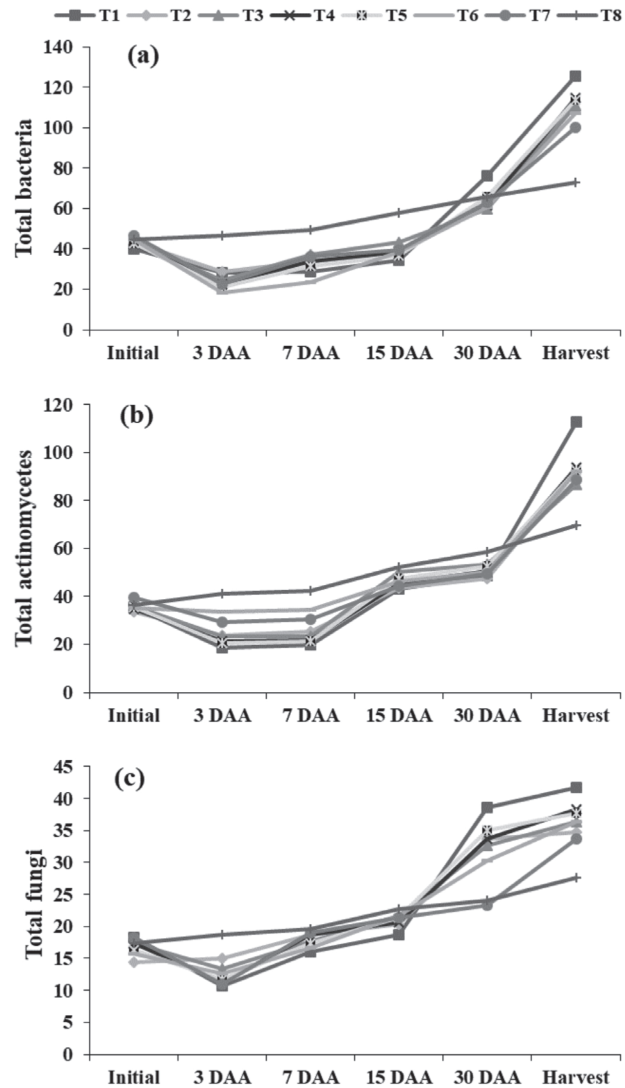

Fig. 1. Effect of weed-control treatments on (*a*) total bacteria (CFU × 10^6/g of soil); (*b*) actinomycetes (CFU × 10^5/g of soil); and (*c*) fungi (CFU × 10^4/g of soil) population.

Table 4. Effect of weed-control treatments on yield attributes and yield of direct-seeded rice (pooled over 2 years)

Treatment	Effective tillers/m^2	Filled grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	increase in yield (%) over control
T_1	204	71.67	2.77	4.07	40.51	168.9
T_2	174	64.67	2.51	3.66	40.71	143.7
T_3	195	69.66	2.70	3.98	40.45	162.1
T_4	207	72.67	2.89	4.08	41.46	180.6
T_5	219	74.33	2.99	4.29	41.07	190.3
T_6	192	68.33	2.68	3.92	40.57	160.2
T_7	216	72.33	2.95	4.22	41.12	186.4
T_8	156	52.33	1.03	1.49	40.87	-
SEm±	1.88	0.66	0.04	0.05	0.30	-
CD (*P*=0.05)	5.69	2.01	0.11	0.14	NS	-

NS, Non-significant.

tion of chemicals in soil leads to an increase of soil microflora. Raj *et al*. (2015) did not observe any adverse effect on microbial population after combined application of bispyribac-Na + metamifop (60–90 g/ha).

Correlation and regression analysis

The weed density and dry matter had highly significant negative correlation with the yield attributes and yield of rice in both the years (Table 5 and Fig. 2*a*, *b*, *c*). However, the yield attributes like effective tillers and filled grains were positively correlated with yield components (Table 5 and Fig. 2*d*). It implies that yield attributes and yield components of rice decreased with proportional increase in weed interference and vice-versa. Similar negative correlation between weeds and crop was reported by Ganai *et al*. (2014), who stated that higher weed density and biomass caused significant reductions in yield attributes which in turn reduced the crop yield significantly.

From the present study, it may be inferred that the complex weed flora observed in DSR can be effectively managed through combined application of pyrazosulfuron ethyl + pretilachlor @ 3.50 kg/ha (pre-mix) at 20 days after sowing. This would lead to better weed control with improved crop growth and grain yield of rice under direct-seeded condition and may be recommended in DSR particularly when pre-emergence application of herbicide is not feasible.

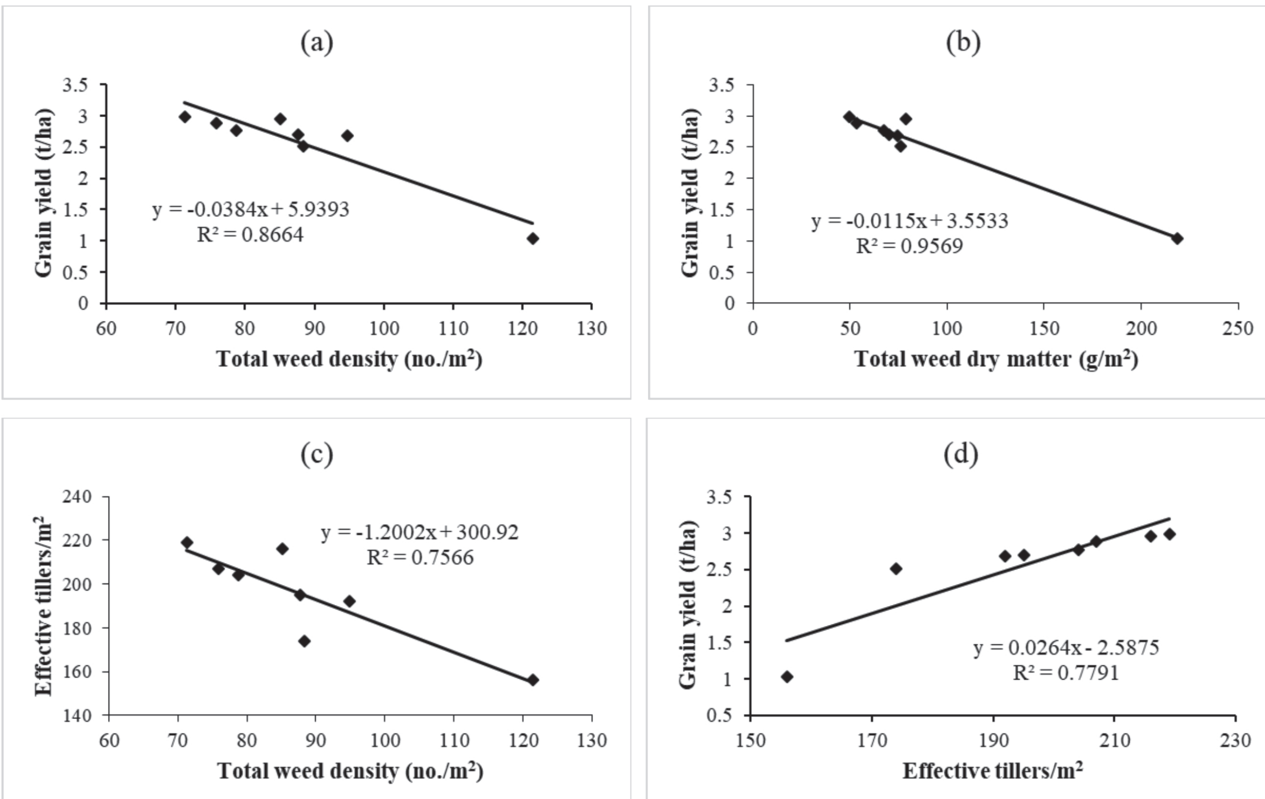

Fig. 2. Relationship between (*a*) grain yield and weed density; (*b*) grain yield and weed dry matter; (*c*) effective tillers and weed density; and (*d*) grain yield and effective tillers as affected by various weed-control treatments.

Table 5. Pearson's correlation matrix among the weed density and dry weight at 30 days after application of herbicides and yield components

Parameter	Weed density (no./m^2)	Weed dry weight (g/m^2)	Effective tillers/m^2	Filled grains/ panicle	Grain yield (t/ha)	Straw yield (t/ha)
Weed density (no./m^2)	1					
Weed dry weight (g/m^2)	0.937**	1				
Effective tillers/m^2	-0.870**	-0.796*	1			
Filled grains/panicle	-0.950**	-0.943**	0.950**	1		
Grain yield (t/ha)	-0.931**	-0.978**	0.883**	0.978**	1	
Straw yield (t/ha)	-0.921**	-0.981**	0.866**	0.972**	0.998**	1

Value followed by * and ** denote correlation is significant at 0.05 and 0.01 level respectively (2-tailed).

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