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ESTIMATION OF CRITICAL COMPETITION PERIOD OF RED SPRANGLETOP (*LEPTOCHLOA CHINENSIS* L.) IN DIRECT-SEEDED FINE GRAIN RICE (*ORYZA SATIVA* L.)

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Abstract

Red sprangletop (*Leptochloa chinensis* L.) has become one of the most troublesome weeds for direct-seeded rice (DSR). The degree of cost-effectiveness of any weed control strategy against this weed needs accurate information about its critical timing of weed removal (CTWR) in DSR production system. A two-year field study was executed to estimate yield losses and critical period of competition of red sprangletop weed in the fine-grain DSR. Experimental treatments were crop-weed competition periods of 7, 8, 9, 10 weeks after emergence (WAE) of rice crop. A full season weed free and weed infested plots were also kept as controls for comparison purpose. Results exhibited that during both years, each successive prolongation in weed competition period significantly increased red sprangletop dry weight and its N, P and K uptake causing significant reduction in yield attributes and paddy yield. Consequently, during years 2018 and 2019, the highest values of weed dry weight (1168 and 1452 kg ha^{-1}, respectively) and N, P and K uptakes (33.5 and 41.7, 7.67 and 9.62, 31.1 and 42.3 kg ha^{-1}, respectively) were recorded with full season red sprangletop competition. In comparison to weed free control, this treatment resulted in the highest reduction in plant height (30-49%), panicle length (23-45%), tillers m^{-2} (66-78%), grains panicle^{-1} (42-61%), 1000-grain weight (31-24%), paddy yield (65-75%) and biological yield (67-70%). The logistic model estimated the CTWR of red sprangletop in DSR to be initial 33-49 DAE and 31-52 DAE in order to prevent 10% yield losses during years 2018 and 2019, respectively.

Key words: Biological yield, Dry weight, Logistic model, Paddy yield, Nutrient uptake.

Introduction

The growing global population and the decreasing availability of agricultural land due to urbanization have made it crucial to enhance the productivity of staple crops per unit of land (Iqbal, 2020; Din *et al*., 2021). Rice (*Oryza sativa* L.), a key food staple, is vital for more than half of the world's population, providing a daily source of nutrition (Chauhan & Johnson, 2011; Abbas *et al*., 2021; Gaballah *et al*., 2023). Beyond its role in food security, rice holds significant economic importance, especially for small landholders in low-income countries (Hakim *et al*., 2021; Islam *et al*., 2021). Despite significant improvements achieved through genetic engineering approaches for many field crops (Hussin *et al*., 2022; Li & Iqbal, 2024), rice productivity has remained low in South Asian countries like Pakistan (Iqbal & Ali, 2015; Hoque *et al*., 2025).

The conventional method for rice planting involves transplantating 35-40 days old nursery seedlings into the puddled and flooded soils. This practice ensures high yield potential, effective weed control, and reduced water infiltration losses throughout the growing season (Sharma *et al*., 2003). According to the contradicting perspective, the puddled transplanted rice (PTR) system is often criticized for being, time-consuming, and resulting in delayed transplantation of over-aged rice seedlings. Besides, manual transplanting has been reported to cause a reduced plant population in the field, leading to a significant decline in paddy yield (Ehsanullah *et al*. 2007). The PTR method also requires substantial water input and intensive land preparation. Furthermore, wheat cultivation following a rice crop necessitates additional tillage operations to break the hardpan formed in the soil (Singh *et al*., 2008).

Water shortage has emerged as one of the most serious issues in a different region of the globe because of the high demand for water for agriculture as well as in industry making a challenge for water and the situation is additionally aggravated because of environmental changes (Iqbal & Iqbal, 2015). To cope with this scenario, direct-seeded rice (DSR) could emerge as a potent rice growing strategy under limited irrigation water resources (Farooq *et al*., 2011). In DSR method, rice seeds are directly sown in soil, and soil moisture is maintained at field capacity throughout the crop's growing period. The DSR method reduces irrigation water usage by 11-18% (Tabbal *et al*., 2002) and labor requirements by 11-66% compared to traditional method, while also allowing the crop to mature earlier (Singh *et al*., 2006). Furthermore, DSR can be harvested at least 7-10 days earlier than the conventional PTR system (Singh *et al*., 2008). However, a significant challenge with DSR is that weeds and crop plants germinate simultaneously, leading to severe competition (Khaliq & Matloob, 2011). Hence, heavy weed infestation poses a substantial barrier to the success of DSR (Chauhan, 2012). Failure in weed control can results in yield losses ranging from 60-100% under severe weed infestations (Rao *et al*., 2007).

Weeds pose serious challenge to sustainability of modern input-intensive farming system (Iqbal *et al.,* 2022; Ali *et al.,* 2023; Mir *et al.,* 2023). Among thses, *Leptochloa chinensis* commonly known as red sprangletop, is a prevalent weed in DSR systems. a This weed thrives under wet, drained and flooded conditions that permit it to compete with rice crop during its vigorous growth stages (Chauhan & Johnson, 2011). Believed to have originated in Asia, *L. chinensis* is commonly found around water channels and rice fields. It has since become a widespread invasive weed in Australia and West African countries. Recently, this weed has adapted to the microclimate of DSR systems in comparison to wet-planted rice (Allard *et al*., 2005). It strongly competes with rice crop for space, supplements, and light (Galinato *et al*., 1999). Apparently, its seeds fail to germinate under 5 cm of water depth, however, vigorously germinate in saturated soils.

Research on crop-weed competition provides farmers and land managers with important information that helps them decide when weed control is necessary. Furthermore, control methods that would increase efficiency and production, such as comprehending how the aboveground weed population is affected by the behavior of weeds (Hossain *et al*., 2021). These studies play a crucial role in establishing economic thresholds and identifying critical periods for weed control (CPWC), which are essential for crop yield (Rehman *et al*., 2020a, b; Safdar *et al*., 2023). The CPWC of a specific weed refers to the specific phase during the crop's growth cycle when weed presence causes significant yield losses, making it vital to identify this period for effective weed management (Knezevic *et al*., 2002; Rehman *et al*., 2019; Rehman *et al*., 2020). Knowledge of CPWC therefore acts as decision making tool for farmers to decide when to employ weed control to achieve the highest herbicide efficiency in terms of both the ecological and economic perspectives. The CPWC of a specific weed in certain crop, however, varies under variable agro-ecological conditions. For *L. chinensis* in DSR, determining its degree of competitiveness and CPWC is critical for effective management. This knowledge is particularly important to ensure the sustainability of the dry production system of rice under semi-arid conditions. Accordingly, a research investigation was designed to study the competition behavior and determine the CPWC of *L. chinensis* in the DSR system, aiming to enhance the sustainability of rice production in such environments.

Material and Methods

Site description: Field studies were carried out during summer seasons of two consecutive years (2018 and 2019) at the research area, College of Agriculture, University of Sargodha, Punjab, Pakistan. The experiment site is situated at geographical coordinates of 32.08°N, 72.66°E and 190 m altitude. Field previously vacated from wheat crop was selected for experiment. Metrological data were collected from Agricultural Meteorology Cell of In-service Training Institute Sargodha, Pakistan near research farm and presented in Figs. 1 and 2. The meteorological data of the study locality have been presented in Figure 1.

Soil characteristics: In each year before sowing, soil was subjected to physico-chemical analysis. Five soil samples were taken at the depth of 0-15 and 15-30 cm before sowing. These samples were gathered and make one combine sample for further analysis. The pH meter (PHS-3C) and EC meter (DDS-307) were used to assurance of soil pH and electrical conductivity (EC). Ginning and Hibbard's approach was followed to determine the nitrogen (N) content involving H_2SO_4 digestion, followed by refinement using macro Kjeldhal's apparatus (Jackson, 1962). The available phosphorus (P) in the soil was determined by the Olsen approach (Sims, 2000). For potassium (K) extraction, a 0.5 mol/L acetic acid solution was added to the air-dried soil sample and mixed with a mechanical stirrer for 30 min. This method sufficiently dislodged accessible K^+ particles. Subsequently, flame photometer was used to find-out K content of the filtered extract. The physico-chemical analysis of soil was conducted by collecting soil samples from 15-30 depth of the experimental block and data have been presented in Table 1. The soil pH ranged from 7.75 to 7.85 and organic matter content was 0.72-0.73. However, the soil was found to be deficient in all macronutrinets (N, P and K).

Experimentation and crop husbandry: Experimental treatments during both years comprised of four competition periods: 7, 8, 9, and 10 weeks after crop emergence (WAE). Control plots were maintained as either weedy or weed-free throughout the crop's growing period. The experiment was laid out as randomized completely block design (RCBD) with four replications. After the harvesting of wheat crop from the experimental site, the seedbed was prepared by cultivating the soil 2 to 3 times by using Tractor to the depth of 30 cm followed by planking. Paddy (cv. Super Basmati using seed rate of 35 kg ha^{-1}*)* was sown as planting material in June 2018 and 2019. Before crop sowing, rice seed (paddy) were soaked in water for the period of 8 hours and sown manually using a hand drill, maintaining 25 cm row spacing. Irrigation was applied just after sowing, and red sprangletop seeds with 90% germination were broadcasted in the field. Net plot size was 1.5 m × 5 m. The fertilizers N (200 kg ha^{-1}), P (150 kg ha^{-1}) and K (100 kg ha^{-1}) were applied using urea (46% N), di-ammonium phosphate (46% P and 18% N) and sulphate of potash (50%), respectively. One-third of the nitrogen and full doses of phosphorous and potassium were applied at time of sowing. Second dose of N was applied 35 days after sowing and the final dose was applied at flowering. Other weeds except red sprangletop were manually uprooted from the field just after their emergence. After prescribed weed competition period according to treatment plan, red sprangletop weeds were removed manually from the plots. Irrigation was applied as per requirement. At maturity, harvesting was done and response variables of weed (weed fresh weight, weed dry weight and NPK uptakes) and crop (plant height using a tailor's measuring tap, manual counting of number of tillers m^{-2}, spike length and number of grain $spike^{-1}$, whereas 1000-grain weight, grain yield, and biological yield were estimated using a balance) were recorded by following the standard protocols. Harvest index of DSR was estimated by following the equation 1.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100 \qquad (1)$$

Red sprangletop NPK uptakes: Red sprangletop plants from each treatment were put into the oven for drying at 70ºC till getting constant weight. The grinding of dried samples was done with the help of an electric grinder. Then mixing of 1 g of powdered sample with 10 mL H_2SO_4 in a conical flask was done and it was left at room temperature overnight. Subsequently, 5 mL of H_2O_2 was added and the flasks were placed on a hot plate and heated gradually until the mixture become colorless transparent. Each digested sample was diluted to 50 mL with distilled water and stored in clean plastic bottles. For nitrogen (N) determination, 10 mL of diluted sample was taken for the distillation of NH_3 by adding 40% NaOH with the help of a micro-Kjeldhal's apparatus. The N was collected as NH_3 in micro-Kjeldhal's receiver containing 4% boric acid solution mixed with Methyl red and Bromocresol green indicators. Titration was carried out alongside 0.1N H_2SO_4. A spectrophotometer (Beckman) and flame photometer (Jenway 8505) were employed for estimating P and K contents, respectively.

Statistical analysis: The collected data were subjected to statistical analysis by Fisher's ANOVA (analysis of variance) technique to determine the significance of employed treatments, whereas differences among treatments were compared using the least significant difference (LSD) test at 5% probability level (Steel *et al*., 1997). Statistix 8.1 computer software was used for data analysis. Moreover, arranged significant contrast comparisons for various weed-crop competition duration were made utilizing a single degree of freedom (df) contrast strategy (Little & Hills, 1978). Furthermore, to quantify the impact of weed-free and weedy duration on relative grain yield of rice, a three-parameter logistic equation was utilized. By the repetitious use of the NLIN method in SAS (SAS Institute, 2008), in line with the Knezevic *et al.* (2002), nonlinear regression model (equation) was fitted as follows:

$$Y= ((1/ (EXP (K^* (T-X)) + F)) + ((F-1)/ F)) *100$$

while Y is grain yield of rice (% of season-long weed-free yield), T is the time as days after crop emergence (DAE), while X presents the deflection point (DAT), and K and F are constants (Knezevic *et al*., 2002).

Results

Weed fresh and dry weight: The recorded data (Table 2) exhibited that fresh and dry weights of red sprangletop increased gradually with the prolongation in duration of its competition with rice. The highest fresh weight (2651.6 and 1168.2 kg ha^{-1}) and dry weight (3388.4 and 1452.5 kg ha^{-1}) of red sprangletop were recorded in 2018 and 2019, respectively full season competition. The contrast analysis indicated that with each successive increase in the competition period of red sprangletop resulted in a significant enhancement in both fresh and dry weights (Table 2). Moreover, fresh and dry biomass of red sprangletop harvested from plots with full-season competition remained statistically higher than the cumulative average fresh and dry biomass recorded from plots with competition durations of 7, 8, 9 and 10 WAE during both the years of study.

NPK uptake: The N, P and K are applied as primary nutrients for crop production that enhance the crop growth and development. Data representing NPK uptake by red sprangletop depicted that red sprangletop uptake of all the nutrients got successive incline in response to extension in period of its competition in rice crop during both the years of study (Table 3). Thus, significantly the highest uptake of N (33.52 and 41.76 kg ha^{-1}), P (7.67 and 9.62 kg ha^{-1}) and K (31.11 and 42.31 kg ha^{-1}) were recorded in 2018 and 2019, respectively from plots where red sprangletop was allowed to compete with rice crop throughout its growing period. However, the lowest N uptake (1.77 and 2.60 kg ha^{-1}), P uptake (0.33 and 0.50 kg ha^{-1}) and K uptake (1.70 and 2.40 kg ha^{-1}) in 2018 and 2019, respectively were chronicled from the plots where weed competition was allowed up to 7 WAE. In contrast, it was noted that with each succeeding increase in red sprangletop competition period, significant enhancement in its N, P, K occurred (Table 3). Moreover, N, P, and K uptake by red sprangletop harvested from plots of its full-season competition remained statistically higher than that of its average N, P, and K uptake within 7, 8, 9 and 10 WAE competition plots during both the study years.

Rice growth: Data pertaining to growth-related traits i.e. plant height and panicle length of rice under the influence of varied red sprangletop competition durations have been presented in Table 4. Results showed that plant height and panicle length of rice were gradually reduced by increasing red sprangletop competition duration from 7 WAE to full season competition. Consequently, the lowest plant height (57.3 cm and 43.9 cm) and panicle length (16.5 cm and 13.6 cm) of rice were recorded in 2018 and 2019, respectively with full season red sprangletop competition. The contrast analysis indicated that plant height of rice did not reduce by increasing red sprangletop competition duration from 9 WAE to 10 WAE (Table 4). However, the panicle length of rice was reduced by increasing red sprangletop competition duration from 9 WAE to 10 WAE in both years.

Rice yield and yield-related traits of rice: Paddy yield depends on three main plant traits viz., number of tillers, number of grains per panicle and 1000-grain weight collectively referred to as yield-related traits. The number of productive tillers per unit area is a major component contributing positively towards the paddy yield. The number of tillers m^{-2} showed a progressive downfall by an expansion in the weed-crop competition duration from zero competition to full season competition (Table 5). Subsequently, the lowest number of tillers (152.8 and 101.5 m^{-2} for the 2018 and 2019, respectively) were counted from plots with the full-season weed-crop competition. A similar trend was observed for the number of grains per panicle which reached its highest value (88.5

and 91.8 in the year 2018 and 2019, respectively) under weed-free conditions and declined significantly with increased competition duration. The full season weedy conditions thus resulted in the lowest grains per panicle (51.4 and 35.6) in 2018 and 2019, respectively. From contrast comparison, it is clear that each week increase in competition duration caused significant decline in number of tillers and number of grains from that recorded with the previous one (Table 5). However, increase in red sprangletop competition period from 8 WAE to 9 WAE did not cause significant reduction in number of grains per panicle of rice during both the years of study. Moreover, the values of both these parameters averaged across 7 to 10 WAE remained statistically higher than those recorded with full season weed competition for both years.

Data pertaining to the effect of increasing red sprangletop competition duration on 1000-grain weight and paddy yield of rice have been presented in Table 6. Data indicated that 1000-grain weight of rice was dropped up to 30% linearly with an increase in weed competition duration. Weed free plots produced the highest 1000-grain weight (21.7 and 22.3 g in 2018 and 2019, respectively (Table 6). The lowest value of 1000-grain weight of rice (16.8 and 15.6 g) was noted from plots where red sprangletop was allowed to compete with rice throughout its duration in 2018 and 2019, respectively. Contrast analysis showed that prolonging red sprangletop competition from 8 to 10 WAE did not result in a significant decline in the 1000-grain weight of rice (Table 6). However, further extending the competition duration beyond 10 WAE caused a significant reduction in this parameter during both the years of the study.

Paddy yield (kg ha^{-1}): The paddy yield was reduced linearly in response to extension in red sprangletop competition period from 0 WAE to full crop season (Table 6). The highest paddy yield (2731.0 kg ha^{-1} in 2018 and 2876.3 kg ha^{-1} in 2019) was recorded from plots with full-season weed free conditions. While, the least paddy yield (949.4 kg ha^{-1} in 2018 and 707.8 kg ha^{-1} in 2019) was observed in plots where red sprangletop competed with rice for the whole growing season, amounting to a 65% to 75% reduction compared to weed-free plots. The contrast analysis revealed that paddy yield experienced significant decrease with each week increase in red sprangletop competition (Table 6). However, paddy yields from plots with 9 WAE and 10 WAE remained statistically at par with one another in both years, indicating no significant decline in paddy yield between these durations. The logistic model of weed-crop competition (Figs. 3 and 4) identified the critical period of weed removal (CTWR) to prevent a 10% yield loss. The CTWR for direct-seeded rice was determined to be 33-49 DAE in 2018 and 31-52 DAE in 2019.

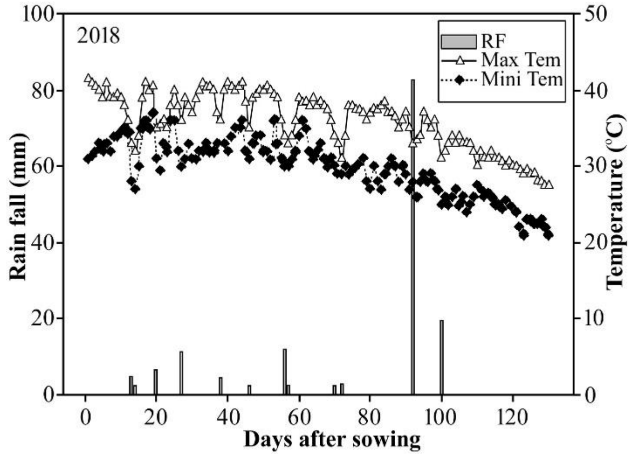

Fig. 1. Metrological data for the study year 2018.

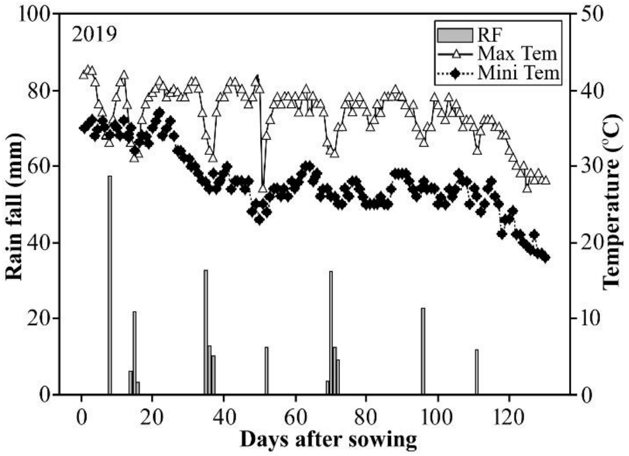

Fig. 2. Metrological data for the study year 2019.

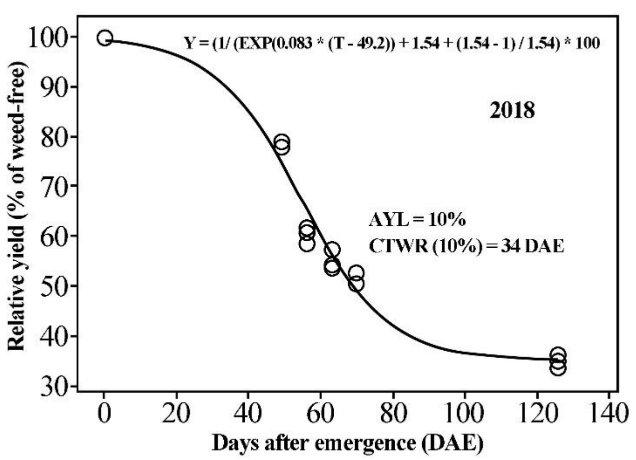

Fig. 3. Logistic model showing relative grain yield of Rice (DSR) at different weed competition durations during the year 2018.

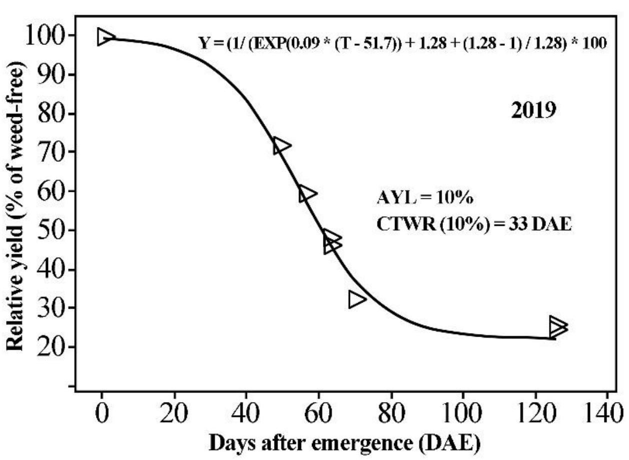

Fig. 4. Logistic model showing relative grain yield of Rice (DSR) at different weed competition durations during the year 2019.

Table 1. Physio-chemical analysis of soil.

Soil characteristics	Unit	Year			
		2018		2019	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH	-	7.7	7.8	7.8	7.9
Electrical conductivity	dS m^{-1}	1.73	1.80	1.76	1.79
Organic matter	%	0.90	0.55	0.93	0.53
Total N	%	0.043	0.039	0.045	0.040
Available P	ppm	8.4	4.1	8.5	4.2
Available K	Ppm	162	148	165	155
Texture	-	Loam		Loam	

Table 2. Effect of dissimilar weed-crop competition duration of *L. chinensis* fresh and dry weight (kg ha^{-1}) in DSR.

Treatments	Weed fresh weight kg ha^{-1}		Weed dry weight kg ha^{-1}	
	2018	2019	2018	2019
Full season weed-free	-------	-------	-------	-------
7 Week after emergence	138.8 e	295.4 e	70.0 e	101.4 e
8 Week after emergence	301.6 d	962.3 d	167.8 d	367.2 d
9 Week after emergence	591.5 c	1145.0 c	281.6 c	428.2 c
10 Week after emergence	1070.8 b	1342.0 b	437.0 b	583.1 b
Full season weedy	2651.5 a	3388.4 a	1168.2 a	1452.5 a
LSD	**83.44**	**111.84**	**90.84**	**58.63**
Contrasts				
7 WAE vs 8 WAE	138.8 vs 301.6**	295.4 vs 962.3**	70.0 vs 167.8**	101.4vs 367.2**
9 WAE vs 10 WAE	591.5 vs 1070.8**	1145 vs 1342**	281.6 vs 437.0**	428.2 vs 583.1*
7 WAE vs 8+9+10 WAE	138.8 vs 343.97**	295.4 vs 800.87**	70.0 vs 295.4**	101.4 vs 298.95**
10WAE vs Full season	1070.8 vs 2651.5**	1342 vs 3388.4**	437.0 vs 1168.2**	583.1 vs 1452.5**
7+8+9+10 WAE vs full season	525.68 vs 2651.5**	936.15 vs 3388.4**	239.1 vs 1168.2**	369.99 vs 1452.5**

Mean values in a column with dissimilar lettering vary significantly ($p<0.05$) from one another based on the least significant difference (LSD) test, ** Indicates significant at $p<0.01$

Table 3. Effect of dissimilar weed-crop competition durations on nitrogen, phosphorous and potassium uptake by *L. chinensis* in DSR.

Treatments	Nitrogen uptake (kg ha^{-1})		Phosphorous uptake (kg ha^{-1})		Potassium uptake (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019
Full season weed-free	--------	------	-------	-------	-------	--------
7 Week after emergence	1.77 e	2.60 e	0.33 e	0.50 e	1.70 e	2.40 e
8 Week after emergence	4.38 d	9.60 d	0.90 d	2.04 d	4.15 d	8.79 d
9 Week after emergence	7.51 c	11.55 c	1.63 c	2.47 c	7.02 c	10.91 c
10 Week after emergence	12.06 b	16.21 b	2.65 b	3.60 b	11.29 b	15.71 b
Full season weedy	33.52 a	41.76 a	7.67 a	9.62 a	31.11 a	42.31 a
LSD	**2.52**	**1.67**	**0.53**	**0.43**	**2.31**	**1.71**
Contrasts						
7 WAE vs 8 WAE	1.77 vs 4.38**	2.6 vs 9.6**	0.33 vs 0.90**	0.50 vs 2.04**	1.7 vs 4.15**	2.4 vs 8.79**
9 WAE vs 10 WAE	7.51 vs 12.06**	11.55 vs 16.21**	1.63 vs 2.65**	2.47 vs 3.6**	7.02 vs 11.29**	10.91 vs 15.71**
7 WAE vs 8+9+10 WAE	1.77 vs 7.98**	2.6 v 7.91**	0.33 vs 1.73**	0.50 vs 1.7*	1.7 vs 7.49**	2.4 vs 11.80**
10WAE vs Full season	12.06 vs 33.52**	16.21 vs 41.76**	2.65 vs 7.67**	3.6 vs 9.62**	11.29 vs 31.11**	15.71 vs 42.31**
7+8+9+10 WAE vs full season	6.43 vs 33.52**	9.99 vs 41.76**	1.38 vs 7.67**	2.17 vs 9.62**	6.04 vs 31.11**	19.43 vs 42.31**

Mean values in a column with dissimilar lettering vary significantly ($p<0.05$) from one another based on the least significant difference (LSD) test, ** Indicates significant at $p<0.01$

Biological yield (kg ha^{-1}): The biological yield and harvest index of rice were also considerably influenced by durations of weed-crop competition (Table 7). A progressive decline in these parameters was observed as the competition duration of red sprangletop weed increased. The highest biological yield (12871 and 13324 kg ha^{-1}) and harvest index (21.2% and 21.5%) in 2018 and 2019, respectively were noted with weed-free conditions throughout crop growing season. Conversely, the lowest biological yield (6169 and 4322 kg ha^{-1}) and harvest index (15.7% and 16.3%) in 2018 and 2019, respectively were recorded with full-season weedy conditions prevailed by red sprangletop. The contrast analysis showed that biological yield and harvest index significantly declined with each additional week of red sprangletop competition compared to the preceding week (Table 7). However, biological yield did not decline significant by extending red sprangletop competition duration from 9 WAE to 10 WAE during both years.

Table 4. Effect of dissimilar weed-crop competition durations on plant height (cm) and panicle length (cm) of rice in DSR.

Treatments	Plant height (cm)		Panicle length (cm)	
	2018	2019	2018	2019
Full season weed-free	81.1 a	84.9 a	21.0 a	24.8 a
7 Week after emergence	63.3 b	62.6 b	19.8 b	19.7 b
8 Week after emergence	64.0 c	59.2 c	19.1 c	18.0 c
9 Week after emergence	61.3 d	53.1 d	18.9 c	17.1 c
10 Week after emergence	60.4 d	51.5 d	17.4 d	14.5 d
Full season weedy	57.3 e	43.9 e	16.5 e	13.6 e
LSD	**0.92**	**1.49**	**0.39**	**0.78**
Contrasts				
7 WAE vs 8 WAE	63.3 vs 64.0**	62.6 vs 59.2**	19.8 vs 19.1**	19.7 vs 18.0**
9 WAE vs 10 WAE	61.3 vs 60.4^{NS}	53.1 vs 51.5^{NS}	18.9 vs 17.4**	16.6 vs 14.5**
7 WAE vs 8+9+10 WAE	63.3 vs 61.9**	62.6 vs 54.6**	19.8 vs 19.2**	19.7 vs 16.5**
10WAE vs Full season	60.4 vs 57.3**	51.5 vs 43.9**	17.4 vs 16.5**	14.5 vs 13.6**
7+8+9+10 WAE vs full season	62.2 vs 57.3**	56.6 vs 43.9**	18.8 vs 16.5**	17.3 vs 13.6**

Mean values in a column with dissimilar lettering vary significantly (p<0.05) from one another based on the least significant difference (LSD) test, ** Indicates significant at p<0.01

Table 5. Effect of dissimilar weed-crop competition durations on number of tiller m^{-2} and number of grain panicle^{-1} of rice in DSR.

Treatments	Number of productive tiller m^{-2}		Number of grains panicle^{-1}	
	2018	2019	2018	2019
Full season weed-free	455.7 a	468.5 a	88.5 a	91.8 a
7 Week after emergence	262.0 b	267.5 b	73.7 b	64.2 b
8 Week after emergence	223.2 c	196.2 c	69.7 c	56.0 c
9 Week after emergence	197.5 d	161.2 d	68.2 c	53.3 c
10 Week after emergence	183.0 e	139.7 e	60.8 d	44.2 e
Full season weedy	152.7 f	101.5 f	51.4 e	35.6 f
LSD	**13.15**	**6.08**	**2.75**	**3.04**
Contrasts				
7 WAE vs 8 WAE	262.0 vs 223.2**	267.5 vs 196.2**	73.7 vs 69.7**	64.2 vs 56.0**
9 WAE vs 10 WAE	197.5 vs 183.0**	161.2 vs 139.7**	68.2 vs 60.8*	53.3 vs 44.2*
7 WAE vs 8+9+10 WAE	262.0 vs 227.5**	267.5 vs 208.3**	73.7 vs 70.5**	64.2 vs 57.5**
10WAE vs Full season	183.0 vs 152.7**	139.7 vs 101.5**	60.8 vs 51.4**	44.2 vs 35.6**
7+8+9+10 WAE vs full season	216.4 vs 152.7**	191.1 vs 101.5**	68.1 vs 51.4**	54.2 vs 35.6**

Mean values in a column with dissimilar lettering vary significantly (p<0.05) from one another based on the least significant difference (LSD) test, ** Indicates significant at p<0.01

Table 6. Effect of dissimilar weed-crop competition durations on 1000-grain weight (g) and paddy yield (kg ha^{-1}) of rice in DSR.

Treatments	1000-grain weight (g)		Paddy yield (kg ha^{-1})	
	2018	2019	2018	2019
Full season weed-free	21.7 a	22.3 a	2731.0 a	2876.3 a
7 Week after emergence	19.3 b	19.8 b	2140.5 b	2070.5 b
8 Week after emergence	18.4 c	18.5 c	1685.1 c	1710.8 c
9 Week after emergence	18.1 c	18.0 c	1490.4 d	1364.0 d
10 Week after emergence	17.8 c	18.0 c	1422.0 d	1322.0 d
Full season weedy	16.8 d	15.6 d	949.4 e	707.8 e
LSD	**0.78**	**0.51**	**71.58**	**23.63**
Contrasts				
7 WAE vs 8 WAE	19.3 vs 18.4*	19.8 vs 18.5**	2140.5 vs 1685.1**	2070.5 vs 1710.8**
9 WAE vs 10 WAE	18.1 vs 17.8^{NS}	17.8 vs 16.1^{NS}	1490.4 vs 1422^{NS}	1364 vs 1322^{NS}
7 WAE vs 8+9+10 WAE	19.3 vs 18.6**	19.8 vs 18.1**	2140.5 vs 1772**	2070.5 vs 1465.6**
10 WAE vs Full season	17.8 vs 16.8**	16.1 vs 15.6**	1422 vs 949.4**	922 vs 707.8**
7+8+9+10 WAE vs full season	18.4 vs16.8**	18.6 vs 15.6**	1684.5 vs 949.4**	1616.83 vs 707.8**

Mean values in a column with dissimilar lettering vary significantly (p<0.05) from one another based on the least significant difference (LSD) test, ** Indicates significant at p<0.01

Table 7. Effect of dissimilar weed-crop competition durations on biological yield (kg ha^{-1}) and harvest index of rice in DSR.

Treatments	Biological yield (kg ha^{-1})		Harvest index (%)	
	2018	2019	2018	2019
Full season weed-free	12871 a	13324 a	21.2 a	21.5 a
7 Week after emergence	10494 b	10242 b	20.4 b	20.2 b
8 Week after emergence	8462 c	8958 c	19.9 c	19.0 c
9 Week after emergence	8000 d	7418 d	18.9 d	18.3 d
10 Week after emergence	7850 d	7125 d	17.7 e	17.6 e
Full season weedy	6169 e	4322 e	15.7 f	16.3 f
LSD	**397.10**	**289.55**	**0.35**	**0.58**
Contrasts				
7 WAE vs 8 WAE	10494 vs 8462**	10242 vs 8958**	20.4 vs 19.91*	20.22 vs19.09**
9 WAE vs 10 WAE	8000 vs 7850^{NS}	7418 vs 7125^{NS}	18.99 vs 17.77**	18.39 vs 17.66*
7 WAE vs 8+9+10 WAE	10494 vs 8985.34**	10242 vs 7833**	20.4 vs 19.77**	20.22 vs 19.23**
10WAE vs Full season	7850 vs 6169**	5225 vs 4322**	17.77 vs 15.77**	17.66 vs 16.39**
7+8+9+10 WAE vs full season	8701 vs 6169**	8435 vs 4322**	19.27 vs 15.77**	18.84 vs 16.39**

Mean values in a column with dissimilar lettering vary significantly ($p<0.05$) from one another based on the least significant difference (LSD) test, ** Indicates significant at $p<0.01$

Discussion

The shift from puddled transplanted rice to dry DSR systems has led to the emergence of red sprangletop as a serious weed in DSR. Previously, under puddled transplanted rice, red sprangletop could not thrive due to standing water conditions. In contrast, the dry DSR system provides favorable conditions for this weed, enabling it to grow much faster than rice, dominate the crop within 30 DAE, and attain its full height by 50 DAE. Under high rainfall conditions of tropical areas, red sprangletop competes with DSR from the middle vegetative growth phase to grain filling (Pane *et al.*, 1996). Pane & Mansor (1996) estimated a 41% grain yield loss in DSR due to red sprangletop competition, identifying 14 to 28 DAE as the critical period of its competition. However, its competitive behavior in low rainfall semi-arid areas was less understood. Hayyat *et al*., (2023) estimated the grain yield losses of up to 69% in DSR under semi-arid conditions and an economic threshold of 1.73 plants per m^2. The present investigation under sub-tropical semi-arid conditions of Punjab demonstrated that the prolongation of red sprangletop competition in DSR led to increased fresh and dry weight and nutrient uptake by the weed, while simultaneously reducing rice growth, yield, and yield-related traits. The linear increase in red sprangletop biomass and nutrient uptake with extended competition periods can be attributed to prolonged growth, allowing greater biomass accumulation. Our outcome also confirmed by Khaliq & Matloob (2011), who reported that weed dry weight significantly increased with the increase in competition duration. Similar observations were made by Akhtar *et al*., (2000) in wheat, Safdar *et al*., (2023) in extended weed-crop competition periods, and Nawaz & Farooq (2016), as well as Mehmood *et al*., (2018), who documented the highest NPK uptake in plots where alligator weed competed throughout the rice crop's growing season. Anjum *et al*., (2007) and Ikram *et al*., (2012) also noted increased NPK uptake by weeds under untreated weedy-check conditions. These consistent findings underscore the competitive dominance of red sprangletop in DSR systems, particularly under semi-arid conditions, and highlight the critical need for timely weed management strategies.

Plant height indicates the overall vegetative growth performance of crop while panicle length expresses the growth of plant during reproductive growth phase of crop. Rice crop takes about 9 WAE to complete its vegetative growth after which panicle initiation (PI) occurs (Brinkhoff *et al.*, 2023). Therefore, any environmental stress at this growth stage results in substantial reduction in its panicle length (Espe *et al.*, 2017). In this study, plant height was reduced while panicle length was not reduced by increasing red sprangletop competition from 8 WAE to 9 WAE. However, a further extension of red sprangletop competition from 9 WAE to 10 WAE resulted in a significant decline in panicle length. This might be because 9 WAE to 10 WAE corresponds to the critical phase of panicle growth and development in rice. Weed competition stress during this phase likely diverted essential resources, such as nutrients and moisture, away from the rice crop, thereby resulting in a decline in panicle length without significantly affecting the plant height. However, plant height was reduced in response to further extension in red sprangletop competition period up to whole growing season. These outcomes were similar with the findings of Rehman *et al*., (2020), Begum *et al*., (2006) who stated that significant reduction in plant height of rice when weed-crop competition was established with *Fimbristylis miliacea* for the period of 70 days. Maximum plant height and panicle length of rice was recorded with weed-free conditions, while the lowest values for these traits were recorded from plots subjected to season-long competition as reported by Mehmood *et al*., (2018). Similarly, Begum *et al*., (2008) documented the tallest rice plants in treatments with eliminated weed-crop competition. Our outcomes are also similar with those of Chauhan & Johnson (2011), who revealed a decrease plant height in rice exposed to increasing densities of *E. colona*. These results are according with the findings of Radosevich & Roush (1990), who measured the shortest panicle length of rice under full-season weedy conditions.

Tillering and the number of productive tillers are critical determinants of rice yield. A higher the number of productive tillers results in increased paddy yield. Tillers are branches that arises from the leaf axil at nodes of stem (Ling *et al.*, 2000). Tillering is considered an adaptive mechanism in cereals like rice which allowed plants to match the number of sinks with available resources (Assuero & Tognetti, 2010). In DSR, tillering occurs between 15 to 40 DAE (Yan *et al.,* 2010). However, higher planting density in DSR, lead to a higher tiller mortality rate at later growth stages, which is further augmented by prevailing stress factors (Ahmed *et al*., 2014). In our study, the number of tillers continued to decline with the increase in red sprangletop competition period. Similar to our outcomes, Khaliq & Matloob (2011) noted that weed-free plots produced the higher number of productive tillers of rice as compared to weedy plot. Juraimi *et al*., (2009) also observed a significant reduction in the number of productive tillers with increased weed infestation in transplanted rice. The number of grains per panicle of rice is a trait that is closely associated with the panicle length (Wang *et al.,* 2024). Grains develop during the panicle elongation phase, so greater panicle length typically results in more grains per panicle. Environmental factor that affect panicle elongation also influence grain numbers. In our studies, the number grains per panicle decreased consistently with an extension in red sprangletop competition, mirroring the decline in panicle length, except between 8 WAE and 9 WAE. This suggests that the reduction in grain numbers is linked to shorter panicle length. Previous studies byEkeleme *et al*., (2007), Begum *et al*., (2008), and Khaliq & Matloob (2011) stated that number of grains per panicle significantly reduced by the prolonged crop-weed competition. The 1000-grain weight is the one of the most important yield contributing traits that also determines the grain quality. Grain weight in turn depends on rate and duration of grain filling. Grain filling is the post-anthesis stage of rice growth when fertilized ovaries develop into caryopses (Wang *et al.,* 2012). The grain filling stage of rice usually exists during 60 DAE to crop maturity (Boonjung *et al.,* 1996). Grain weight is considered somewhat more genetically dependent trait (Chen *et al.,* 2021), although environmental factors mainly temperature also have some important role (Yan *et al.,* 2021). In the present studies, 1000-grain weight continued to decline in response to increase in red sprangletop competition period up to 8 WAE. Afterwards, no decrease was observed in this parameter till 10 WAE and then a further decrease was observed up to full season weed competition. The decrease in 1000-grain weight of rice in response to elongation in weed-competition period seems to be the result of competition stress at pre-anthesis and post-anthesis phases of grain development. These results are in line with the observations of Mehmood *et al*., (2018), who reported the 23% reduction in 1000-grain weight of rice due to alligator weed competition throughout growing duration of rice. Begum *et al*., (2008) also observed a significant effect on 1000-grain weight of rice due the competition with *F. miliacea*. Conversely, Shultana *et al*., (2013) noted that even the full season competition of *Echinochloa crusgalli* with rice could not influence its 1000-grain weight. Among panicle number, grains per panicle and 1000-grain weight of direct-seeded rice, Pane *et al*., (1996) found that although 1000-grain weight was significantly influenced by red sprangletop competition, it was not significantly correlated with paddy yield.

The biological yield of rice encompasses all the harvestable components, including paddy yield and leftover plant material. In our study, consistent decrease in the biological yield of rice with the increase in the weed-crop competition duration might be attributed to a combined result of diminished plant height of rice alongside its different yield attributed traits. These results are in line with the observations of Mehmood *et al*., (2018) and Safdar *et al*., (2023) who reported that the biological yield of rice was decreased with the increasing infestation period of alligator weed. Paddy yield is the ultimate goal of rice growers as paddy is the only harvestable and marketable produce of rice. In present studies, a consistent decline in paddy yield was observed from 7 WAE to 9 WAE after which it did not decrease up to 10 WAE red sprangletop competition. While a further reduction in paddy yield was noted extending red sprangletop competition up to full growing season. The paddy yield reduction in response to extending red sprangletop competition period seems to be the result of cumulative effect of number of productive tillers m^{-2}, the number of grains $panicle^{-1}$ and 1000-grain weight that also declined due to weed competition. Our results are in line with the findings of Hakim *et al*., (2013) and Shultana *et al*., (2013) who reported that rice grain yield decreased linearly with the increase in infestation period of weed. Additionally, Ekeleme *et al*., (2007) also inferred that increased duration of weed-crop competition significantly decreased rice yield attributes and paddy yield compared to weed-free plots kept for whole crop growth duration. Similarly, Khaliq & Matloob (2011) observed 89% reduction in the grain yield in DSR by full-season weed competition. Chauhan & Johnson (2011) reported that paddy yield of direct-seeded rice was decreased by 24% owing to weed competition for a period of 28 days after sowing (DAS).

In present studies, a three-parameter logistic equation was utilized to quantify the impact of weed-free and weedy duration on relative grain yield of rice. Logistic model showed that the CTWR for direct seeded rice was 33-49 DAE and 31-52 DAE in 2018 and 2019, respectively, in order to prevent production losses of 10%. Various researchers estimated variable critical weed-crop competition periods of rice depending on growing conditions. El-Desoki (2003) noted a sigmoidal relation among paddy yield attributes and weed-crop competition periods. Moreover, Mehmood *et al*., (2018) reported 4 WAE as a critical period of alligator weed in the transplanted rice. Johnson et al. (2004) estimated 38 DAS and 32 DAS to be the critical weed-crop competition periods in wet direct-seeded and dry direct-seeded rice, respectively.

Conclusion

Under chnaging climatic scenarios, global warming and irrigation water scarcity have seriously threatened the sustainability of water-intensive crops especially rice in semi-arid regions of the world. The direct seeding of rice has emerged as one of the potent strategy to grow rice under water deficient conditions, however weeds particularly red sprangletop pose serious challenge to paddy yield grown as direct seeded crop. Our results revealed that red sprangletop caused up to 75% yield losses of dry direct-seeded fine grain rice. The initial crop growth phase of 31-52 days after crop emergence was proved to be critical timing of control of this weed. Therefore, based on recorded findings, rice growers could be recommended to keep this weed under threshhold level during this period in order to prevent 10% yield losses of direct seeded rice. Future research studies need to focus on studying red sprangletop in combination with other weed species under varying agro-climatic conditions to sort-out the critical control period for boosting paddy yield in direct seeded rice production system in semi-arid climatic conditions.

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