Research Article

Weed Control and Yield Performance of Direct-Seeded Rice with Varying Rates of Post-Emergence Herbicides

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Abstract | Weeds are serious pests in rice sown under direct-seeded rice (DSR) technology. Herbicide-based weed management is becoming increasingly popular, but there is a dire need to choose appropriate herbicides and their effective dose for controlling weeds in DSR fields. A field trial was conducted to appraise the comparative efficacy of three post-emergent herbicides applied at different doses [Clover 20% EC (bispyribac sodium) at 39.54, 59.30, and 79.07 g a.i. ha^{-1}, Pyranex Gold 30% WDG (bispyribac sodium + bensulfuron methyl) at 74.13, 111.20, and 148.26 g a.i. ha^{-1}, and Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 and 92.66 g a.i. ha^{-1}] at 20 days after sowing (DAS) for weed control and paddy yield performance under DSR system. A weedy check was retained as control. Results revealed that Clover and Pyranex Gold applied at either dose significantly ($p \leq 0.05$) reduced the population and growth of *Cyperus iria* (90-97% weed density and 93-97% weed dry biomass) and *Echinochloa colona* (94-97% weed density and weed dry biomass) weeds over control, while Puma Super proved efficient in suppressing *Leptochloa chinensis* and *Echinochloa colona* weeds. Among all the tested treatments, application of Puma Super at 92.66 g a.i. ha^{-1} furnished the highest number of tillers (137.3 in 2014 and 141.3 in 2015), grains panicle^{-1} (77 in 2014 and 79 in 2015), final paddy yield (1983.8 and 1570 kg ha^{-1} in 2014 and 2015, respectively), and net economic returns (Rs. 95915 ha^{-1}), followed by the use of Puma Super at 46.33 g a.i. ha^{-1} which offered the next best economic benefits (Rs. 81906 ha^{-1}). Thus, applying Puma Super at 92.66 g a.i. ha^{-1} is appeared viable approach to control grassy weed flora and ensure higher paddy yield with higher economic returns when rice is sown under DSR technology.

Received | April 19, 2023; **Accepted** | January 15, 2024; **Published** | April 12, 2024
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Citation | Hussain, S., A. Ameen, M.E. Safdar, M.A. Naeem, A. Jawad, M. Ali, A. Nadeem, G. Abbas, M. Arif, M.A. Zafar and Z. Hassan. 2024. Weed control and yield performance of direct-seeded rice with varying rates of post-emergence herbicides. *Sarhad Journal of Agriculture,* 40(2): 362-371.
DOI | https://dx.doi.org/10.17582/journal.sja/2024/40.2.362.371
Keywords | Direct-seeded rice, Weed management, Post-emergence herbicides, Weed density and biomass, Yield traits and paddy yield, Net-economic returns

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Introduction

Rice (*Oryza sativa* L.) is a cereal crop which serves as primary food for above half of the people across the world (Khush, 2005). Being a main food as well as cash crop, rice holds a vital place in the agriculture of Pakistan which contributes about 0.4% in gross domestic product (GDP) and about 1.9% value addition in agriculture (Govt. of Pakistan, 2022-23). Rice is traditionally established in puddled soil via manual transplanting which is a common practice in Southeast Asia as well as in major rice growing areas (Punjab and Sindh) of Pakistan. The technique of puddling (wet tillage) proves beneficial in reduction of percolation losses, facilitating rice transplanting, killing weeds, and providing anaerobic conditions that helps to increase the availability of soil nutrients (Sanchez, 1973). Meanwhile, continuous puddling can destroy soil aggregates, break capillary pores as well as compact the soil and also result in formation of a shallow hardpan (usually within soil depth of 15-25 cm) (Kukal and Aggarwal, 2003a, b; Gathala *et al*., 2017, 2020; Choudhary *et al*., 2018) which ultimately results in reduced root growth and nutrients absorption by rice plants. This deterioration of soil physical characteristics would definitely affect negatively the growth of other crops in rotation with rice (Gathala *et al*., 2011). In puddled manual transplanted rice, the process of puddling requires a lot of energy input (Verma and Dewangan, 2006; Choudhary *et al*., 2018) and constant flooding for first 30 days after seedling transplanting necessitates a large quantity of irrigation water (Sudhir-Yadav *et al*., 2011). Meanwhile, large labor input is also required to transplant the rice nursery in the puddled soil which was not a major issue few years back when labor was easily available with reasonable charges (Bhatt *et al*., 2016). Thus, above mentioned scenario necessitates to develop alternative methods of rice production system in this region.

Recently in some Asian countries, manual transplanting of rice is being replaced by direct-seeded rice (DSR) rather than puddling and transplanting rice seedlings due to the reduced availability of water and labor (Pandey and Velasco, 2005). Direct-seeded rice farming system is advantageous over transplanted rice in terms of being more favorable to mechanization, easy and more rapid planting, less laborious, use of less irrigation water, and reduced emission of greenhouse gases such as methane (Farooq *et al*., 2011; Chauhan, 2012, Chauhan *et al*., 2012). In DSR system, dry seeds are sown in no-till condition or by using seed drill in a well-prepared seedbed. However, weeds are major debacle in the success of DSR (Chauhan and Johnson, 2010). The aerobic DSR seedbed is favorable for germination and setting up of diverse weed flora unlike that of puddled transplanted rice (Gill *et al*., 2013). Thus, DSR may be seriously vulnerable to be affected by weeds, and if weeds are not managed timely and efficiently, yield decline may reach up to 100% (Singh *et al*., 2014; Martin *et al*., 2017). The main reasons of weed problem in DSR system are the absence of standing water at the time of rice seedling emergence to suppress weeds and lack of the advantage of rice seedling size over weeds. As the rice and weeds seedlings emerge concurrently in DSR system, suitable weed control time and method becomes complex phenomenon (Khaliq and Matloob, 2011). Therefore, an early and effective weed control approach is imperative for DSR technique intended to accomplish greater paddy production and net profit (Jaya Suria *et al*., 2011).

For weed management in DSR, numerous approaches are being performed which include agronomic practices as well as manual, mechanical, and chemical weed control (Rao *et al*., 2007). However, the choice of weed management methods depends on soil type, climatic conditions, farmer's economic situation and yield target, and is evaluated by comparing the weed control cost with the estimated value of resultant yield increment (Khaliq *et al*., 2012). Weeding in Pakistan is usually carried out through labor; however, it is becoming unpopular due to labor availability issues at critical weeding time and higher labor costs. Chemical weed control in DSR has appeared as an auspicious solution of weed problem, as it is easy, fast, cost-effective and feasible. A number of pre-emergence herbicides were used alone or accompanied with hand weeding which offered sufficient weed control in DSR (Baloch *et al*., 2005; Ramesha *et al*., 2017; Zahan *et al*., 2018). However, short application time span, a critical moisture regime, and toxicity to rice crop are the concomitant challenges. Under this situation, post-emergence herbicides provide an option of alternate weed control (Khaliq *et al*., 2012; Zahan *et al*., 2018). Post-emergence herbicides, for example puma super, bispyribac sodium, and bensulfuron methyl have differential suppression effects on weeds and have narrow spectrum of controlling grasses and some sedges (Saha and Rao, 2010; Jat *et al*., 2021; Saha *et* *al*., 2021). Regarding appropriate dose, several studies has reported post-emergence application of bispyribac sodium at 30 g a.i. ha^{-1} as a suitable herbicide for the efficient control of mixed weed flora, increased paddy yield and maximum marginal rate of return (Khaliq *et al*., 2013; Kumar *et al*., 2013). It was also inferred that bensulfuron-methyl application at 60 g a.i. ha^{-1} proved effective in wet direct-seeded rice for broad spectrum weeds control (Saha and Rao, 2010). Fenoxaprop-p-ethyl @ 500 ml ha^{-1} applied at 1-2 leaf stage is also recommended for effective weed management in rice (Rana *et al*., 2012). However, farmers in Pakistan are still hesitating in adoption of DSR technology due to lack of a potential weed control strategy (Khaliq *et al*., 2011). Hence, it is necessary to evaluate the efficacy of different post-emergence herbicides with optimum dose to control weeds efficiently in DSR system with maximum net economic returns. Also, continuous herbicides selection is essential to overcome the rapidly evolving herbicides resistance in weeds; thus warranting low-input, environment safe, and sustainable production. Therefore, present study was planned to explore the effects of three post-emergence herbicides (Clover (bispyribac sodium), Pyranex Gold (bispyribac sodium + bensulfuron methyl), and Puma Super (fenoxaprop-p-ethyl)) on weed dynamics, paddy yield, and net economic benefits in DSR system.

Table 1: *Physical and chemical properties of the experimental site.*

Characteristics	Value
Texture	Clay loam
Soil pH	8.3
EC (mS cm^{-1})	2.0
Organic Matter (%)	0.73
Available Phosphorus (mg/kg)	5.2
Available Potassium (mg/kg)	81

Materials and Methods

A field experiment was conducted at PARC Farm, Kala Shah Kaku, Lahore during summer 2014 and 2015 to evaluate the bio-efficacy of various doses of three post-emergence herbicides in weed control and paddy yield of rice sown under DSR system. A field previously under wheat crop was selected based on prior field inspection regarding occurrence of different grassy and sedges weed species. The soil was alkaline in nature and clay loam in texture. The main physical and chemical properties of the experimental site are given in Table 1. The experiment was laid out in a randomized complete block design (RCBD) having three repeats with net plot size of 3 m × 5 m. The treatments consisted of a weedy check (control) and application of early post-emergence herbicides namely Clover 20% EC (bispyribac sodium) at 39.54, 59.30, and 79.07 g a.i. ha^{-1}, Pyranex Gold 30% WDG (18% bispyribac sodium + 12% bensulfuron methyl) at 74.13, 111.20, and 148.26 g a.i. ha^{-1}, and Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 and 92.66 g a.i. ha^{-1}. The rice variety 'Super Basmati' was used as a test crop. The experimental site was selected based on previous history of field. The field remained heavily infested with weeds (i.e., *Cyprus rotundus, Cyprus difformis, Cyprus iria, Cynodon dactylon, Dactyloctenium aegyptium, Echinochloa colona, Echinochloa crus-galli, Paspalum distichum, Leptochloa chinensis, Sphenoclea zeylanica*) having uniform weed density. The crop was sown on fourth week of June directly in field using a manual drill at 35 kg ha^{-1} seed rate in 22.5 cm spaced rows. Fertilizer at 134 kg N, 85 kg P_2O_5, and 60 kg K_2O ha^{-1} was also applied to supplement the crop with nutrients. All the phosphorous and potash and 1/3rd of N fertilizer was applied before seed sowing. The remaining nitrogen was applied at tillering and panicle initiation stages in equal splits. The post-emergence herbicide application treatments were imposed at 20 days after sowing (DAS) using a knapsack sprayer fitted with a flat fan nozzle. The calibration of sprayer was done to determine the water volume (300 L ha^{-1}) before using it. A single dose of zinc @ 25 kg $ZnSO_4$ (27%) ha^{-1} was also applied at 30 DAS. Experimental plots were irrigated as and when moisture deficit was observed. The dominant weeds in the experimental area were *Leptochloa chinensis*, *Cyperus iria*, and *Echinochloa colona*. Data regarding weed dynamics (weed density and dry biomass) of all individual weeds under study were noted 45 DAS (i.e., 25 days after herbicide application) from a randomly selected quadrate (1 m × 1 m) from each experimental plot. Weeds were mowed at the ground level, weighed, and then dried in an electric oven at 70ºC till constant weight in order to determine dry biomass. Data on rice plant height were noted from 10 randomly selected plants from each plot. Two random sites were selected from each plot to count the number of tillers (m^{-1}). Ten panicles from each plot were taken randomly to record number of grains panicle^{-1} and panicle length. To determine 1000-grain weight, grains were manually counted from a random sample of each plot and then weighed using an electric weighing balance. On 2nd week of November, plants from an area of 1.0 m^2 were harvested from each experimental plot, tied into bundles, and then threshed manually to calculate the paddy yield on per hectare basis. The recorded data were analyzed statistically using Statistix 8.1 software and means were grouped by using Fisher's analysis of variance technique at 5% level of probability (Steel *et al*., 1997). Economic analysis was performed to see the comparative profits of various treatments (Khaliq *et al*., 2012).

Results

Individual and total weed density

Significant effects of different herbicides application treatments were observed on total and individual weeds density recorded 45 DAS in both years (Table 2). Regarding individual weed density, infestation of *Leptochloa chinensis* was more severe in 2015 than in 2014, while the reverse phenomenon was observed for *Cyperus iria* and *Echinochloa colona*. In 2014, both doses of Puma Super (fenoxaprop-p-ethyl) i.e., 46.33 and 92.66 g a.i. ha^{-1} highly suppressed ($p \leq 0.05$) the density of *Leptochloa chinensis* (>96%), whereas application of various doses of Pyranex Gold (bispyribac sodium + bensulfuron methyl) and Clover (bispyribac sodium) could not reduce its density but controlled species of *Cyperus iria* (>94%) and *Echinochloa colona* (>95%) significantly. Both doses of Puma Super (fenoxaprop-p-ethyl) failed to control *Cyperus iria* but reduced the density of *Echinochloa colona* significantly compared with control. Higher dose of Puma Super was more efficient in reducing *Echinochloa colona* density; however, it was at par with Clover and Pyranex Gold. Almost similar results were noted in 2015 regarding control of individual weeds. In 2015, application of both doses of Puma Super (fenoxaprop-p-ethyl) at 46.33 and 92.66 g a.i. ha^{-1} greatly inhibited ($p \leq 0.05$) the weed density of *Leptochloa chinensis* (>98%). On the contrary, application of different doses of Clover (bispyribac sodium) and Pyranex Gold (bispyribac sodium + bensulfuron methyl) substantially inhibited ($p \leq 0.05$) the population of *Cyperus iria* (>92%) and *Echinochloa colona* (>94%). Meanwhile, Puma Super application at 92.66 g a.i. ha^{-1} substantiated equally effective in controlling *Echinochloa* colona (91%) in 2015, similar to that observed in 2014. Most of post-emergence herbicides treatments resulted in significantly ($p \leq 0.05$) lower total weed density at 45 DAS in 2015. Maximum total weed density ($p \leq 0.05$) of 76.5 and 89.5 plants m^{-2} was exhibited by the weedy check treatment at 45 DAS both in 2014 and 2015, respectively. Hence, application of Puma Super both at 46.33 and 92.66 g a.i. ha^{-1} proved most effective in controlling >63% of total weed density in 2014, followed by the Pyranex Gold (bispyribac sodium + bensulfuron methyl) application at 111.2 g a.i. ha^{-1} (61%) and Clover application at 59.30 g a.i. ha^{-1} (58%). Similarly, in 2015, Puma Super (fenoxaprop-p-ethyl) application at 46.33 and 92.66 g a.i. ha^{-1} suppressed density of total weed by 74% and 77%, respectively, while other herbicide treatments were less useful (<36%) in controlling total weed population.

Table 2: *Individual and total weed density at 45 days after sowing of rice (25 days after herbicide application) as influenced by various treatments.*

Treatment	Weed density at 45 days after sowing							
	Leptochloa chinensis		*Cyperus iria*		*Echinochloa colona*		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
T_0	32.3 bcd	64.8 bcd	23.3 a	13.3 b	20.8 a	11.3 a	76.5 a	89.5 a
T_1	37.0 abc	73.6 abc	1.33 b	0.66 c	1.00 c	0.33 c	39.3 bc	74.6 bc
T_2	30.6 cd	61.1 cd	1.00 b	0.66 c	0.66 c	0.33 c	32.3 cd	62.1 cd
T_3	38.6 ab	77.3 ab	1.00 b	0.33 c	0.66 c	0.66 c	40.3 bc	78.3 ab
T_4	41.3 a	82.6 a	1.00 b	1.00 c	0.66 c	0.66 c	43.0 b	84.3 ab
T_5	28.3 d	56.0 d	0.66 b	0.66 c	0.66 c	0.66 c	29.6 d	57.3 d
T_6	37.6 abc	78.5 a	0.66 b	0.66 c	1.00 c	0.66 c	39.3 bc	79.8 ab
T_7	1.00 e	0.66 e	22.6 a	18.0 a	4.16 b	4.83 b	27.8 d	23.5 e
T_8	0.66 e	0.33 e	24.6 a	19.5 a	1.66 c	1.00 c	27.0 d	20.8 e
LSD	7.083	12.52	2.77	2.391	2.38	2.334	8.66	13.69

Different lowercase letters in a column means significant difference among means at $p \leq 0.05$. T_0= weedy check (control); T_1= Clover 20% EC (bispyribac sodium) at 39.54 g a.i. ha^{-1}; T_2= Clover 20% EC at 59.30 g a.i. ha^{-1}; T_3= Clover 20% EC at 79.07 g a.i. ha^{-1}; T_4= Pyranex Gold 30% WDG (18% bispyribac sodium + 12% bensulfuron methyl) at 74.13 g a.i. ha^{-1}; T_5= Pyranex Gold 30% WDG at 111.20 g a.i. ha^{-1}; T_6= Pyranex Gold 30% WDG at 148.26 g a.i. ha^{-1}; T_7= Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 g a.i. ha^{-1}; T_8= Puma Super 7.5% EW at 92.66 g a.i. ha^{-1}

Table 3: *Individual and total weed dry biomass at 45 days after sowing of rice (25 days after herbicide application) as influenced by the various treatments.*

Treatment	Weed dry biomass at 45 days after sowing							
	Leptochloa chinensis		*Cyperus iria*		*Echinochloa colona*		Total	
	2014	2015	2014	2015	2014	2015	2014	2015
T_0	82.7 a	140.4 bc	77.3a	44.7 b	67.2 a	60.5 a	227.3 a	245.7 a
T_1	82.2 a	145.7 b	5.33 b	2.63 c	3.43 c	1.54 c	91.03 b	149.8 bc
T_2	80.9 a	128.2 cd	4.89 b	2.41 c	2.17 c	1.53 c	88.02 b	132.1 cd
T_3	82.7 a	165.3 a	4.09 b	1.30 c	2.27 c	2.73 c	89.08 b	169.4 b
T_4	87.2 a	120.7 d	3.42 b	3.64 c	2.32 c	2.86 c	92.98 b	127.3 d
T_5	79.5 a	119.5 d	2.41 b	2.41 c	2.64 c	2.99 c	84.56 b	124.9 d
T_6	78.0 a	115.7 d	2.67 b	2.63 c	3.26 c	3.04 c	84.01 b	121.4 d
T_7	4.47 b	3.56 e	74.3 a	67.6 a	11.5 b	16.2 b	90.36 b	87.46 e
T_8	3.31 b	1.28 e	74.4 a	68.3 a	5.86 c	5.17 c	83.60 b	74.76 e
LSD	9.436	14.980	7.320	7.891	4.67	6.921	14.328	19.985

Different lowercase letters in a column means significant difference among means at $p \le 0.05$. T_0= weedy check (control); T_1= Clover 20% EC (bispyribac sodium) at 39.54 g a.i. ha^{-1}; T_2= Clover 20% EC at 59.30 g a.i. ha^{-1}; T_3= Clover 20% EC at 79.07 g a.i. ha^{-1}; T_4= Pyranex Gold 30% WDG (18% bispyribac sodium + 12% bensulfuron methyl) at 74.13 g a.i. ha^{-1}; T_5= Pyranex Gold 30% WDG at 111.20 g a.i. ha^{-1}; T_6= Pyranex Gold 30% WDG at 148.26 g a.i. ha^{-1}; T_7= Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 g a.i. ha^{-1}; T_8= Puma Super 7.5% EW at 92.66 g a.i. ha^{-1}

Individual and total weeds dry biomass

Individual and total weeds dry biomass was also significantly influenced by various herbicide application treatments as recorded 45 DAS and followed a similar trend as for weed density (Table 3). A higher dry biomass of *Leptochloa chinensis* while lower dry biomass of *Cyperus iria* and *Echinochloa colona* was perceived in 2015 than in 2014. Puma Super application at 92.66 and 46.33 g a.i. ha^{-1} significantly reduced ($p \le 0.05$) the dry biomass of *Leptochloa chinensis* in 2014 by 96% and 94%, respectively and in 2015 by 99% and 97%, respectively; while both Clover and Pyranex Gold applied at either dose could not suppress the dry biomass of this weed by >5%. For *Cyperus iria*, application of Pyranex Gold (bispyribac sodium + bensulfuron methyl) at 111.20 g a.i. ha^{-1} in 2014 and Clover at 79.07 g a.i. ha^{-1} in 2015 highly suppressed ($p \le 0.05$) the dry biomass (97%), and both of these were at par with various dose application of Clover and Pyranex Gold, reducing about >91% dry biomass. Among herbicides, Puma Super (fenoxaprop-p-ethyl) was ineffective in reducing the dry biomass of *Cyperus iria* in both years. Highest dry biomass of *Echinochloa colona* was in weedy check, while Clover (bispyribac sodium) application at 59.3 g a.i. ha^{-1} significantly reduced ($p \le 0.05$) its dry biomass by >96 in 2014 and by >97% in 2015, and this treatment was statistically at par with other herbicide application treatments (reducing >91% dry biomass of *Echinochloa colona* in both years), except for Puma Super application at 46.33 g a.i. ha^{-1} that was least efficient, suppressing about 82% and 73% dry biomass in 2014 and 2015, respectively. All treatments of herbicide application reduced total weed dry biomass vs. control; however, Puma Super application at 92.66 g a.i. ha^{-1} was the most valuable in declining 63% and 69% of total weed dry biomass in 2014 and 2015, respectively.

Rice yield components and economic analysis

Differences in yield components and paddy yield were obvious under different weed control treatments (Table 4). Weed competition throughout the season in weedy check reduced paddy yield and yield related attributes in both study years. Plant height varied significantly under the influence of different weed control treatments. Shortest plants were observed in weedy check, while all herbicide application treatments enhanced ($p \le 0.05$) plant height in both years. Significantly more number of tillers ($p \le 0.05$) was recorded in herbicide treated plots over control in both years. Puma Super (fenoxaprop-p-ethyl) application at 92.66 g a.i. ha^{-1} gave the highest tiller number per unit area ($p \le 0.05$; 134% increase in 2014 and 371% increase in 2015 over control), followed by the Puma Super application at 46.33 g a.i. ha^{-1} (113% and 301% increase in 2014 and 2015, respectively vs. control). Least number of grains $panicle^{-1}$ were noted in weedy check during both years, while different herbicide treatments significantly ($p \leq 0.05$) enhanced number of grains panicle^{-1}, with Puma Super application at 92.66 g a.i. ha^{-1} being the top performer (34% increase in 2014 and 55% increase in 2015). Grain size is a critical yield contributing parameter. 1000-grain weight expresses the seed size and paddy with bold grains furnish higher yields. However, 1000-grain weight remained unaffected ($p>0.05$) by various herbicide application treatments during both years in present study. Of the most importance, paddy yield is the demonstration of collective effects of various yield traits developed under the specific environmental conditions. The lowest paddy yield was exhibited by the weedy check with unattended weed growth, while application of fenoxaprop-p-ethyl at 92.66 g a.i. ha^{-1} furnished the significantly highest paddy yield ($p \leq 0.05$) that was about 168% and 947% more than weedy check in 2014 and 2015, respectively. The next best treatment in terms of high paddy yield was Puma Super applied at 46.33 g a.i. ha^{-1} that enhanced yield by 132% in 2014 and 751% in 2015 vs. control. Regarding economic analysis, all herbicide application treatments gave higher net returns compared with weedy check (Table 5). Puma Super applied at 92.66 g a.i. ha^{-1} gave the highest net benefit of Rs. 95915 ha^{-1}, followed by Puma Super application at 46.33 g a.i. ha^{-1} with net return of Rs. 81906 ha^{-1}, while lowest economic benefits were achieved by control (Rs. 25068 ha^{-1}).

Table 4: *Yield and yield contributing parameters as influenced by the various weedicide treatments.*

Treatment	Yield and yield components of rice									
	Plant height (cm)		Tillers per m^2		Grains per panicle		1000-grain weight (g)		Paddy yield (kg ha^{-1})	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
T_0	93.6 b	90.80 c	58.6 d	30.0 f	57.3 d	51.0 c	21.0	21.2	741.3 e	150.0 g
T_1	105.8 a	103.7 ab	111.0 c	84.0 de	72.0 abc	71.6 ab	21.3	21.0	1326.0 c	756.7 ef
T_2	106.1 a	101.2 b	107.6 c	88.3 cd	72.3 abc	67.6 b	21.0	21.3	1301.1 cd	770.0 def
T_3	105.9 a	100.2 b	109.6 c	78.00 e	75.6 ab	70.1 b	21.3	21.3	1197.0 d	686.7 f
T_4	104.5 a	103.7 ab	104.0 c	95.00 c	72.6 abc	68.0 b	20.6	21.6	1220.2 cd	916.7 c
T_5	104.7 a	106.3 a	106.0 c	91.00 cd	69.6 c	68.3 b	21.0	21.6	1240.7 cd	883.3 cd
T_6	105.0 a	102.8 ab	110.0 c	83.67 de	72.0 abc	70.3 b	21.6	21.0	1269.4 cd	833.3 cde
T_7	106.1 a	106.5 a	125.0 b	120.3 b	70.3 bc	70.6 b	21.0	21.1	1719.7 b	1276.7 b
T_8	102.3 a	100.8 b	137.3 a	141.3 a	77.0 a	79.0 a	21.6	21.6	1983.8 a	1570.0 a
LSD	4.977	4.764	8.084	9.156	5.72	7.626	NS	NS	123.47	121.81

Different lowercase letters in a column means significant difference among means at $p \leq 0.05$; NS = non-significant. T_0= weedy check (control); T_1= Clover 20% EC (bispyribac sodium) at 39.54 g a.i. ha^{-1}; T_2= Clover 20% EC at 59.30 g a.i. ha^{-1}; T_3= Clover 20% EC at 79.07 g a.i. ha^{-1}; T_4= Pyranex Gold 30% WDG (18% bispyribac sodium + 12% bensulfuron methyl) at 74.13 g a.i. ha^{-1}; T_5= Pyranex Gold 30% WDG at 111.20 g a.i. ha^{-1}; T_6= Pyranex Gold 30% WDG at 148.26 g a.i. ha^{-1}; T_7= Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 g a.i. ha^{-1}; T_8= Puma Super 7.5% EW at 92.66 g a.i. ha^{-1}

Table 5: *Economic analysis of different weedicide treatments in direct-seeded rice.*

Variable	Weed control treatments									Remarks
	T_0	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	
Total yield†	446	1041	1036	942	1068	1062	1051	1498	1777	Average yield of both years (kg ha^{-1})
Adjusted yield	401	937	932	848	962	956	946	1348	1599	To bring at farmer's level (10%)
Gross income	25068	58576	58250	52979	60100	59738	59138	84274	99951	Rs. 62.5 kg^{-1}
Cost of herbicides	0	1730	2595	3459	2100	3150	4201	1668	3336	Total price of herbicide ha^{-1}
Spray application cost	0	700	700	700	700	700	700	700	700	Rs. 700/man, one man day^{-1} ha^{-1}
Cost that vary	0	2430	3295	4159	2800	3850	4901	2368	4036	Rs. ha^{-1}
Net benefit	25068	56146	54955	48820	57300	55888	54237	81906	95915	Rs. ha^{-1}

†Total yield is average of two study years. T_0= weedy check (control); T_1= Clover 20% EC (bispyribac sodium) at 39.54 g a.i. ha^{-1}; T_2= Clover 20% EC at 59.30 g a.i. ha^{-1}; T_3= Clover 20% EC at 79.07 g a.i. ha^{-1}; T_4= Pyranex Gold 30% WDG (18% bispyribac sodium + 12% bensulfuron methyl) at 74.13 g a.i. ha^{-1}; T_5= Pyranex Gold 30% WDG at 111.20 g a.i. ha^{-1}; T_6= Pyranex Gold 30% WDG at 148.26 g a.i. ha^{-1}; T_7= Puma Super 7.5% EW (fenoxaprop-p-ethyl) at 46.33 g a.i. ha^{-1}; T_8= Puma Super 7.5% EW at 92.66 g a.i. ha^{-1}

Discussion

The present study reveals that post-emergence herbicides differed in their efficacy. Clover (bispyribac sodium) and Pyranex Gold (bispyribac sodium + bensulfuron methyl) proved promising herbicides for averting weed growth of *Cyperus iria* and *Echinochloa colona*, while Puma Super (fenoxaprop-p-ethyl) was promising in case of *Leptochloa chinensis* and overall weed control. The performance of these herbicides might be ascribed to the suppression of respective weed species and their selective nature (Khaliq *et al*., 2012). Previously, it was reported that application of bispyribac sodium at 25-30 g a.i. ha^{-1} could be an appropriate herbicide for effective control of diverse rice weed flora under different systems (Kumar *et al*., 2013; Dhillon and Bhullar, 2016; Martin *et al*., 2020). Bispyribac sodium belongs to pyrimidinyloxy benzoic family and is ALS inhibitor in susceptible plants. It retards synthesis of branched chain amino acids (Darren and Stephen, 2006). Its effectiveness in DSR is also reported elsewhere (Mahajan *et al*., 2009; Khaliq *et al*., 2011; Saha *et al*., 2021). Bispyribac sodium + bensulfuron methyl is a new herbicide combination reported to provide effective control of *Cyperus iria* and grasses in rice (Sunil *et al*., 2010). Similarly, fenoxaprop-p-ethyl is aryloxy phenoxy-propionate herbicide. It is absorbed through leaves and stems of weeds. It inhibits fatty acids synthesis in grass meristemtic tissue. Our findings on individual and collective weed density and biomass are also in agreement with the previous researches (Mahajan *et al*., 2009; Sunil *et al*., 2010; Khaliq *et al*., 2011, 2012).

Plant height depicts the genetics and environmental conditions experienced by the plant during its growth. In present study, lower height in check plot was due to competition for growth resources between weeds and rice plants. These observations are in line with Mann *et al*. (2007), who told short plants in weedy plots. Improved plant height was exhibited by better crop growth with herbicides. Total tillers is an important agronomic trait that represents plant population. It represents emergence percentage and seedling establishment. It is also influenced by environmental and genetic factors. Lowest number of tillers observed in weedy check in this study was due to weed dominance where rice plants were unable to attain proper resources, while more number of tillers in Puma Super (fenoxaprop-p-ethyl) treated plots were due to efficient control of weed population which facilitated the crop to acquire abundant resources (Khaliq *et al*., 2011). Grains number $panicle^{-1}$ adds materially to the final paddy yield. Higher number of grains $panicle^{-1}$ in herbicides treated plots especially with Puma Super (fenoxaprop-p-ethyl) was attributed to less competition due to lower weed growth, better nutrient uptake and better assimilates translocation through efficient weed control. Similar conclusion was also drawn by Mann *et al*. (2007). In this study, significantly more than 2 times and 10 times higher paddy yield during two years with Puma Super application at 92.66 g a.i. ha^{-1} than control could be attributed to the better weed control rather than unattended weed growth and more number of tillers and grains $panicle^{-1}$. Rice remains a poor weed competitor and is particularly vulnerable to weeds particularly during the initial stages of development in DSR system (Khaliq and Matloob, 2011). Such weed losses tend to increase manifold when rice is sown directly under DSR technology (Rao *et al*., 2007). An increase of 947% in 2015 was ascribed to a very low number of tillers and ultimately low paddy yield in weedy check. Puma Super at 46.33 g a.i. ha^{-1} proved comparatively effective in weed control and paddy yield. Broadly speaking, fenoxaprop-p-ethyl applied at both doses appeared paramount for most of the yield traits and paddy yield due to reduced weed-crop competition throughout the critical phase of crop establishment. Higher paddy yield due to efficient weed control is also reported by several other researchers (Mahajan *et al*., 2009; Jaya Suria *et al*., 2011; Akbar *et al*., 2011). The efficacy of a production technique is finally assessed by its economics. Economic analysis is a fundamental tool to determine the profitable treatment. Our data exposed that there was a general increase in net return in various herbicide application treatments over control. The highest net income was furnished by Puma Super application at 92.66 g a.i. ha^{-1}, while second best treatment was Puma Super application at 46.33 g a.i. ha^{-1} regarding net return. Higher net returns in fenoxaprop-p-ethyl treated plots were ascribed to efficient weed control that led to greater paddy yield. Other studies also conclude that use of appropriate herbicides is an effective and economical method for weed control in DSR (Mahajan *et al*., 2009; Khaliq *et al*., 2012; Ali *et al*., 2015).

Conclusions and Recommendations

The present study concludes that all herbicide application treatments prominently suppressed the weed growth and improved the yield and yield traits of rice planted under DSR system as compared to weedy check. Application of Clover (bispyribac sodium @ 39.54, 59.30 or 79.07 g a.i. ha^{-1}) and Pyranex Gold (bispyribac sodium + bensulfuron methyl @ 74.13, 111.20 or 148.26 g a.i. ha^{-1}) at either dose (lower or higher) emerged as an auspicious approach in control of weed density and dry biomass of *Echinochloa colona* and *Cyperus iria*, while Puma Super applied at 92.66 g a.i. ha^{-1} appeared most promising in suppression of *Leptochloa chinensis* as well as total weeds and improving yield traits particularly number of tillers and grains $panicle^{-1}$, which ultimately led to increased paddy yield and higher net returns.

Therefore, a mixed of the above studied post-emergence herbicides (Clover, Pyranex Gold and Puma Super) is recommended in order to effectively control the weed population and growth of grasses and sedges and to get highest net benefits under DSR technology.

Acknowledgements

The authors of this manuscript would like to thank Pakistan Agricultural Research Council, Rice Programme, Kala Shah Kaku, Lahore for their guidance and help.

Novelty Statement

Continuous herbicides selection is essential to overcome the rapidly evolving herbicides resistance in weeds. This is a novel study that evaluates the efficacy of post-emergence herbicides with different doses in order to suppress the weed population and growth efficiently in DSR system for achieving the maximum net economic returns.

Author's Contribution

Shahbaz Hussain: Conceptualization and project supervision.
Asif Ameen: Wrote original draft, correspondence.
Muhammad Ehsan Safdar: Review and editing.
Atif Naeem: Methodology.
Ahmad Jawad and Madad Ali: Formal analysis.
Muhammad Ather Nadeem: Review and editing.
Ghulam Abbas, Muhammad Arif, Muhammad Ahmad Zafar and Zahid Hassan: Assistance in major revision and final review.

Conflict of interest
The authors have declared no conflict of interest.

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