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Efficacy of pre-seeding application of two formulations of paraquat dichloride in managing weeds in dry direct-seeded rice

Tej Pratap*, V. Pratap Singh, S.P. Singh, Abnish Kumar, Soniya Saini and Neeta Tripathi

G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263145, India

Email: drtpsingh2010@gmail.com*

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ABSTRACT

A field experiment was conducted at GBPUA&T, Pantnagar during *Kharif* (rainy) season of 2015 to evaluate and compare the efficacy of pre-seeding application, at 2 days before seeding (DBS), of two formulations of paraquat dichloride on weeds associated with dry direct-seeded rice (dry-DSR) and assess their possible phytotoxicity to rice crop. Two formulations of paraquat dichloride include: i. Sponsor sample (SS) (paraquat dichloride 45% SL) tested at 300, 450, 800, 1600 g/ha and ii. Commercially available paraquat dichloride market sample (MS) tested at 800 g/ha. The paraquat dichloride at 1600 g/ha provided 85-95% weed control efficiency at all crop growth stages. All the herbicidal treatments were found significantly superior over hand weeding twice [(before sowing and at 20 days after seeding (DAS)]. The highest grain yield (3.3 t/ha) was obtained with paraquat dichloride 1600 g/ha followed by 800 g/ha. No symptoms of phytotoxicity were observed on dry-DSR at any of the doses of both the formulations of paraquat dichloride applied two days before seeding rice. Paraquat dichloride (SS) efficacy at 1600 and 800 g/ha applied 2 DBS was at par with each other in effectively managing broad spectrum weeds in dry direct-seeded rice in *Tarai* water (lowland) region of Uttarakhand.

Rice (*Oryza sativa* L.) is the major staple crop of India accounting for 39.64% of total food grain production (284.83 million tons) during 2017-18 (DOES 2018). In India, rice occupies an area of 43.1 million hectares and its productivity is low (around 2.6 t/ha) (India Stat, 2017-18). To meet the future food demand, the productivity of rice in India is to be increased. The major challenge is to achieve higher grain yield with less water, labor, and chemicals, thereby ensuring long-term sustainability. Since rice is mostly grown under flooded condition in puddled soil by transplanting rice (PTR), which is highly cumbersome and laborious. Over the years, transplanted rice culture, a labour-intensive establishment system with high and stable yield was highly suited to the labour surplus in India till the fanged of late 20th century. Eliminating manual transplanting operation which requires 238 man-hours/ha (Dixit and Khan 2011) could result in savings anywhere between ₹ 7500-10000/ha. To avoid nursery raising and transplanting of rice, direct-seeding of rice (DSR) by both dry- and wet-seeding methods have been considered good. Reduced duration of crop (7-12 days) under direct-seeding of rice adds to crop intensification in a year (Mondal *et al.* 2015). Thus, DSR is considered as the best alternative for transplanting (Kaur and Singh 2017). Heavy weed infestation is one of the major constraints for DSR adaptation.

In India, yearly loss of rice grain production is around 15 million tonnes due to heavy weed infestation (Singh *et al.* 2018). Weed management is considered as most critical in dry direct-seeded rice (dry-DSR) due to simultaneous emergence of crop and weeds (Rao *et al.* 2007). In DSR, the critical period of crop weed competition has been reported to be 14–41 days after sowing (Chauhan and Johnson 2011). Thus, in DSR it is important to minimize the crop-weed competition during the early stages of the crop before it forms a closed leaf canopy to reduce the weed competition and for effective utilization of available resources for enhanced productivity (Singh 2008). The manual weeding is the traditional method but increased wages and demand for labour at peak periods are major limitations of using hand weeding. Hence, chemical weed management was found to be highly efficient and cost-effective method of managing weeds in DSR. Keeping this in view, a field experiment was conducted to evaluate and compare

the bio- efficacy of pre-seeding application of two formulations of paraquat dichloride on the weeds associated with dry-DSR and also to assess their possible phytotoxicity on rice.

The field experiment was conducted at GBPUA&T, Pantnagar (29ÚN latitude, 27.3ÚE longitude and at an altitude of 243.8 m above mean sea level) during *Kharif* (rainy) season of 2015. The climate of Pantnagar is very hot in summers and cold in winters. The soil of the experimental site is clay loam in texture. During crop growth period (July to November, 2015) the area received total rainfall of 769.9 mm and the average maximum and minimum temperatures were 31.5ºC and 21.0ºC, respectively. The experiment was laid out in randomized block design with three replications. Eight treatment combinations comprised of four doses (300, 450, 800 and 1600 g/ha) of sponsor sample of paraquat dichloride [paraquat dichloride 45% SL] (SS); commercially available paraquat dichloride market sample (MS) as standard check 800 g/ha; pendimethalin at 1000 g/ha, hand weeding twice (before sowing and at 20 DAS) and weedy check. Herbicides were applied with knapsack sprayer fitted with flat fan nozzle using 500-liter water/ha. For phytotoxicity study, SS (paraquat dichloride 45% SL) at 450, 800 and 1600 g/ha was applied two days before sowing of dry direct-seeded rice and compared with control. A rice variety '*Govind*' was sown manually with 20 x 10 cm planting geometry in a plot size of 5.0 x 4.0 m with seed rate of 50 kg/ha. Thinning was done manually to maintain plant population. Irrigation was applied in the field as per requirement. Recommended dose of fertilizer (70:60:40 kg NPK/ha) was applied as per package of practices of crop for the area. Both the formulations of paraquat and pendimethalin were sprayed 2 days before sowing.

Category-wise weed count (density) and their dry biomass accumulation (biomass) and total weed density and biomass were measured at 15, 30, 45 days after application (DAA) by placing a quadrate of 0.25 m^2 randomly at 3 places in each plot and were subjected to square-root transformation $(\sqrt{x+1})$ before analysis and weed control efficiency was calculated. Data were analyzed by using standard statistical techniques (STPR package). Treatment means were separated using the least significant difference (LSD) at the 5% level of significance. Differences were considered significant only at P=0.05. Crop was harvested on November 05, 2015 and left in the field for 5-7 days for sun drying. The number of panicles/m^2, grains/panicle, 1000 grain weight, grain yield and straw yield were recorded. Phytotoxic symptoms were recorded at 1, 3, 5, 7 and 10 days after application of paraquat dichloride 450, 800 and 1600 g/ha and were compared with weedy check. Carry over effect of applied herbicides were also observed on succeeding wheat crop by recording wheat yield parameters and yield at harvest of wheat grown in rotation in the experimental plots, using standard procedures.

Effect on weeds

The weed species observed in the experimental field at the time of herbicide application were; *Echinochloa colona*, *Eleusine indica*, *Panicum maximum*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium* among the grasses; *Phyllanthus niruri* and *Ammania baccifera* among the broad-leaved weeds and *Cyperus iria*, *Cyperus halpans* and *Cyperus rotundus* among the sedges. Among all the weed species, *Echinochloa colona*, *Eleusine indica* and *Cyperus iria* were most predominant as reported earlier also by Maity and Mukherjee (2008).

The tested weed control treatments had significant effect on weeds density at 15, 30 and 45 days after application (DAA). There was considerable increase in the weed control efficiency of paraquat dichloride (SS) with the increase in rate from 300 to 1600 g/ha in reducing the density of all grassy and non-grassy weeds. *P. maximum*, *D. sanguinalis* and *D. aegyptium* among the grassy; *P. niruri* among the broad-leaf weeds and *C. iria* and *C. halpans* among the sedges were completely controlled with application of paraquat dichloride (SS) at 1600 g/ha and was at par with its lower dose (800 g/ha). At 45 DAA, *D. sanguinalis* was completely controlled with paraquat dichloride (SS) applied at 800 and 1600 g/ ha, which was also effective in reducing the density of other non-grassy weeds (**Table 1-3**). Being a non-selective contact-herbicides, paraquat dichloride (post-emergence) showed promising broad-spectrum control of diverse weeds by desiccation and defoliation during critical period of crop weed competition with an extended period of 30-40 days of crop establishment (Hofstra *et al.* 2001)**.**

The lowest total weed density was recorded with paraquat dichloride at 1600 g/ha and was significantly superior to rest of the herbicidal treatments at all stages of crop growth (**Table 4**). The lowest total weed biomass and highest weed control efficiency was recorded with application of paraquat dichloride 1600 g/ha followed by paraquat dichloride 800 g/ha, at all stages of crop growth (**Table 4**). This is due to the broad-spectrum control of weeds

Table 1. Effect of different treatments on weed density at 15 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. baccifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	4.8 (21.7)	5.1(25.3)	2.5(5.3)	2.2(4.0)	2.2(4.0)	1.0(0.0)	3.0(8.0)	1.9(2.7)	1.3(0.8)	3.4(10.7)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.0(14.7)	2.8(6.7)	1.5(1.3)	1.7(2.0)	1.7(2.0)	1.0(0.0)	2.8(6.7)	1.0(0.0)	1.0(0.0)	2.8(6.7)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.4(10.7)	1.9(2.7)	1.0(0.0)	1.5(1.3)	1.0(0.0)	1.0(0.0)	2.6(6.0)	1.0(0.0)	1.0(0.0)	1.5(1.3)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.3(10.0)	1.9(2.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.9(7.3)	1.0(0.0)	1.0(0.0)	1.6(1.7)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.9(17.3)	2.9(7.3)	1.0(0.0)	1.9(2.7)	1.5(1.3)	1.0(0.0)	2.5(5.3)	1.0(0.0)	1.0(0.0)	2.5(5.3)
Pendimethalin-1000 g/ha 2 DBS	4.5(19.3)	3.4(10.7)	2.9(7.3)	1.0(0.0)	1.0(0.0)	1.9(2.7)	2.5(5.3)	1.5(1.3)	2.1(3.2)	3.8(13.3)
Hand weeding twice before sowing and 20 DAS	2.8(6.7)	3.4(10.7)	1.8(2.7)	1.9(2.7)	2.8(6.7)	1.9(2.7)	2.8(6.7)	4.1(16.0)	1.7(2.0)	3.2(9.3)
Weedy check	7.7(58.0)	6.3(38.7)	4.4(18.7)	2.8(6.7)	4.3(17.3)	2.8(6.7)	4.3(17.3)	8.5(72.0)	6.7(44.0)	4.9(22.7)
LSD (p=0.05)	0.5	0.56	0.56	0.41	0.36	0.3	0.40	0.39	0.38	0.61

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

Table 2. Effect of different treatments on weed density at 30 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. bacifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	5.4(28.7)	4.3(17.3)	3.0(8.0)	2.4(4.7)	1.9(2.7)	1.7(2.0)	2.9(7.3)	2.5(5.3)	1.0(0.0)	5.0(24.0)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.5(19.3)	3.2(9.3)	2.5(5.3)	1.5(1.3)	1.5(1.3)	1.0(0.0)	2.9(7.3)	1.5(1.3)	1.0(0.0)	4.9(22.7)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.6(11.7)	2.8(6.7)	2.2(4.0)	1.0(0.0)	1.5(1.3)	1.0(0.0)	3.0(8.0)	1.5(1.3)	1.0(0.0)	4.4(18.7)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.2(9.3)	2.8(6.7)	2.1(3.3)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.8(6.7)	1.0(0.0)	1.0(0.0)	4.3(17.3)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.7(21.0)	3.4(11.0)	2.6(6.0)	2.1(3.3)	2.2(4.0)	1.4(1.0)	3.2(9.7)	2.0(3.0)	1.0(0.0)	5.2(26.0)
Pendimethalin-1000 g/ha 2 DBS	4.8(22.3)	3.6(12.0)	4.0(14.7)	1.5(1.3)	1.0(0.0)	2.2(4)	3.7(12.7)	3.5(11.7)	2.7(6.3)	4.9(22.7)
Hand weeding twice before sowing and 20 DAS	2.9(7.8)	2.1(3.3)	2.2(3.1)	1.7(2.0)	1.7(2.0)	1.5(1.3)	2.1(3.3)	2.2(3.1)	1.5(1.3)	3.5(11.6)
Weedy check	8.5(71.0)	7.2(51.3)	6.2(37.3)	3.3(9.7)	4.9(23.3)	3.2(9.3)	4.7(21.0)	8.9(79.0)	8.0(63.3)	7.2(50.7)
LSD (p=0.05)	0.33	0.44	0.3	0.65	0.42	0.3	0.3	0.49	0.14	0.76

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

Table 3. Effect of different treatments on weed density at 45 days after herbicide application

Treatment	Weed density (no./m^2)									
	Grassy					Broad-leaved		Sedges		
	E. colona	*E. indica*	*P. maximum*	*D. sanguinalis*	*D. aegyptium*	*P. niruri*	*A. bacifera*	*C. iria*	*C. halpans*	*C. rotundus*
Paraquat dichloride (SS) 300 g/ha 2 DBS	6.0(34.7)	4.8(21.7)	3.5(11.0)	2.4(5.0)	2.2(4.0)	2.1(3.3)	3.3(10.0)	3.4(10.7)	2.5(5.3)	5.4(28.7)
Paraquat dichloride (SS) 450 g/ha 2 DBS	4.7(21.0)	3.6(11.7)	4.4(18.7)	1.7(2.0)	1.8(2.3)	1.5(1.3)	3.2(9.3)	2.2(4.0)	1.9(2.7)	5.0(24.0)
Paraquat dichloride (SS) 800 g/ha 2 DBS	3.6(12.3)	3.0(8.0)	2.7(6.3)	1.0(0.0)	1.7(2.0)	1.3(0.7)	2.9(7.7)	2.1(3.3)	1.4(1.0)	4.6(20.3)
Paraquat dichloride (SS) 1600 g/ha 2 DBS	3.5(11.0)	2.9(7.3)	2.6(5.7)	1.0(0.0)	1.4(1.0)	1.3(0.7)	2.8(7.0)	1.9(2.7)	1.3(0.7)	4.2(17.0)
Paraquat dichloride (MS) 800 g/ha 2 DBS	4.8(22.7)	3.6(12.0)	3.1(8.7)	1.6(1.7)	1.6(1.7)	1.4(1.0)	3.4(10.3)	2.4(4.7)	2.0(3.0)	5.3(26.7)
Pendimethalin-1000 g/ha 2 DBS	5.2(26.3)	4.3(17.7)	4.6(20)	3.0(8.3)	2.1(3.3)	3.0(8.0)	4.0(15.3)	3.6(12.3)	3.5(11.7)	5.5(29.0)
Hand weeding twice before sowing and 20 DAS	4.2(16.7)	4.1(15.7)	4.4(18.3)	3.5(11.0)	3.5(10)	3.7(12.7)	4.0(15.0)	4.2(16.7)	2.8(7.0)	5.4(28.3)
Weedy check	8.2(66.0)	8.3(67.3)	7.0(48.3)	4.3(17.3)	6.3(39.0)	4.2(16.6)	6.3(39.3)	9.5(89.3)	8.5(70.6)	8.6(73.0)
LSD (p=0.05)	0.28	0.31	0.41	0.3	0.46	0.22	0.40	1.7	1.1	0.84

DBS: Days before sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

by paraquat dichloride (Singh *et al.* 2016). The highest herbicide efficiency index (HEI) was also observed (3.3%) with the paraquat dichloride 1600 g/ha followed by paraquat dichloride 800 g/ha. Application of pendimethalin (standard check) at 1000 g/ha obtained lowest weed persistence index (0.98%) followed by paraquat dichloride applied at 450 g/ha.

Effect on rice yield attributing characters and grain yield

The hand weeding twice (before sowing and at 20 DAS) was found to be superior in obtaining the highest rice grain yield and yield attributing characters (**Table 5**). However, among different herbicidal treatments, highest number of panicles/m^2, grains/panicle and 1000 grain weight was recorded with

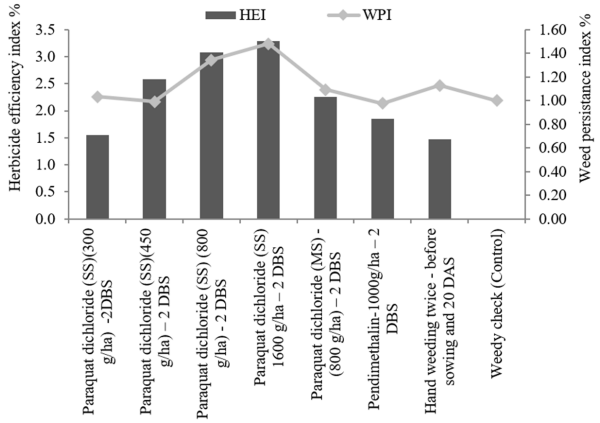

Figure 1. Effect of treatments on herbicide efficiency index (HEI) and weed persistence index (WPI)

paraquat dichloride (SS) at 800 g/ha, which was at par with all other herbicidal treatments except lower dose of paraquat dichloride 300 g/ha. These effects are mainly due to lower crop-weed competitions for various growth factors during the crop growth period.

Paraquat dichloride (SS) at higher dose (1600 g/ha) was found superior in achieving the highest rice grain (3.3 t/ha) and straw yield (5.2 t/ha), which was at par with its respective lower doses at 450 and 800 g/ha as well as MS at 800 g/ha. Maximum increase in rice grain yield (95.98%) over weedy check was recorded with paraquat dichloride (SS) at 1600 g/ha and next maximum increase was with 800 g/ha. This might be due to higher weed control efficiencies of these treatments that reduced the crop-weed competition for resources and allowed the crop to grow to its best potential which in turn positively influenced grain and straw yield of rice (Ganai*et al.* 2014).

Phytotoxicity

There were no phytotoxic symptoms observed on dry direct-seeded rice crop of SS (paraquat dichloride) applied 2 days before seeding at all three doses (450, 800 and 1600 g/ha), even when the herbicide was applied on emerging of weeds at 3-5 leaf stage.

Table 4. Effect of treatment on total weed density and biomass and weed control efficiency at different stages of dry direct-seeded rice

Treatment	Total weed density (no./m^2)			Total weed biomass (g/m^2)			Weed control efficiency (%)		
	15 DAA	30 DAA	45 DAA	15 DAA	30 DAA	45 DAA	15 DAA	30 DAA	45 DAA
Paraquat dichloride (SS) 300 g/ha 2 DBS	9.1(82)	10.0(100)	11.6(134)	8.08(64)	9.8(95)	11.0(121)	77.00	75.83	73.66
Paraquat dichloride (SS) 450 g/ha 2 DBS	6.4(40)	8.3(68)	9.9(97)	5.74(32)	7.5(55)	9.2(84)	88.59	86.13	81.73
Paraquat dichloride (SS) 800 g/ha 2 DBS	4.8(22)	7.3(52)	7.9(62)	4.62(20)	6.9(47)	8.6(72)	92.74	88.13	84.27
Paraquat dichloride (SS) 1600 g/ha 2 DBS	4.8(22)	6.7(43)	7.4(53)	4.52(19)	6.5(41)	8.3(69)	93.06	89.60	85.08
Paraquat dichloride (MS) 800 g/ha 2 DBS	6.8(45)	9.3(85)	10.9(101)	6.52(41)	9.0(79)	9.9(96)	85.16	79.91	79.01
Pendimethalin-1000 g/ha 2 DBS	8.0(63)	11.3(108)	13.3(125)	7.78(60)	9.5(90)	10.4(106)	78.68	77.12	76.85
Hand weeding twice before sowing and 20 DAS	8.2(66)	6.4(40)	15.9(151)	7.67(58)	6.0(35)	12.3(149)	79.33	91.10	67.52
Weedy check	17.4(302)	20.4(416)	23.0(526)	16.75(279)	19.9(394)	21.5(460)	-	-	-
LSD (p=0.05)	0.26	0.36	0.13	1.2	1.8	2.5	-	-	-

DBS: Days before sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

Table 5. Effect of treatments on yield and yield attributes of dry direct-seeded rice

Treatment	Panicles (no./m^2)	Grains/ panicle	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Percent increase in grain yield over weedy check (%)
Paraquat dichloride (SS) 300 g/ha 2 DBS	152	78.7	22.2	2.8	4.1	68.99
Paraquat dichloride (SS) 450 g/ha 2 DBS	162	86.7	22.6	3.2	5.0	88.96
Paraquat dichloride (SS) 800 g/ha 2 DBS	163	87.7	22.8	3.2	5.1	93.94
Paraquat dichloride (SS) 1600 g/ha 2 DBS	162	87.0	22.8	3.3	5.2	95.98
Paraquat dichloride (MS) 800 g/ha 2 DBS	160	87.0	22.6	3.2	5.0	89.62
Pendimethalin-1000 g/ha 2 DBS	151	86.7	22.6	2.9	4.3	74.99
Hand weeding twice before sowing and 20 DAS	170	89.0	22.9	3.2	5.3	90.94
Weedy check	70	61.7	21.6	1.7	2.5	-
LSD (p=0.05)	15.5	6.2	0.49	2.94	9.10	-

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample

Table 6. Effect of various doses of paraquat dichloride applied in dry direct-seeded rice on the succeeding wheat crop during the *Rabi* (rainy) season

Treatment applied in DSR	No. of wheat plants/ m^2 at 15 DAS	Wheat Spikes (no./m^2)	No. of grains/ spike of wheat	1000 grain weight of wheat (g)	Wheat grain yield (t/ha)	Wheat straw yield (t/ha)
Paraquat dichloride (SS) 300 g/ha 2 DBS	103.7	291	48.5	43.7	4.3	6.9
Paraquat dichloride (SS) 450 g/ha 2 DBS	91.7	292	48.1	42.8	4.3	6.9
Paraquat dichloride (SS) 800 g/ha 2 DBS	95.3	273	47.5	43.7	4.4	7.0
Paraquat dichloride (SS) 1600 g/ha 2 DBS	103.7	293	52.8	43.4	4.4	7.0
Paraquat dichloride (MS) 800 g/ha 2 DBS	91.0	277	51.8	44.7	4.5	7.2
Pendimethalin-1000 g/ha 2 DBS	94.0	268	52.2	42.8	4.2	7.0
Hand weeding twice before sowing and 20 DAS	82.0	279	49.4	43.1	4.4	7.1
Weedy check	89.7	285	47.1	43.4	4.4	7.0
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

DBS: Days before rice sowing; DAS: Days after sowing; SS: Sponsor sample; MS: Market sample

Carryover effect

In succeeding wheat crop, the plant stands at harvest as well as wheat yield and yield attributing characters were not influenced significantly due to various weed control treatments applied during preceding rice crop and they were statistically similar to each other (**Table 6**). This concludes that pre-seeding application of paraquat dichloride in direct-seeded rice crop during *Kharif* (rainy) season was very safe for growing wheat crop during *rabi* season. No visual symptom of injury or phytotoxicity was observed due to any treatment used during the previous rice crop indicating their safety to wheat grown in rotation.

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