Original Research Article

Impact of pre and post-emergence herbicide mixtures in direct seeded rice (*Oryza sativa* L.)

Abstract

Rice (*Oryza sativa* L.) is a major source of food for more than half of the world population especially in South and Southeast Asia and Latin America. A field experiment was conducted at Krishi Vigyan Kendra, Yamunanagar district, Haryana during *Kharif* season of 2022 to study the effect of pre and post-emergence herbicides combinations herbicides in direct-seeded rice under irrigated condition. The experiment was laid out in a Randomized block design with three replications. The weed management treatments were T_1: Pendimethalin + pyrazosulfuron T_2:Pendimethalin + pyroxasulfone, T_3:Pretilachlor + pyrazosulfuron, T_4: Fenoxaprop-p-ethyl with safener + ethoxysulfuron,T_5: Cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl, T_6.:Triafamone + ethoxysulfuron, T_7: Pendimethalin + pyrazosulfuron *fb* bispyribac-sodium, T_8: Pendimethalin + pyroxasulfone *fb* bispyribac-sodium, T_9:Pretilachlor + pyrazosulfuron *fb* bispyribac-sodium, T_{10}:Pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron T_{11}: Weed free, T_{12}:Weedy check. Among herbicides, application T_{10} (pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron) and T_5 (cyhalofop-butyl+ penoxsulam and metsulfuron methyl + chlorimuron ethy (pre-mix) was superior over other treatment. Application of pendimethalin fenoxaprop-p-ethyl + ethoxysulfuron reduced 58.89% grassy weed and 50 % BLWs compared to weedy check plot at 60 DAS. Assessment at 60 DAS and at harvest showed that bispyribac-sodium was effective in controlling *E. colona* and *E. crus-galli*. However, bispyribac-sodium did not control *D. aegyptium and L. chinensis*. Fenoxaprop significantly reduced the densities of *Dactyloctenium aegyptium, L. chinensis,* and *Digitaria sanguinalis*. Fenoxaprop tank-mix with ethoxysulfuron appeared to be synergistic for the control of *E. crusgalli* and *E. colona*, and *Cyperus sp.* as this tank mixture. Integration of pendimethalin *fb* fenoxaprop-p-ethyl+ ethoxysulfuron provided control of all type of weeds with highest grain yield (6.1 t ha^{-1}) among different treatments which was statistically at par with weed free (6.3 t ha^{-1}). In economics points of views, the highest B-C ratio (3.03) was obtained in cyhalofop-butyl + penoxsulam + metsulfuron methyl + chlorimuron ethy followed by pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron (2.98).

Key words: Direct seeded rice, Pre-emergence herbicide, Post-emergence herbicide, Tank-mixture, Economic analysis.

1. Introduction

Over half of the global population relies on rice (*Oryza sativa*) as a staple meal and main cereal crop. Conventional wet-tillage involves placing seedlings into puddled soil and keeping them submerged for the majority of the growth season. This is the main method used to cultivate rice. By puddling the soil, you may minimise deep-percolation losses and ensure optimal crop establishment while controlling weeds with standing water (Sharma *al et.,* 2003). Predominant weeds in the rice-growing tracts may be suppressed in the traditional method due to the puddled soil conditions, preliminary tillage, and standing water (Chauhan, 2012). In direct sowing, however, controlling weeds poses a significant difficulty (Ahmed and Chauhan, 2014 Chauhan and Abugho, 2012; Chauhan *et al.,* 2015). The Rice-wheat cropping system is indeed one of the largest agricultural production systems in the world, covering a vast area of 26 million hectares. It is primarily found in the Indo-Gangetic Plains (IGP) region of South Asia (Chauhan *et al*., 2012; Shweta and Malik, 2017). In India specifically, the IGP covers around 20% of the total geographical area, which amounts to approximately 329 million hectares. Within this area, the RWCS occupies about 27% of the utilized agricultural land. Despite covering a relatively small proportion of the agricultural area, the RWCS plays a crucial role in the food production of the country. (Kumar *et al*., 2018). Because of high rate of withdrawal of groundwater in conventional tillage based puddled transplanted rice, water tables in some areas of North-West Indo-Gangetic Plains (IGP) has been declining by 0.1-1m per year, resulting in increased cost of water pumping (Humphreys *et al.,* 2010). In DSR systems, dry rice seeds are sown with or without tillage and irrigation is applied periodically to maintain soil at field capacity. DSR can save 11–18% of the water used for irrigation (Tabbal *et al.,* 2002) and depends on the season, region, and kind of DSR, lowers the overall labour need (11-66%) in comparison to puddled transplanted rice (PTR) (Kumar *et al.,* 2009). Because weeds are so diverse and severe in DSR systems, there is no standing water layer to reduce weeds when rice emerges, and rice has no size advantage over weed seedlings because both emerge at the same time, weed control is very difficult in these systems. According to Khalid and Matloob (2011), weeds grow more quickly in damp soil in DSR than in PTR and emerge at the same time of rice seedlings, severely competing with the crop for resources.

Land preparation activities have an impact on the relative abundance of weed species and the distribution of weed seeds in the soil profile in DSR systems (Chauhan and Opena, 2012). The yield losses in DSR due to weeds can range from 50% to 91%. This suggests that weeds have a major influence on direct seeded output; thus, weed control is essential for rice production that is sustainable in dry-seeded conditions. However, in DSR, varied weeds were not efficiently controlled by applying pre- or post-emergence herbicides alone (Awan *et al*., 2015). Herbicides are typically applied by farmers by combining them with sand to make the process easier. They also prefer to use pre- or post-herbicides just once, which is ineffective in controlling the variety of weed flora found in DSR (Chauhan, 2012; Chauhan and Opena, 2012). Herbicides used before weeds emerge may not be as effective in suppressing weeds that arise later in life or that are more established. Conversely, post-emergence herbicides are sprayed on actively developing weeds after they have emerged. Post-emergence herbicides work well against weeds that develop later in the growing season or that pre-emergence herbicides have not been able to sufficiently suppress (Chauhan *et al*., 2015). Grain yield from the DSR system can resemble PTR when all of its components are used well (Gill *et al.,* 2013; Bhullar *et al.,* 2018). However, the use of DSR technology typically results in a change in the composition of weeds, favoring those that are challenging to control (Singh *et al.,* 2013). In this case, the use of herbicides is growing in popularity in DSR due to its increased effectiveness, ease of application, ability to give targeted control, reduced manpower expenses, and lower cost.

2. Material and methods

2.1. Study location

In the Kharif season of 2022, the experiment was started at Krishi Vigyan Kendra in the Yamunanagar (30^0 08' N latitude and 77^0 21' E longitude, 270 m above mean sea level) area of Haryana. The primary farming system in the area is rice-wheat, which is well-known for its basmati and scented rice production. In *Rabi* 2021–2022, the experimental field was under a rice-wheat system; in Kharif 2022, it was under a DSR. The soil of the Yamunanagar district are mainly silty loam (Khadar), Loam (Bhangar and Nardak) and Silty-clay. The soil was classified by National Bureau of Soil Survey and Land-Use Planning (NBSS-LUP,ICAR,Nagpur).

2.2. Experimental Design and treatments

The experiment was laid out in a Randomized block design with 12 treatments (3 only pre-emergences, 3 only post-emergences, 4 pre-emergence *fb* post-emergence, one weed free and one weedy check) combinations and three replications. Recommended dose of N, P_2O_5 and K_2O were applied at 80, 60 and 40 kg ha^{-1}, respectively. The experimental plot size was 24 m^2 (6m × 4m) and at a line there were 12 strips. The weed management treatments were T_1: Pendimethalin 1000 g ha^{-1} + pyrazosulfuron (TM) 20 g ha^{-1} (PRE), T_2: Pendimethalin 1000 g ha^{-1} + pyroxasulfone (TM) 127.5 g ha^{-1} (PRE), T_3: Pretilachlor + pyrazosulfuron (pre-mix) 615 g ha^{-1} (PRE), T_4: Fenoxaprop-p-ethyl with safener 69 g ha^{-1} + ethoxysulfuron (TM) 18 g ha^{-1} (POE), T_5: Cyhalofop-butyl + penoxsulam (pre-mix) 137.7 g ha^{-1} and metsulfuron-methyl + chlorimuron-ethyl (pre-mix) 4 g ha^{-1} (POE), T_6.: Triafamone + ethoxysulfuron (pre-mix) 67.5 g ha^{-1} (POE), T_7: Pendimethalin 1000 g ha^{-1} + pyrazosulfuron (TM) 20 g ha^{-1} (PRE) *fb* bispyribac-sodium 25 g ha^{-1} (POE), T_8: Pendimethalin 1000 g ha^{-1}+ pyroxasulfone (TM) 127.5 g ha^{-1} (PRE) *fb* bispyribac-sodium 25 g ha^{-1} (POE), T_9: Pretilachlor + pyrazosulfuron (pre-mix) 615 g ha^{-1} (PRE) *fb* bispyribac-sodium 25 g ha^{-1} (POE), T_{10}: Pendimethalin 1000 g ha^{-1} (PRE) *fb* fenoxaprop-p-ethyl 69 g ha^{-1} + ethoxysulfuron (TM) 18 g ha^{-1} (POE), T_{11}: Weed free, T_{12}: Weedy check.

2.3. Experimental Details

The experimental area was silty loam texture. Its normal soil PH was 7.3, its organic carbon content was 0.35, its EC was 0.08, its available nitrogen was 126 kg ha^{-1}, its available P_2O_5 was 8 kg ha^{-1}, and its available potassium was 360 kg ha^{-1}. Before rice was sown, half of the total nitrogen as well as the entire dosage of potassium and phosphorus were applied as a basal. The other half dose of nitrogen, in the form of urea, was top dressed in two equal portions at the stages of panicle start and active tillering. The rice cultivar "PR-126" was directly seeded by seed drill with a seed rate of 20 kg ha-1 at a row spacing of 20 cm after the field had been tilled. Irrigation (Irrigation at 17 DAS and subsequent irrigation given at weekly interval based on rainfall 8 to 9 times flooding method of irrigation was used). With the exception of weed management, the crop was consistently managed over the growing season. Herbicides were administered pre-emergence (on the day of sowing) and post-emergence (on the 21 DAS) using a backpack sprayer that was set to provide 500 litres of water per hectare using a flat-fan nozzle. A 0.5-meter-by-0.5-meter area was arbitrarily chosen from two locations within each plot. Weed samples were gathered from this area at harvest and 60 days later, and were classified as grasses, broad-leaved weeds, and sedges. When the plants reached maturity, the total number of tillers from five randomly chosen plants was counted from each plot. Five plants were chosen at random from each plot. On each of these five carefully chosen plants, the count of effective tillers was made. Likewise, five plants were chosen at random from each plot. For each of these five carefully chosen plants, the length of the panicle was measured. From the panicle's base to its tip, the length of the panicle was measured. Five panicles were chosen at random from each plot. On these five particular panicles, the quantity of grains was counted. The mean number of grains per panicle was then determined using the individual counts. The collected weed samples were first allowed to air dry for two days, and then they were oven-dried at 65±5°C until they reached a consistent dry weight. This method produces a more accurate estimation of the bio-efficacy of weed control treatments. (Das, 2001). Rice crop was harvested at physiological maturity and grain yield was recorded at 14% moisture content. Minimum support price was used to calculate the economics.

The various impact assessment indices namely weed control efficiency (WCE%) and weed index (WI%) were calculated as per formulae suggested by USDA/ICAR AICRPWC (1988) and Gill and Kumar (1966) respectively. Data on total weed count and weed dry weight were subjected to square root ($\sqrt{x+1}$) transformation to normalize the distribution. Weed control efficiency (WCE %) was calculated by using the following formula (USDA/ICAR AICRPWC, 1988)

$$\text{WCE (\%)} = \frac{\text{Dry weight of weeds in weedy check (g m}^{-2}\text{)} - \text{Dry weight of weeds in treatment (g m}^{-2}\text{)}}{\text{Dry weight of weeds in weedy check (g m}^{-2}\text{)}} \times 100$$

Weed index (WI %) is figured by applying the pattern given by Gill and Kumar, (1966)

Grain yield from weed free (kg ha^{-1}) – Grain yield from treatment (kg ha^{-1})

$$WI (\%) = \frac{\qquad}{\text{Grain yield from weed free (kg ha}^{-1}\text{)}} \times 100$$

2.3. Statistical analysis

Each set of data was examined independently using OP-STAT. Fisher's "analysis of variance" approach was used to statistically analyses the data in order to determine the significance of the effects of the treatments (Fisher, 1950). The 'F' test was used to determine the significant treatment impact at the 5% significance level.

3. Experimental results and discussion

3.1. Weed flora infestation on station trial

Rice crop was infested with grassy, sedges and broad-leaved weeds. The predominant weeds observed during the experiment were *E. colona*, *E. crusgalli*, *Alternanthera sessilis, D. aegyptium, Cyperus rotundus, Leptochloa chinensis, Eleusine indica, Commelina benghalensis*, *Trianthema portulacastrum.*, *Phyllanthus niruri*, *Paspalum distichum* and *Digitaria sanguinalis, D. aegyptium, C. rotundus, E. colona, A. sessilis, E. indica, and P. niruri* were the predominant weeds in trial field.

3.2. Weed density and dry matter

The highest weed density was recorded in weedy check grassy (11.58 m^{-2}), sedges (5.46 m^{-2}) and BLWs (9.36 m^{-2}) at 60 DAS. Pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron was found to have the least amount of grassy weed flora (4.76 m^{-2}) compared to T_5 (cyhalofop-butyl + penoxsulam 137.7 g ha-1 and metsulfuron methyl + chlorimuron ethyl 4 g ha^{-1}). A single application of pendimethalin + pyrazosulfuron, pendimethalin + pyroxasulfuron, pretilachlor + pyrazosulfuron (pre), or fenoxaprop-p-ethyl with safener + ethoxysulfuron (post) resulted in 7.74, 6.16, and 6.51 grassy weeds m^{-2}, respectively, and demonstrated a 33-47% decrease in weed density in comparison to the weedy check. It was discovered that using pre-emergence and post-emergence herbicides in succession led to a 44-59% decrease in the density of grassy weeds. After pre-emergence applications of pendimethalin + pyrazosulfuron and pendimethalin + pyroxasulfone, the density of broadleaved weeds was 5.58 and 4.98 plants m^{-2}, respectively. These numbers were 40.38 and 46.79% lower than the 9.36 plants m^{-2} in the weedy check at 60 DAS (Table 1). Although it was not as good as pre-fb post-mergence treatment at 60 DAS, the density of sedges after pre-emergence herbicides was in the range of 1-4 plants m^{-2} as opposed to 5.46 plants m^{-2} in the weedy check. Among the herbicide treatments, 100% control of C. rotundus was achieved at 60 DAS and harvest by using pendimethalin + pyrazosulfuron and pendimethalin + pyrazosulfuron *fb* bispyribac-sodium. When pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron was applied at 60 DAS, compared to a weedy check plot, 58.89% of grassy weed and 50% of BLWs were decreased (Table 2). Although the broad-leaved weed was effectively decreased (1.91 m^{-2}) by post-emergence treatment of metsulfuron methyl + chlorimuron ethyl 4 g ha^{-1}, the outcomes of T_2 (pendimethalin + pyroxasulfone) and T_8 (pendimethalin + pyroxasulfone *fb* bispyribac-sodium) were statistically identical (Table 1). Although maximum amount of grassy and sedges were controlled by pendimethalin + pyroxasulfone and pendimethalin + pyroxasulfone fb bispyribac-sodium, the phytotoxicity symptoms of pyroxasulfone decrease the initial growth stage and yield parameters. Density generally decreases when crop-weed competition is over, reaching a minimum after harvest. In the study, effective BLW and sedge weed control was obtained by using combinations of pendimethalin + pyrazosulfuron, metsulfuron-methyl + chlorimuron, and ethoxysulfuron treatment at 60 DAS and at harvest also (Table 2). During the whole trial, using herbicides in a sequential manner proved to be more effective at suppressing weeds in DSR than applying pre- or post-emergence treatments alone.

Annual grass weeds such *Dactyloctenium aegyptium, E. colona*, *E. crus-galli*, *A. racemosa*, *L. chinensis*, and *Digitaria sp.* were successfully controlled by pendimethalin + pyrazosulfuron. Evaluation at harvest and 60 DAS indicated that bispyribac-sodium was successful in suppressing *E. colona* and *E. crus-galli*. Bispyribac-sodium, however, was unable to inhibit *L. chinensis* or *D. aegyptium*. *Digitaria sanguinalis*, *L. chinensis*, and *Dactyloctenium aegyptium* densities were all considerably lowered by fenoxaprop. The combination of ethoxysulfuron and fenoxaprop-p-ethyl in a tank mixture seems to work well together to manage *E. colona*, *E. crusgalli*, and *Cyperus sp.* (Table 2). Bispyribac-sodium is efficient in controlling of typical rice grass weeds such as *E. colona* (Chauhan, 2011), however, it has low efficiency weak against aerobic grass weeds such as *D. aegyptium* and *Leptochloa chinensis* (Bhullar *et al.,* 2016). Suganya *et al*. (2022) determined that application of bensulfuron methyl 0.6% + pretilachlor 6% GR @ 10 kg ha^{-1} on 8 DAS *fb* post-emergence application of metsulfuron methyl 10% + chlorimuron ethyl 10% @ 20 g ha^{-1} on 25 DAS *fb* hand weeding on 45 DAS found lower weed population, dry matter and higher yield compared to unweeded check. Among the herbicide treatments, 100% control of *C. rotundus* was achieved at 60 DAS and harvest by pendimethalin + pyrazosulfuron and pendimethalin + pyrazosulfuron *fb* bispyribac-sodium (Fig. 1). Maximum control over weed density was achieved with pendimethalin + pyrazosulfuron *fb* bispyribac-sodium, pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron which was comparable to cyhalofop-butyl + penoxsulam and metsulfuron methyl + chlorimuron ethyl at 60 DAS and at harvest. The findings imply that herbicide treatments were successful in lowering the average density and biomass of weeds by over 40–50% as well as the weeds' competition with the crop for resources and space. When compared to the initial weed development, the successive administration of pendimethalin *fb* fenoxaprop-pethyl + ethoxysulfuron reduced the weed up until harvest, indicating that the weed will eventually be reduced by the sequential use of these herbicides. Pendimethalin, pyrazosulfuron, and pretilachlor + pyrazosulfuron, which is mainly used as herbicide for grass weeds, were able to significantly lower the number of grassy weeds. When compared to the initial weed development, the successive administration of pendimethalin *fb* fenoxaprop-pethyl + ethoxysulfuron reduced the weed up until harvest, indicating that the weed will eventually be reduced by the sequential use of these herbicides. Pendimethalin, pyrazosulfuron, and pretilachlor + pyrazosulfuron, which is mainly used as herbicide for grass weeds, were able to significantly lower the number of grassy weeds at primary stages of weed growth (Table 1,2).

Table 1: Effect of pre and post-emergence herbicides treatments on weed density in direct seeded rice at 60 DAS.

Sr. No.	Treatments	Weed density 60 DAS (No.m^{-2})		
		Grasses	Sedges	BLWs
T_1	Pendimethalin + pyrazosulfuron (TM) (PRE)	7.74 (59.13)	1.00 (0.00)	5.85 (34.07)
T_2	Pendimethalin + pyroxasulfone (TM) (PRE)	6.16 (37.07)	3.08 (10.67)	4.98 (24.00)
T_3	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE)	8.85 (77.40)	4.02 (16.23)	7.43 (54.47)
T_4	Fenoxaprop-p-ethyl with safener + ethoxysulfuron (TM) (POE)	6.51 (41.80)	2.51 (5.33)	6.62 (43.13)
T_5	Cyhalofop-butyl + penoxsulam (PRE-MIX) and metsulfuron-methyl + chlorimuron-ethyl (PRE-MIX) (POE)	5.66 (31.27)	1.91 (2.66)	4.58 (20.13)
T_6	.Triafamone + ethoxysulfuron (PRE-MIX) (POE)	7.39 (53.73)	2.51 (5.33)	6.61 (42.73)
T_7	Pendimethalin + pyrazosulfuron (TM) (PRE) *fb* bispyribac-sodium (POE)	6.02 (35.30)	1.00 (0.00)	5.70 (31.70)
T_8	Pendimethalin + pyroxasulfone (TM) (PRE) *fb* bispyribac-sodium (POE)	4.72 (21.47)	3.05 (8.33)	4.83 (22.67)

T_9	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE) *fb* bispyribac-sodium (POE)	6.47 (41.00)	3.12 (9.33)	6.28 (38.73)
T_{10}	Pendimethalin (PRE*)* *fb* fenoxaprop-p-ethyl + ethoxysulfuron (TM) (POE).	4.76 (21.87)	1.91 (2.66)	4.68 (21.27)
T_{11}	Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_{12}	Weedy check	11.58 (133.10)	5.46 (29.03)	9.36 (86.60)
	SEm ±	0.28	0.58	0.32
	C.D. (p=0.05)	0.83	1.71	0.97

Original values are in parenthesis and before statistical analysis were subjected to square root transformation (√x+1).

PRE= Pre-emergence, POE=Post-emergence, TM= Tankmix, PRE-MIX= Already mixed before used.

Table 2: Effect of pre and post-emergence herbicides treatments on weed density in direct seeded rice at harvest.

Sr. No.	Treatments	Weed density at harvest (No. m^{-2})		
		Grasses	**Sedges**	**BLWs**
T_1	Pendimethalin +pyrazosulfuron (TM) (PRE)	7.30 (52.47)	1.00 (0.00)	5.79 (32.80)
T_2	Pendimethalin + pyroxasulfone (TM) (PRE)	5.94 (34.23)	3.18 (9.60)	4.71 (21.20)
T_3	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE)	8.00 (63.07)	2.73 (6.60)	7.14 (50.13)
T_4	Fenoxaprop-p-ethyl with safener + ethoxysulfuron (TM) (POE)	6.42 (40.20)	2.36 (4.80)	6.53 (41.87)
T_5	Cyhalofop-butyl + penoxsulam (PRE-MIX) and metsulfuron-methyl + chlorimuron-ethyl (PRE-MIX) (POE)	5.64 (30.87)	1.47 (1.60)	4.29 (17.53)
T_6	Triafamone + ethoxysulfuron (PRE-MIX) (POE)	7.18 (50.70)	2.08 (4.00)	6.41 (40.27)
T_7	Pendimethalin + pyrazosulfuron (TM) (PRE) *fb* bispyribac-sodium (POE)	5.90 (34.00)	1.00 (0.00)	5.60 (30.53)
T_8	Pendimethalin + pyroxasulfone (TM) (PRE) *fb* bispyribac-sodium (POE)	4.56 (20.13)	3.02 (8.13)	4.16 (17.53)
T_9	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE) *fb* bispyribac-sodium (POE)	6.42 (40.40)	2.55 (6.80)	6.28 (38.67)
T_{10}	Pendimethalin (PRE*)* *fb* fenoxaprop-p-ethyl + ethoxysulfuron (TM) (POE).	4.79 (21.93)	1.41 (1.33)	3.69 (12.73)
T_{11}	Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
T_{12}	Weedy check	10.77 (115.00)	5.29 (27.33)	9.57 (90.67)
	SEm ±	0.26	0.41	0.31
	C.D. (p=0.05)	0.75	1.20	0.93

Original values are in parenthesis and before statistical analysis were subjected to square root transformation (√x+1).

PRE= Pre-emergence, POE=Post-emergence, TM= Tankmix, PRE-MIX= Already mixed before used.

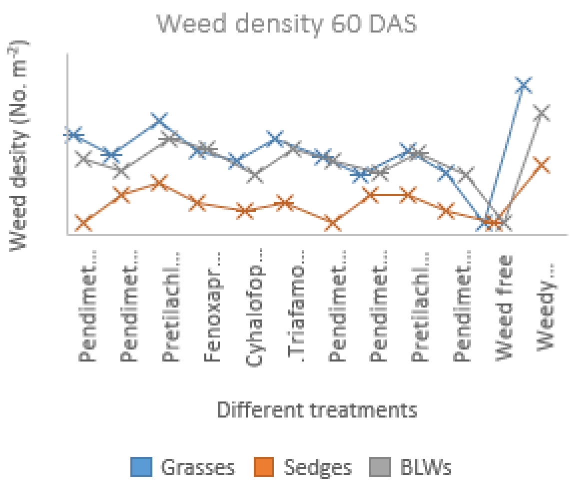

Fig. 1: Weed density found in different treatment at 60 DAS.

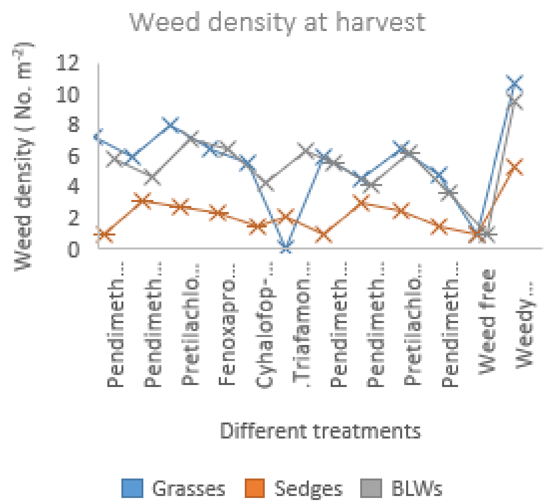

Fig. 2: Weed density found in different treatment at harvest.

3.3. Effect on weed control efficiency (WCE) and weed index (WI)

The hand-weeded plots had the lowest weed biomass at 60 DAS (Table 3). The pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron treatment had the lowest reported weed biomass among the herbicidal treatments, with 56% and 54% less biomass than the weedy plot at 60 DAS and harvest, respectively (Table 3). T_{10} (pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron) had the lowest weed index (2.46%) among the various herbicidal treatments, followed by T_5 (cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl) (8.83%) weed management methods. The best WCE at 60 DAS was found to be T_{10} (pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron), which was followed by T8 (pendimethalin + pyroxasulfone fb bispyribac-sodium), which was 80.33%, and T_5 (cyhalofop-butyl + penoxsulam and metsulfuron methyl + chlorimuron ethyl), which was 79.70%. Among the several herbicide treatments, pretilachlor + pyrazosulfuron had the lowest WCE, or 34.88% (Table 3). At the harvesting stage, T_{10} (pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron) had the highest percentage of weed control (79.40%), followed by T_5 (78.06%) and T_8 (78.46%), in that order (Table 4). Because annual grasses and broadleaf weeds had the highest weed density in this study, it is best to use pre-emergence herbicides according to the target weed type. Compared to pretilachlor + pyrazosulfuron (WCE 34.88%) at 60 DAS, pendimethalin + pyrazosulfuron and pendimethalin + pyrazosulfuron shown superior efficacy in regulating weed density and biomass during growing seasons, with weed control effectiveness of 60.3% and 72.8%, respectively (Table 4).

The post-emergence herbicide fenoxaprop-p-ethyl + ethoxysulfuron exhibited a greater reduction in the dry matter of grassy weeds, namely *Echinochloa sp., Dactylactinium sp., and Leptochloa sp.,* than did cyhalofop-butyl + penoxsulam. At 60 DAS, broad-leaved weeds and several sedges showed significantly reduced dry matter after being treated with metsulfuron-methyl + chlorimuron-ethyl. Similarly, Jaiswal *et al.,* (2022) found that oxadiargyl fb fenoxaprop-p-ethyl + ethoxysulfuron herbicide was more effective against complex weed flora. Grass, sedge, and broadleaf weeds were among the several weed species that this combination treatment successfully controlled. The broad-spectrum action of a mixture of successive herbicides on weeds may be the cause of this. After the pre-emergence treatment with pendimethalin, weeds that had developed were further controlled by applying fenoxaprop-p-ethyl and ethoxysulfuron post-emergence. While ethoxysulfuron targets both broadleaf and grassy weeds, fenoxaprop-p-ethyl is well-known for its effectiveness against grassy weeds. According to a research, major weed species including *Echinochloa colona* and *Eleusine indica* can necessitate the administration of a combination of pendimethalin and broad-spectrum herbicides (Rahman, 2012). Additionally, Mahajan *et al*. (2009) discovered that superior weed control in DSR was achieved by applying pendimethalin 1000 g ha^{-1} PRE *fb* bis-pyribacsodium 30 g ha^{-1} sequentially 15 DAS. Mitra *et al*. (2022) conducted the experiment on transplanted rice and the result concluded that the combination of bispyribac-sodium 10% SP + pyrazosulfuron 10% WP was shown to be the most efficient in suppressing all weed flora at both 35 and 55 DAT among the five post-emergence herbicide treatments.

Table 3: Effect of pre and post-emergence herbicides treatments on weed control efficiency and weed index in direct seeded rice at 60 DAS and at harvest.

Sr. No.	Treatments	Dry weight of weeds (g m^{-2})		Weed control efficiency (%) and weed index (%)		
		60 DAS	At harvest	60 DAS	At harvest	WI (%)
T_1	Pendimethalin + pyrazosulfuron (TM) (PRE)	12.92 (166.06)	13.48 (180.80)	60.38	56.98	19.71
T_2	Pendimethalin + pyroxasulfone (TM) (PRE)	10.71 (113.93)	11.14 (123.16)	72.82	70.71	47.11
T_3	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE)	16.53 (272.76)	16.88 (284.00)	34.88	32.48	38.06
T_4	Fenoxaprop-p-ethyl with safener + ethoxysulfuron (TM) (POE)	12.48 (154.86)	13.42 (179.00)	63.09	57.44	27.07
T_5	Cyhalofop-butyl + penoxsulam (PRE-MIX) and metsulfuron-methyl + chlorimuron-ethyl (PRE-MIX) (POE)	9.28 (85.13)	9.65 (92.16)	79.70	78.06	8.83
T_6	Triafamone + ethoxysulfuron (PRE-MIX) (POE)	13.32 (176.46)	13.62 (184.46)	51.39	56.16	27.07
T_7	Pendimethalin + pyrazosulfuron (TM) (PRE) *fb* bispyribac-sodium (POE)	12.15 (146.87)	12.53 (156.24)	64.95	62.78	15.59
T_8	Pendimethalin + pyroxasulfone (TM) (PRE) *fb* bispyribac-sodium (POE)	9.13 (82.56)	9.57 (90.68)	80.32	78.46	44.22
T_9	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE) *fb* bispyribac-sodium(POE)	12.45 (154.17)	12.85 (164.24)	63.23	60.95	17.85
T_{10}	Pendimethalin (PRE) *fb* fenoxaprop-p-ethyl + ethoxysulfuron (TM) (POE).	9.02 (80.43)	9.34 (86.44)	80.82	79.40	2.46
T_{11}	Weed free	1.00 (0.00)	1.00 (0.00)	100.00	100.00	0.00
T_{12}	Weedy check	20.50 (419.5)	20.53 (420.58)	0.00	0.00	49.56
	SEm ±	0.21	0.16	1.378	1.390	2.7
	C.D. (p=0.05)	0.62	0.46	4.066	4.377	8.11

PRE= Pre-emergence, POE=Post-emergence, TM= Tankmix, PRE-MIX= Already mixed before used.

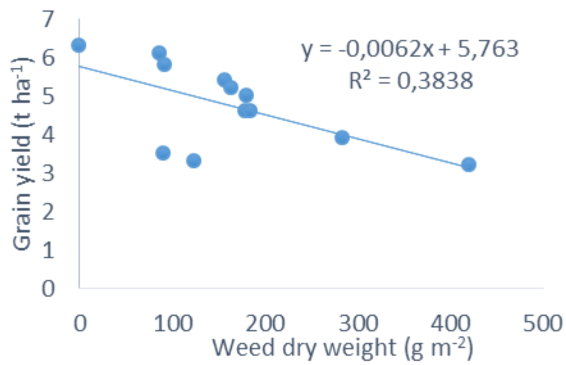

Fig. 3: Relationship between weed dry weight and grain yield

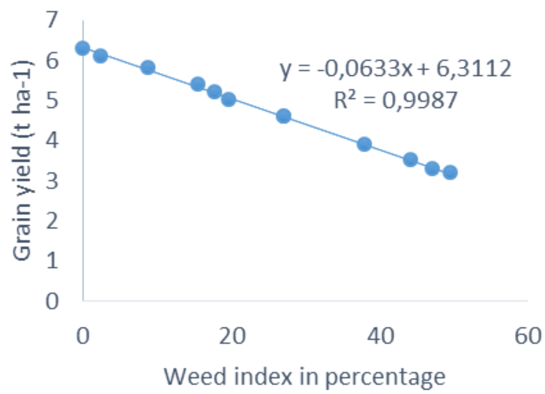

Fig. 4: Relationship between weed index and grain yield

3.4. Effect on Growth parameters and yield assessment

The outcomes confirm that applying pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron will increase grain yield. Effective weed control is crucial for optimizing crop output, as evidenced by the maximum grain yield and yield characteristics recorded in the weed-free plots (Table 4). The T_{10} treatment, which included pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron, outperformed the T_5 treatment in terms of test weight (22.6 g), effective tiller m^{-2} (260.5 m^{-2}), no. of grains panicle^{-1} (1077.7), panicle length (24.2 cm), weight of panicle (2.4 g), and test weight (6.2 t ha^{-1}). The lowest weed index and greater weed control efficacy in these two treatments may be the cause of this. By successfully suppressing weeds, treatments T_{10} (pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron), T_5 (cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl), and T_7 (pendimethalin + pyrazosulfuron fb bispyribac-sodium) continued to outperform other treatments in terms of panicle length and number of tillers m^{-2} (Table 4). The rice grain yield under various weed management treatments may be explained by the larger negative association between weed biomass and rice grain production at 60 DAS and harvest. better wide spectrum weed control, as evidenced by enhanced crop biomass and panicle production, was linked to the greater rice grain yield in the combination of pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron compared to their usage alone. It was found that there is a negative relationship between weed dry matter and grain yield (Fig. 3). The combination of the fenoxaprop-p-ethyl + ethoxysulfuron and cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl provided low weed competition environment for the crop, which resulted in the highest grain yield and also the highest economic returns. This suggests that in DSR rice production systems, using pre-emergence herbicides to manage weeds is safe. For example, even though there were signs of phytotoxicity at the rice emergence stage, pendimethalin + pyroxasulfone produced a better yield than the control. Sen *et al.* (2018) indicated that without efficient weed management, yield losses in DSR can range from 50 to 90%. It must be stressed that the mechanization of rice sowing which eliminates the need for labor-intensive physical work for transplanting traditional puddled rice is the main factor luring local farmers in the Indian states of Punjab and Haryana to DSR. The necessity of properly integrating herbicides is further highlighted by these results.

Table 4: Effect of pre and post-emergence herbicides treatments on yield parameters in direct seeded rice.

Sr. No.	Treatment	Number of effective tillers (No. m^{-2})	Length of panicle (cm)	No. of Grains $Spike^{-1}$	Grain weight per panicle	1000-grain weight (g)
T_1	Pendimethalin + pyrazosulfuron (TM) (PRE)	224.3	22.5	103.7	2.3	22.3
T_2	Pendimethalin + pyroxasulfone (TM) (PRE)	168.8	19.2	94.3	2.2	21.9
T_3	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE)	185.9	21.6	98.2	2.1	21.9
T_4	Fenoxaprop-p-ethyl with safener + ethoxysulfuron (TM) (POE)	205.1	21.9	101.5	2.3	22.6
T_5	Cyhalofop-butyl + penoxsulam (PRE-MIX) and metsulfuron-methyl + chlorimuron-ethyl (PRE-MIX) (POE)	250.1	23.8	104.5	2.4	21.7
T_6	Triafamone + ethoxysulfuron (PRE-MIX) (POE)	194.4	21.8	99.3	2.2	21.1
T_7	Pendimethalin + pyrazosulfuron (TM) (PRE) fb bispyribac-sodium (POE)	234.4	23.8	105.2	2.4	22.6
T_8	Pendimethalin + pyroxasulfone (TM) (PRE) fb bispyribac-sodium (POE)	172	20.9	100.2	2.1	21.2
T_9	Pretilachlor + pyrazosulfuron (PRE MIX) (PRE) fb bispyribac-sodium (POE)	226.1	23.6	105.1	2.3	22.4
T_{10}	Pendimethalin (PRE) fb fenoxaprop-p-ethyl + ethoxysulfuron (TM) (POE).	260.5	24.2	107.7	2.4	22.6
T_{11}	Weed free	269.1	25.9	109.6	2.5	22.7
T_{12}	Weedy check	169.6	19.3	90	1.9	21.0
	SEm ±	8.2	1.2	1.8	0.1	0.83
	C.D. (p=0.05)	24.3	3.4	5.5	NS	NS

PRE= Pre-emergence, POE=Post-emergence, TM= Tankmix, PRE-MIX= Already mixed before used.

4. Effect on Economics

In the present investigation, T_{10} (Pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron) (Rs. 115281 ha^{-1}) recorded 2.5% higher net returns over weed free (Rs. 112365 ha^{-1}) (Table 5). Though the weed free condition has highest gross returns (Rs. 157890 ha^{-1}), but the obtained B-C ratio was higher (3.03) in T_5 (cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl). T_5 (cyhalofop-butyl + penoxsulam and metsulfuron-methyl + chlorimuron-ethyl) had superior outcomes in comparison to T10 (pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron). In terms of the B-C ratio, the successive application of pendimethalin fb fenoxaprop-p-ethyl + ethoxysulfuron was more advantageous economically than the weed-free treatment that was left untreated (Table 5). The manpower costs to keep the area free of weeds were greater despite the treatments producing grain at comparable yields. In direct seeded rice, the herbicides pendimethalin *fb* fenoxaprop-p-ethyl + ethoxysulfuron might be employed to effectively control weeds in the case of a manpower shortage and ongoing rains. The cost of applying herbicides would also go up if fenoxaprop or other weed-specific herbicides were used, either as early as or later in the process of efficient weed control, either in tankmix with bispyribac-sodium and azimsulfuron

(Chauhan *et al.,* 2015; Mahajan and Chauhan, 2015). Numerous studies have also recommended the use of successive herbicides in conjunction with one-hand weeding in DSR at 35-60 DAS (Ahmed and Chauhan, 2014; Chauhan and Abugho, 2013; Ganie *et al.,* 2014). This increases the difficulty of DSR when looking at both weed management and economic factors.

Table 5: Effect of pre and post-emergence herbicides treatments on Economics in direct seeded rice.

Sr. No.	Treatment	Grain Yield (t ha^{-1})	HI (%)	Gross returns/ ha (Rs.)	Net returns/ ha (Rs.)	B:C Ratio
T_1	Pendimethalin +pyrazosulfuron (TM) (PRE)	5.0	41.6	126666	91766	2.6
T_2	Pendimethalin + pyroxasulfone (TM) (PRE)	3.3	38.4	83464	44689	1.1
T_3	Pretilachlor + pyrazosulfuron (PRE-MIX) (PRE)	3.9	40.6	98006	65131	1.9
T_4	Fenoxaprop-p-ethyl with safener + ethoxysulfuron (TM) (POE)	4.6	43.3	115062	79162	2.2
T_5	Cyhalofop-butyl + penoxsulam (PRE-MIX) and metsulfuron -methyl + chlorimuron-ethyl (PRE-MIX) (POE)	5.8	41.2	143872	108147	3.0
T_6	.Triafamone + ethoxysulfuron (PRE-MIX) (POE)	4.6	40.8	115062	81162	2.4
T_7	Pendimethalin + pyrazosulfuron (TM) (PRE) *fb* bispyribac-sodium (POE)	5.4	42.2	133364	96464	2.6
T_8	Pendimethalin + pyroxasulfone (TM) (PRE) *fb* bispyribac-sodium (POE)	3.5	39.3	88071	47296	1.2
T_9	Pretilachlor + pyrazosulfuron (PRE MIX) (PRE) *fb* bispyribac-sodium (POE)	5.2	41.8	129753	94878	2.7
T_{10}	Pendimethalin (PRE) *fb* fenoxaprop-p-ethyl + ethoxysulfuron (TM) (POE).	6.1	43.6	153931	115281	2.9
T_{11}	Weed free	6.3	43.9	157890	112365	2.5
T_{12}	Weedy check	3.2	37.4	79580	48305	1.5
	SEm ±	0.17	0.63	NS	NS	NS
	C.D. (p=0.05)	0.51	1.86	NS	NS	NS

PRE= Pre-emergence, POE=Post-emergence, TM= Tankmix, PRE-MIX= Already mixed before used.

5. Conclusion

This study looked at how weed richness and abundance in trial areas were affected by the combination of pre- and post-emergence herbicides. Herbicides applied before, during, and after emergence enhanced rice crops' competitiveness, decreased weed biomass, and raised the yield of rice that was directly sown. Pendimethalin 1000 g ha^{-1} *fb* fenoxaprop-p-ethyl 69 g ha^{-1} + ethoxysulfuron 18 g ha-1 was the weed management practice that produced the highest grain yield and yield attributes. This treatment was significantly better than other herbicidal treatments. Farmers should be encouraged to administer herbicides depending on weed flora and should not apply herbicides in tankmixes in a generalised manner. Given this, expanding extension services can help rice farmers become more proficient in applying pre-emergence herbicide in DSR production systems and improve their technical abilities. Additional research on the adjustments to the integration with herbicide combinations and with better spray technology is required, particularly in circumstances where weeds pose a threat and where weed flora diversity is substantial.

9. Reference

Ahmed, S., Chauhan, B.S., 2014. Performance of different herbicides in dry-seeded rice in Bangladesh. Science World J. 14.

AICRPWC, USDA/ICAR. Third Annual Report of All India Coordinated Research Proect on Weed Control.Sriniketan Center, Viswa Bharati, Sriniketan. 1988: 185-190.

Awan, T.H., Sta Cruz, P.C., Chauhan, B.S. Agronomic indices, growth, yield-contributing traits, and yield of dryeseeded rice under varying herbi cides. Field Crop. Research. 2015;177: 15-25.

Bhullar, M.S., Kumar, S., Kaur, S., Kaur, T., Singh, J., Yadav, R., Chauhan, B.S., Gill, G. Management of complex weed flora in dry-seeded rice. Crop Protection. 2016;83:20-26.

Bhullar, M.S., Singh, S., Kumar, S., Gill, G. Agronomic and economic impacts of direct seeded rice in Punjab. Agricultural Research Journal. 2018 (Accepted).

Chauhan, B.S. Crowfoot grass (*Dactyloctenium aegyptium*) germination and response to herbicides in the Philippines. Weed Science. 2011; 59:512-516.

Chauhan, B.S., 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. Weed Technol. 2012; 26: 1-13.

Chauhan, B.S., Abugho, S. Weed management in mechanized-sown, zero-till dry-seeded Rice. Weed Technology. 2013;27:28-33.

Chauhan, B.S., Abugho, S.B. Effect of growth stage on the efficacy of post-emergence herbicides on four weed species of direct-seeded rice. Science World Journal. 2012.

Chauhan, B.S., Ahmed, S., Awan, T.H., Jabran, K., Sudheesh, M., 2015. Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. Crop Protection. 2015;71:19-24.

Chauhan, B. S., Awan, T. H., Abugho, S. B., & Evengelista, G. Effect of crop establishment methods and weed control treatments on weed management, and rice yield. *Field Crops Research*. 2015;172: 72-84.

Chauhan, B.S., Mahajan, G., Sardana, V., Timsina, J., Jat, M.L. Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. Advances Agronomy. 2012; 117: 315–369.

Chauhan, B.S., Opena, J. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. Field Crops Research. 2012;137:56–69.

Das, T.K. Towards better appraisal of herbicide bioefficacy. Indian Journal of Agricultural Sciences. 2001;71:676-678.

Fisher, R. A. Technique of analysis of variance. Handbook of Agricultural Statistics. 1950;B-29-110.

Ganie, Z.A., Singh, S., Singh, S. Integrated weed management in dry-seeded rice. Indian Journal of Agronomy. 2014;46:172-173.

Gill, G., Bhullar, M.S., Yadav, A., Yadav, D.B. Technology for Successful Production of Direct Seeded Rice. A Training Manual Based on the Outputs of ACIAR (Australian Centre for International Agricultural Research) Funded Project CSE/ 2004/033. (A Joint Publication of University of Adelaide, South Australia. 2013; p. 32. Punjab Agricultural University Ludhiana, Punjab; CCS Haryana Agricultural University, Hisar, Haryana).

Gill, G.S. and Kumar, V. Weed index. A new method for reporting weed control trials. Indian Journal Agronomy. 1966; 14(1):96-98.

Humphreys, E., Kukal, S.S., Christen, E.W., Hira, G.S., Singh, B., Yadav, S., Sharma, R.K. Halting the groundwater decline in north-west India-Which crop technologies will be winners? Advances in Agronomy. 2010;109:155-217.

Jaiswal, D. K., Duary, B., Madhukar, B., & Jaiswal, D. Influence of Rice Herbicides on Weed Growth and Nutrient Removal under Different Tillage in Rice–Yellow Sarson Cropping Sequence. International Journal of Bio-resource and Stress Management. 2022;13(12):1458-1464.

Khaliq, A., Matloob, A. Weed crop competition period in three fine rice cultivars under direct seeded rice culture. Pakistan Journal Weed Science Research. 2011;17:229-243.

Kumar, N., Hazra, K. K., Nath, C. P., Praharaj, C. S., & Singh, U. Grain legumes for resource conservation and agricultural sustainability in South Asia. Legumes for soil health and sustainable management. 2018:77-107.

Kumar, V., Ladha, J.K., Gathala, M.K., 2009. Direct drill-seeded rice: a need of the day. In: Annual Meeting of Agronomy Society of America, November 1-5, 2009, Pittsburgh. Html. (accessed 25.09.15.).

Mahajan, G., Chauhan, B.S., Johnson, D.E. Weed management in aerobic rice in north western Indo-Gangetic Plains. J. Crop Improvement. 2009;23:366-382.

Mahajan, G., Chauhan, B.S. Weed control in dry direct-seeded rice using tank mixtures of herbicides in South Asia. Crop Protection. 2015;72:90-96.

Mitra, B., Patra, K., Bhattacharya, P. M., Ghosh, A., Chowdhury, A. K., Dhar, T., and Gathala, M. K. Efficacy of pre-and post-emergence herbicide combinations on weed control in no-till mechanically transplanted rice. Cogent Food & Agriculture. 2022;8(1):2139794.

Rahman, Moshiur. Response of weed flora to different herbicides in aerobic rice system. Science Research Essays. 2012;7(1):12-23.

Sen, S., Kaur, R., Das, T. K., Shivay, Y. S. and Sahoo, P. M. Bio-efficacy of sequentially applied herbicides on weed competition and crop performance in dry direct-seeded rice (*Oryza sativa*). Indian Journal of Agronomy. 2018;63(2):230-233.

Sharma, P.K., Ladha, J.K., Bhutan, L. Soil physical effects of puddling in the rice-wheat cropping system. In: Ladha, J.K., et al. (Eds.), Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts, ASA Spec Publ. 65. ASA, CSSA, and SSA, Madison, WI. 2003; pp. 97-114.

Shweta, M. M., & Malik, M. Improving wheat productivity in rice-wheat cropping system through crop establishment methods. International Journal of Pure and Applied Bioscience. 2017;5(3): 575-578.

Singh, V.P., Singh, S.P., Dhyani, V.C., Tripathi, N., Banga, A., Yadav, V.R. Effect of establishment methods on shifting of weed flora in rice-wheat cropping system. In: Proc. 24th Asian-Pacific Weed Science Society Conference" October 22-25, 2013, Bandung, Indonesia, pp. 494.

Suganya, R., Kumar, S. M. and Baradhan, G. Efficacy of new generation herbicidal combination for weed management in direct seeded rice (*Oryza sativa* L.). Crop Research. 2022;57(5 & 6):297-303.

Tabbal, D.F., Bouman, B.A.M., Bhuiyan, S.I., Sibayan, E.B., Sattar, M.A. On farm strategies for reducing water input in irrigated rice: case studies in the Philippines. Agric. Water Management. 2002;56:93-112.