Society for Advancement of Wheat and Barley Research
ICAR-Indian Institute of Wheat & Barley Research
Karnal - 132 001, India

Journal of Cereal Research

11(3): 257-267

Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Research Article

Evaluation of flucetosulfuron and ready-mix of penoxsulam + bentazone as post-emergent weed control options in direct seeded and transplanted rice

Rajender Singh Chhokar*, Ramesh Kumar Sharma, Subhash Chander Gill, Ankur Chaudhary and Ram Kumar Singh

ICAR-Indian Institute of Wheat and Barley Research, Karnal, Haryana-132 001, India

Article history

Received: 28 Dec., 2019
Revised: 30 Dec., 2019
Accepted: 31 Dec., 2019

Citation

Chhokar RS, RK Sharma, SC Gill, A Chaudhary and RK Singh. 2019. Evaluation of flucetosulfuron and ready-mix of penoxsulam + bentazone as post-emergent weed control options in direct seeded and transplanted rice. *Journal of Cereal Research* **11**(3): 257-267. http://doi.org/10.25174/2249-4065/2019/96493

****Corresponding author***
Email: Rajender.Chhokar@icar.gov.in

Abstract

Post-emergent herbicides were evaluated in a series of field experiments for control of weeds in rice nursery as well as, direct seeded and transplanted rice during the *kharif* seasons of 2014 and 2015. Results of one of the studies showed that flucetosulfuron at 25-30 g ha^{-1} applied at 15-18 DAS (days after sowing) was effective for control of many broad-leaved weeds and some grass weeds [*Echinochloa crus-galli* (L.) Beauv.]. However, flucetosulfuron was not reasonably effective against major upland rice weeds namely *Dactyloctenium aegyptium* (L.) Willd and *Digitaria sanguinalis* (L.) Scop. infesting rice nursery and direct seeded rice (DSR). Under puddle transplanted rice (PTR) conditions, flucetosulfuron 25-30 g ha^{-1} applied at 15-19 days after transplanting had similar weed control levels and rice grain yields as obtained with bispyribac-Na at 20 g ha^{-1} and azimsulfuron at 35 g ha^{-1}. However, in the DSR, weed control and rice grain yields with flucetosulfuron were poorer to that observed with application of azimsulfuron 35 g ha^{-1}. In another field study, ready-mixture of penoxsulam + bentazone (1:36) at 840-1110 g ha^{-1} as post-emergent (18 DAS or 20 DAT) option was evaluated against weeds in DSR and PTR along with standard check herbicides, azimsulfuron 35 g ha^{-1}, and cyhalofop-p-butyl 80 g ha^{-1}. Penoxsulam + bentazone at 925-1110 g ha^{-1} was very effective for control of grass weed, *E. crus-galli* (98-100% control) and many broad-leaved weeds but was not effective against *D. aegyptium and D. sanguinalis* found in DSR. Consequently, the poor weed control (508-524 g m^{-2} total weed dry weight) with application of penoxsulam + bentazone combination at 925-1110 g ha^{-1} resulted in 1.45-1.48 t ha^{-1} lesser grain yield compared to azimsulfuron 35 g ha^{-1} (218.2 g m^{-2} total weed dry weight). Under puddle transplanted conditions, penoxsulam + bentazone combination and azimsulfuron 35 g ha^{-1} provided significantly better weed control than cyhalofop-p-butyl. The weed competition caused higher rice grain yield reductions in DSR (86-100%) than PTR conditions (25-52%). The results indicated azimsulfuron as better herbicide option for DSR than flucetosulfuron, penoxsulam, penoxsulam + bentazone and bispyribac-Na due to diverse weed flora control. Also, pot studies indicated that flucetosulfuron and azimsulfuron should be applied with cationic surfactant at 1000 ml ha^{-1} for better weed control efficacy.

Keywords: Azimsulfuron, bentazone, bispyribac-Na, cyhalofop-p-butyl, *Dactyloctenium aegyptium,* direct seeded rice, *Echinochloa crus-galli*, flucetosulfuron, penoxsulam, puddle transplanting, rice nursery, surfactant

1. Introduction

Rice (*Oryza sativa* L.) a prime cereal crop is cultivated on about 43.5 m ha in India (27% of 162.0 m ha world rice acreage) with production (paddy) of 163.5 MT (23% of 728.1 MT world's production) (FAO, 2019; IRRI, 2019). Its assured supply is recognized as an important factor for global food security as it feeds about half of the world's population. Weed infestation is one of the major problems in rice cultivation. In India, weeds cause a loss of about 15-66% in DSR (Direct Seeded Rice) and 6-30% in PTR (Puddle Transplanting Rice) (Gharade *et al.*, 2018). Whereas, globally, 30-98 per cent losses in rice grain yields in DSR have been observed by various workers (Oerke and Dehne, 2004; Rao *et al.*, 2007; Kumar and Ladha, 2011; Chhokar *et al.*, 2014). Oerke (2006) have reported that although globally weeds cause an average 37.1% potential loss in rice grain yield but even after implementing weed control measures still 10.2% loss in grain yield is observed. So, there is need to adopt efficient crop management practices for weed control in rice.

Worldwide, rice is grown under different ecologies ranging from an up-land to low land situations. However, it is mainly grown as puddled transplanting and fields are flooded during the most of the crop duration. Ponding of water during initial stages reduces germination of weeds and improves the efficacy of herbicides. In addition, the competitive advantage of one month old age rice seedlings in PTR against newly emerged weeds for resources also reduces the weed impact leading to lesser rice yield reductions in this system. On the other hand, the scarcity and costly labour for transplanting is forcing the growers to shift towards the DSR. However, DSR faces the much severe problem of weed infestations than PTR leading to higher yield reductions due to emergence of weeds before or along with the crop and there is no water layer or water ponding protection to suppress weed growth (Chhokar *et al.*, 2014; Rao *et al.*, 2007). The yield reduction due to severe weed infestation is one of the main reasons of low rice productivity particularly in DSR and its poor adoption in India. Thus success of DSR depends mainly on how efficiently weeds are managed.

Weeds also interfere in rice nursery and heavy weed pressure is observed in nursery due to use of farm yard manures as well as alternate wetting and drying. The weeds present in rice nursery beside reducing the seedling vigour also interfere with main crop after being transplanted along with rice seedling because of morphological similarity leading to more yield reductions. Since, the manual removal of morphological similar weed seedlings from rice seedlings in nursery is laborious, time consuming, costly and difficult. Therefore, effective broad-spectrum herbicides are required during nursery raising also to prevent the infiltration of weed seedlings from nursery area to the main fields along with rice seedlings.

Rice yield reductions depend upon weed density, type of weed flora, duration of weed competition, rice cultivar, water management, and crop establishment techniques (Diarra *et al.*, 1985; Fischer and Ramirej, 1993; Eleftherohorinos *et al.*, 2002; Chhokar *et al.*, 2014). Weed diversity and intensity is strongly influenced by the crop establishment techniques i.e. either direct seeded under dry or wet conditions or transplanted under puddled or unpuddled conditions. Various research workers (Walia *et al.*, 2008; Chauhan, 2012; Chhokar *et al.*, 2014) have reported the higher yield reductions in direct seeding compared to transplanting system. Besides yield losses, weed infestation also reduces rice recovery, with consequential grade reduction (Menzes *et al.*, 1997) thereby fetching lower prices at the mill.

For weed control, majority of the farmers are using butachlor, pretilachlor and anilofos in transplanted rice and their efficacies against weeds particularly grass weeds reduce under limited water availability. Also, these pre-emergence options are less effective in rice nursery as well as DSR and under such situations; post-emergence broad-spectrum herbicides can be of immense use for the rice growers. The success of DSR is dependent on the effective weed control and if suitable post-emergence herbicides are made available then area under DSR cultivation can increase. So, the present investigations were undertaken with the objective of evaluating the effectiveness of flucetosulfuron and penoxsulam + bentazone as post-emergent options against weeds in rice nursery, direct seeded and puddled transplanted rice.

2. Materials and methods

Field and pot studies were conducted at the Resource Management Block, ICAR-Indian Institute of Wheat and Barley Research, Karnal during *kharif* seasons of 2014 to 2016. Field studies were conducted keeping three replications in randomized block design. The soil of the experimental field was sandy clay loam with pH of 8.0 and organic matter content 0.41%. The field experiments were conducted under three set of conditions i.e. rice nursery, direct dry seeding and puddling transplanting.

2.1 Evaluation of flucetosulfuron against weeds

2.1.1. Rice nursery

After field preparation, pre germinated seeds of rice cultivar HKR 47 were sown @ 5 Kg per100 m^2 area by uniform broadcasting during last week of May, 2014 and 2015. A plot of 10 m^2 (2m x 5m) for each treatment was kept for spraying herbicides. Weed control treatments consisted of flucetosulfuron (ICH-110) at 15, 20, 25 and 30 g *a.i.* ha^{-1}, bispyribac sodium at 20 g ha^{-1} and untreated weedy check. The herbicides were applied 15 DAS (days after seeding) using knapsack sprayer fitted with flat fan nozzles. Fertilization and irrigation were adopted as per recommendations and need. The observations on weed density were taken 20 days after herbicide application.

2.1.2. Direct seeded rice (DSR)

In DSR, after field preparation sowing of rice cultivar Arize 6129 was done with the help of precision plot seed drill using a seed rate of 35 Kg ha^{-1} at a row to row (R x R) spacing of 20 cm on 6th July 2014 and 16th June 2015. The herbicide treatments comprised of different doses of flucetosulfuron at 15, 20, 25 and 30 g ha^{-1}, bispyribac sodium at 20 g ha^{-1} and azimsulfuron at 35 g ha^{-1}. Weedy control and weed free check were also kept for treatments comparison. Herbicides were applied on 17-18 DAS.

2.1.3. Puddled transplanted rice (PTR)

Rice seedlings of 30-35 days age (cultivar Arize 6129) were transplanted after puddling at 20 cm x 15 cm spacing on 11th July, 2014 and 16th July, 2015 during first and second year, respectively. The herbicide treatments comprised of flucetosulfuron at 15, 20, 25 and 30 g ha^{-1}, bispyribac sodium at 20 and azimsulfuron at 35 g ha^{-1}. Weedy and weed free control were also kept for comparison. Herbicides were applied on 15 and 19 days after transplanting, during first and second year, respectively.

2.2. Evaluation of ready-mix of penoxsulam + bentazone against weeds

2.2.1 Direct seeded rice (DSR)

The herbicide treatments comprised of ready mix combination of penoxsulam + bentazone at 840, 925 and 1110 g ha^{-1}, penoxsulam 22.5 g ha^{-1}, bentazone 960 g ha^{-1}, azimsulfuron 35 g ha^{-1} and cyhalofop-p-butyl at 80 g ha^{-1}. For comparison of herbicide treatments, weedy and weed free control were also kept. The herbicides were applied at 18 DAS.

2.2.2 Puddled transplanted rice (PTR)

The herbicide treatments comprised of ready mix combination of penoxsulam + bentazone at 840, 925 and 1110 g ha^{-1}, penoxsulam 22.5 g ha^{-1}, bentazone 960 g ha^{-1}, azimsulfuron 35 g ha^{-1} and cyhalofop-p-butyl at 80 g ha^{-1}. Weedy control and weed free treatments were also kept for comparison. The herbicides were applied at 20 DAT (days after transplanting).

Herbicides were applied using knapsack sprayer fitted with two flat fan nozzles using 400 litre water ha^{-1}. In puddle conditions, before herbicide spray, water was drained out and flooded after 2-3 days of spray. The recommended dose of fertilizers both for DSR and PTR was 150 Kg N, 60 Kg P_2O_5 and 40 Kg K_2O ha^{-1} and were applied through urea, DAP and MOP. Full dose of P and K along with 23.5 Kg N ha^{-1} were applied as basal during the final land preparation in PTR and DSR. Rest of N was applied in three equal splits at 1, 3 and 6 weeks after transplanting in PTR. While in DSR, time of N top dressing was at 2, 5 and 7 weeks after sowing. Irrigations were done according to recommended package of practice for rice. Observations on weeds were taken by placing a quadrat of 50 cm X 50 cm randomly at two places in each plot. The weed dry weight was recorded 50-60 days after herbicide application in DSR trials and 60-70 days after herbicide application in PTR trials. The weed dry weight (g m^{-2}) was recorded by harvesting weeds using 0.25 m^2 quadrat placed randomly at two places in each plot. The harvested weeds after sun drying were dried in oven at 60 ˚C temperature for 3-4 days till constant weight and then the dry weight recorded and converted to g m^{-2}. The crop from net plots was manually harvested and threshed using small paddy thresher.

Weed Control Efficiency (WCE) in per cent was calculated based on the weeds dry weights using the formula

$$WCE= (WDC-WDT) / WDC \times 100$$

Where, WDC= weed dry weight in weedy check; WDT= weed dry weight in a treatment.

2.3. Effect of surfactant on efficacy of flucetosulfuron and azimsulfuron

Pot experiments were conducted to evaluate the effect of surfactant in improving the efficacy of flucetosulfuron and azimsulfuron during 2016. Three test weed species used in these experiments were barnyard grass (*Echinochloa crus-galli* (L.) Beauv.), crow footgrass (*Dactyloctenium aegyptium* (L.) Willd.), and horsepurslane (*Trianthema portulacastrum* L.). Test weed species were grown in pots (size 4.5 Kg soil capacity) filled with soil: FYM ratio of 6:1 (v/v) after passing through a sieve and thoroughly mixed. Seeding depth was about 2 cm except *Dactyloctenium aegyptium* which was sown at 0.2-0.5 cm depth. Finally 10-12 plants pot^{-1} were maintained. At 3-4 leaf stage or 20 DAS (days after sowing) of *E. crus-galli, D. aegyptium* and 2-3 inch height of *T. portulacastrum,* herbicides were sprayed using spray volume of 400 L ha^{-1} with Knap sack sprayer fitted with flat fan nozzles. Herbicides, flucetosulfuron at 0, 7.5, 15.0 and 30 g ha^{-1} and azimsulfuron at 8.75, 17.5 and 35.0 g ha^{-1} were applied with and without surfactant. The cationic (Polyethelene amine) surfactant was used at 1000 ml ha^{-1}. Finally four weeks after herbicide application, fresh weight pot^{-1} of weeds was recorded and based on fresh weight of control pots, the relative fresh weight reductions under various treatments were calculated. Experiments were repeated and carried out in completely randomized design (CRD) with three replications.

2.4. Statistical analysis

The data of the field experiments were subjected to analysis of variance (ANOVA) in block design using the Statistical Analysis System (SAS, version 9.2) software. The differences amongst the treatment means were compared using the Fischer's LSD test at 0.05 probability. In field studies, the weed dry weight data were square root transformed {√x+1} for statistical analysis, and based on this the interpretation of the results of the original data are given in the tables by mentioning the letters based on the transformed data analysis. In pot studies, data of fresh biomass reduction in comparison to untreated control was calculated and standard error of the mean (SEM) values were worked out (Fig. 1- 3).

3. Results and discussion

The major weeds found infesting the rice nursery and DSR plots were; barnyard grass, *Echinochloa crus-galli* (L.) Beauv.; Jungle rice, *Echinochloa colona* (L.) Link; Purple nutsedge, *Cyperus rotundus* L.; yellow nutsedge, *Cyperus. esculentus*; crow footgrass, *Dactyloctenium aegyptium* (L.) Willd.; large crabgrass, *Digitaria sanguinalis* (L.) Scop; horsepurslane, *Trianthema portulacastrum* L.; Little gooseberry, *Physalis minima;* Monarch redstem, *Ammennia bacciferra; Digera arvensis* Forsk.*;* and gale of the wind, *Phyllanthus niruri* L.; false daisy, *Eclipta alba* (L.) Hassk. Whereas the puddle transplanted plots had major infestation of *E. crus-galli;* smallflower umbrella-sedge *Cyperus difformis* L.*;* pond lovegrass, *Eragrotis japonica* (Thunb.) Trin.**;** Fringerush, *Fimbristylis miliacea* (L.) Vahl. and *A. bacciferra*.

Herbicides were evaluated against these weeds under field conditions and findings of which are presented and discussed below in different heads.

3.1. Evaluation of flucetosulfuron against weeds

3.1.1. Rice nursery

Table 1: Performance of flucetosulfuron against weeds in rice nursery during 2014.

Treatments	Dose g a.i. ha^{-1}	*Weed population no. m^{-2}							
		D. aegyptium	*E. colonum*	*T. portulacastrum*	*P. niruri*	*C. difformis*	*C. esculentus*	Other weeds	Total weeds
Flucetosulfuron	15	24.0	22.0 B	16.0 B	0.7 B	3.3 B	0.0 B	10.0 A	76.0 B
Flucetosulfuron	20	22.0	18.3 B	10.0 C	0.0 B	0.0 B	0.0 B	8.7 AB	59.0 BC
Flucetosulfuron	25	18.0	16.0 B	2.0 E	0.0 B	0.0 B	0.0 B	7.3 ABC	43.3 C
Flucetosulfuron	30	14.0	8.7 C	0.7 F	0.0 B	0.0 B	0.0 B	4.0 CD	27.3 D
Bispyribac-Na	20	26.7	5.3 C	4.0 D	3.3 A	0.0 B	0.0 B	5.3 BCD	44.7 C
Weedy check		28.0	34.0 A	26.0 A	4.0 A	200.0 A	2.7 A	3.3 D	298.0 A
p-value		0.0967	0.0002	<.0001	0.0007	<.0001	<.0001	0.0105	<.0001

*Original weed density values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

Table 2: Performance of flucetosulfuron against weeds in rice nursery during 2015.

Treatments	Dose g a.i. ha^{-1}	*Weed population no. m^{-2}								
		E. crus-galli	*D. aegyptium*	*E. colonum*	*P. niruri*	*C. difformis*	*T. portulacastrum*	*Ammenia bacciferra*	Other weeds	Total weeds
Flucetosulfuron	15	52.7 B	26.0	129.3 AB	6.0 A	1.3 B	103.3 AB	0.0 B	0.0 B	318.7 B
Flucetosulfuron	20	17.3 C	26.0	107.3 B	4.7 A	0.7 B	88.7 BC	0.0 B	0.0 B	244.7 BC
Flucetosulfuron	25	13.3 C	23.3	102.0 B	4.0 A	0.0 B	78.0 BC	0.0 B	0.0 B	220.7 BC
Flucetosulfuron	30	13.3 C	21.3	84.7 B	4.0 A	0.0 B	68.0 BC	0.0 B	2.0 AB	193.3 C
Bispyribac-Na	20	0.0 D	24.0	0.0 C	0.0 B	0.0 B	48.7 C	0.7 B	0.0 B	73.3 D
Weedy Check		184.7 A	24.0	171.3 A	7.3 A	337.3 A	136.7 A	3.3 A	3.3 A	868.0 A
p-value		<.0001	0.9958	<.0001	0.0035	0.0001	0.0214	0.0003	0.0393	<.0001

*Original weed density values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance.

Table 3: Performance of flucetosulfuron against weeds in DSR during 2014.

Treatments	**Dose (g a.i. ha^{-1})**	**Weed dry weight g m^{-2}*									**Weed control efficiency (WCE)%**	**Rice Grain Yield (t ha^{-1})**
		E. crusgalli	*D. arvensis*	*D. aegyptium*	*E. colonum*	*T. portulacastrum*	*C. difformis*	*Eragrotis japonica*	***Other weeds***	***Total weeds***		
Flucetosulfuron	15	90.6 ^{B}	0.3 ^{B}	210.0 ^{A}	159.6 ^{A}	0.8 ^{B}	0.0 ^{B}	34.0 ^{A}	6.1 ^{B}	501.5 ^{AB}	10.1	0.97 ^{EF}
Flucetosulfuron	20	69.0 ^{B}	0.4 ^{B}	186.7 ^{AB}	138.8 ^{A}	0.5 ^{B}	0.0 ^{B}	29.0 ^{A}	1.8 ^{BC}	426.3 ^{AB}	23.6	1.40 ^{DE}
Flucetosulfuron	25	52.8 ^{B}	0.0 ^{B}	167.9 ^{AB}	132.6 ^{AB}	0.0 ^{B}	0.0 ^{B}	33.8 ^{A}	0.6 ^{C}	387.7 ^{B}	30.5	1.80 ^{CD}
Flucetosulfuron	30	49.7 ^{B}	0.0 ^{B}	172.8 ^{AB}	119.1 ^{EB}	0.0 ^{B}	0.0 ^{B}	31.5 ^{A}	0.2 ^{C}	373.3 ^{B}	33.1	1.80 ^{CD}
Weed free	-	0.0 ^{C}	0.0 ^{B}	0.0 ^{D}	0.0 ^{E}	0.0 ^{B}	0.0 ^{B}	0.0 ^{B}	0.0 ^{C}	0.0 ^{D}	100.0	4.55 ^{A}
Bispyribac-Na	20	3.6 ^{C}	0.5 ^{B}	153.3 ^{AB}	15.9 ^{D}	0.2 ^{B}	0.8 ^{B}	41.4 ^{A}	0.7 ^{C}	216.5 ^{C}	61.2	2.38 ^{BC}
Azimsulfuron	35	50.8 ^{B}	0.0 ^{B}	48.1 ^{C}	44.2 ^{C}	1.3 ^{B}	0.0 ^{B}	42.9 ^{A}	1.2 ^{C}	188.5 ^{C}	66.2	2.97 ^{B}
Weedy check	-	217.5 ^{A}	1.5 ^{A}	125.2 ^{B}	86.7 ^{B}	37.5 ^{A}	52.0 ^{A}	24.2 ^{A}	13.4 ^{A}	557.8 ^{A}	0.0	0.66 ^{F}
p-value		<.0001	0.0126	<.0001	<.0001	<.0001	<.0001	0.0013	0.0005	<.0001		<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

Flucetosulfuron applied in rice nursery showed excellent selectivity and no visual phytotoxicity symptoms were observed. There was significant reduction in weed density (Table 1 - 2) by application of flucetosulfuron except *D. aegyptium* and *P niruri* during second year of study. Bispyribac-Na was also not effective for control of *D. aegyptium*. Flucetosulfuron provided good control of *E. crus-galli*, *C. difformis* and *T. portulacastrum.* The performance of flucetosulfuron 25-30 g ha^{-1} in controlling *C. difformis* and *C. esculentus* was similar to bispyribac. However, *E. colona* and *E. crus-galli* control was better with application of bispyribac compared to flucetosulfuron. The total weed density with application of flucetosulfuron 25-30 g ha^{-1} ranged 27.3-43.3 m^{-2} during 2014 and 193.3-220.7 m^{-2} during 2015. The weed density in untreated control was 298 and 868 weeds m^{-2} during 2014 and 2015, respectively. Based on two year studies, it can be recommended that flucetosulfuron and bispyribac can be used for weed control in rice nursery. Dhillon and Bhullar (2016) also reported that application of bispyribac-sodium at 25 g ha^{-1} applied at 15 DAS significantly reduced total weed density and gave weed control efficiency of 90.9 to 97.6% for *E. crus-galli*, *T. portulacastrum* and *Cyperus iria.*

3.1.2 Direct seeding rice

The performance of flucetosulfuron against major weeds in DSR is given in Table 3 and 4. The dominant grass weeds in the experimental fields were *D. aegyptium, E. crus-galli and E. colona,* and among broad-leaved and sedges weeds, major were *E. alba, C. difformis, and F. miliacea*.

The perusal of data showed that the maximum total weed dry weights were in untreated weedy control (Table 3 - 4). The total weed dry weights in weedy check were 557.8 and 876.9 g m^{-2} during 2014 and 2015, respectively. The weed dry weight reduced as the dose of flucetosulfuron increased beyond 20 g ha^{-1}. Among herbicide treatments, over all the lowest weed dry weight was with application of azimsulfuron at 35 g ha^{-1}. Flucetosulfuron and bispyribac were less effective against *D. aegyptium*. However, azimsulfuron, effectively controlled this weed. Singh *et al.* (2016) also reported the better control efficacy of azimsulfuron against sedges than the bispyribac-Na.

Bispyribac-Na provided very good control of dominant grass weed *E. crus-galli.* However, flucetosulfuron and azimsulfuron were comparatively less effective in controlling *E. crus-galli.* All the three herbicides

Table 4: Performance of flucetosulfuron against weeds in DSR during 2015.

Treatments	Dose (g a.i. ha^{-1})	*Weed dry weight g m^{-2}							Weed control efficiency (WCE)%	Rice Grain Yield (t ha^{-1})
		E. crus-galli	*D. aegyptium*	*E. alba*	*C. rotundus*	*F. miliacea*	*Other weeds*	Total weeds		
Flucetosulfuron	15	207.3 ^{B}	362.7 ^{A}	1.4	11.0 ^{A}	0.0 ^{B}	29.0 ^{A}	611.5 ^{B}	30.3	0.04 ^{D}
Flucetosulfuron	20	200.3 ^{B}	348.7 ^{A}	2.5	13.2 ^{A}	0.0 ^{B}	17.8 ^{AB}	582.6 ^{B}	33.6	0.15 ^{CD}
Flucetosulfuron	25	176.6 ^{B}	371.0 ^{A}	2.6	11.8 ^{A}	0.0 ^{B}	19.0 ^{AB}	581.1 ^{B}	33.7	0.58 ^{CD}
Flucetosulfuron	30	122.9 ^{B}	356.1 ^{A}	2.1	15.2 ^{A}	0.0 ^{B}	22.4 ^{AB}	518.6 ^{B}	40.9	0.73 ^{C}
Weed free	-	0.0 ^{C}	0.0 ^{D}	0.0	0.0 ^{C}	0.0 ^{B}	0.0 ^{C}	0.0 ^{E}	100.0	5.39 ^{A}
Bispyribac Na	20	1.4 ^{C}	372.3 ^{A}	1.3	1.8 ^{BC}	0.0 ^{B}	4.1 ^{C}	380.9 ^{C}	56.6	0.70 ^{C}
Azimsulfuron	35	151.1 ^{B}	82.2 ^{C}	2.8	0.9 ^{BC}	0.0 ^{B}	30.8 ^{A}	267.8 ^{D}	69.5	2.22 ^{B}
Weedy check	-	676.8 ^{A}	169.3 ^{B}	3.3	6.6 ^{AB}	9.7 ^{A}	10.6 ^{BC}	876.9 ^{A}	0.0	0.00 ^{D}
p-value		<.0001	<.0001	0.0733	0.0017	0.0005	0.0057	<.0001		<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

provided the good control of broad-leaved and sedges weeds. However, for control of *C. rotundus* azimsulfuron and bispyribac were the better options (Table 4).

The weed free treatment had the minimum dry weight and as a result recorded significant higher grain yield (4.55 and 5.39 t ha^{-1}) than other treatments (Table 3 - 4). Among various herbicide treatments, azimsulfuron at 35 g ha^{-1} recorded significantly better yield but was significantly inferior to weed free check. The weed control efficiency (WCE) based on weed dry weight with azimsulfuron application was 66.2 and 69.5%, during first and second year of studies, respectively. Whereas, the WCE with application of flucetosulfuron 25-30 g ha^{-1} ranged 30.5-33.1 and 33.7-40.9% during first and second year, respectively. The poor WCE was due to its poor efficacy against one of the dominant grass weed *D. aegyptium*.

3.1.3. Transplanted rice

The results regarding bio-efficacy of flucetosulfuron against weeds under puddled transplanted conditions are given in Table 5 - 6. In transplanted rice, major weeds of the experimental fields were *E. crus-galli, C. difformis, E. japonica, and A. baccifera. E. crus-galli* was the most dominant grass weed during both years of experimentation. Some of the grass weeds (*D. aegyptium, D. sanguinalis)* that infested the DSR failed to establish under puddled conditions. Flucetosulfuron at 25-30 g ha^{-1} provided good control of dominant weed (*E. crus-galli).* This herbicide at 25-30 g ha^{-1} was also effective in controlling the broad-leaved weed *A. baccifera* and sedge *C. difformis.* Azimsulfuron and bispyribac also provided the good control of grasses and broad-leaved weeds (Table 5 - 6). All the herbicide treatments were significantly superior to untreated control in reducing the total dry weight of weeds under puddle transplanted conditions. The rice grain yields in plots treated with flucetosulfuron at 25-30 g ha^{-1} were statistically similar to season long weed free situations as well as the recommended treatments of azimsulfuron 35 g ha^{-1} and bispyribac-Na 20 g ha^{-1}. Also, all these herbicide treatments significantly improved the grain yield as compared to untreated weedy control. The better grain yields in these treatments were due to better weed control. The WCE ranged from 93.7 to 96.7% with application of flucetosulfuron at 25-30 g ha^{-1}. The highest WCE was observed with application of bispyribac (98.6 and 99.4%). Earlier studies (Dhillon and Bhullar, 2016; Rao *et al.*, 2015) also reported

Table 5: Performance of flucetosulfuron against weeds in transplanted rice during 2014.

Treatments	Dose (g a.i. ha^{-1})	*Weed dry weight g m^{-2}					Weed control efficiency (WCE)%	Grain Yield (t ha^{-1})
		E. crus-galli	*C. difformis*	*Eragrotis japonica*	Other weeds	Total weeds		
Flucetosulfuron	15	34.6 B	0.0 B	3.7	0.2	38.5 B	87.0	7.72 B
Flucetosulfuron	20	28.3 B	0.0 B	4.0	0.1	32.4 BC	89.0	8.01 AB
Flucetosulfuron	25	7.1 CD	0.0 B	3.5	0.1	10.7 DE	96.4	8.58 A
Flucetosulfuron	30	5.9 CD	0.0 B	3.8	0.0	9.7 DE	96.7	8.68 A
Weed free	-	0.0 D	0.0 B	0.0	0.0	0.0 F	100.0	8.52 A
Bispyrobac Na	20	1.0 D	0.0 B	0.6	0.1	1.7 EF	99.4	8.52 A
Azimsulfuron	35	12.7 BC	0.0 B	3.8	0.5	17.0 CD	94.2	8.40 AB
Weedy check	-	237.8 A	53.5 A	3.8	0.4	295.5 A	0.0	4.20 C
p-value		<.0001	<.0001	0.0619	0.7386	<.0001		<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

Table 6: Performance of flucetosulfuron against weeds in transplanted rice during 2015.

Treatments	Dose (g a.i. ha^{-1})	*Weed dry weight g m^{-2}					Weed control efficiency (WCE)%	Grain Yield (t ha^{-1})
		E. crus-galli	*C. difformis*	*A. bacciferra*	Other weeds	Total weeds		
Flucetosulfuron	15	34.7 B	0.1 B	1.1 B	2.0	37.8 B	86.0	7.29 B
Flucetosulfuron	20	15.8 C	0.0 B	0.8 B	1.9	18.5 C	93.1	7.80 A
Flucetosulfuron	25	13.8 C	0.0 B	0.6 B	2.6	16.9 C	93.7	7.95 A
Flucetosulfuron	30	12.6 C	0.0 B	0.4 B	0.6	13.6 CD	94.9	7.93 A
Weed free	-	0.0 D	0.0 B	0.0 B	0.0	0.0 E	100.0	7.80 A
Bispyribac-Na	20	1.9 D	1.2 B	0.5 B	0.2	3.8 DE	98.6	7.77 A
Azimsulfuron	35	25.2 BC	0.0 B	0.0 B	0.3	25.5 BC	90.5	8.01 A
Weedy check	-	247.2 A	17.5 A	3.1 A	1.4	269.2 A	0.0	6.03 C
p-value		<.0001	<.0001	0.0108	0.4661	<.0001		<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

Table 7: Performance of penoxsulam + bentazone against weeds in DSR.

Treatments	Dose (g a.i. ha^{-1})	*Weed dry weight g m^{-2} E. crus-galli	*D. aegyptium*	*Digitaria sanguinalis*	*E. alba*	*P. niruri*	*C. difformis*	*Fimbristylis miliacea*	*Ammenia bacciferra*	*Physalis minima*	Total weeds	Rice Grain Yield (t ha^{-1})
Penoxsulam + Bentazone (1:36)	840	8.1^{BC}	479.0^{A}	31.9^{B}	0.0^{B}	0.3^{C}	0.0^{B}	0.1	0.0^{B}	0.1^{B}	519.5^{B}	0.51^{CD}
Penoxsulam + Bentazone (1:36)	925	7.9^{C}	502.7^{A}	13.5^{BCD}	0.0^{B}	0.1^{C}	0.0^{B}	0.0	0.0^{B}	0.0^{B}	524.2^{B}	0.66^{C}
Penoxsulam + Bentazone (1:36)	1110	0.0^{C}	502.2^{A}	6.2^{BCD}	0.0^{B}	0.0^{C}	0.0^{B}	0.0	0.0^{B}	0.0^{B}	508.4^{B}	0.69^{C}
Penoxsulam	22.5	12.8^{BC}	471.3^{A}	19.5^{BC}	0.3^{B}	0.2^{C}	0.0^{B}	0.0	(0.1^{B}	0.0^{B}	504.2^{B}	0.65^{C}
Bentazone	960	535.4^{A}	195.7^{B}	21.9^{BC}	0.0^{B}	0.1^{C}	0.0^{B}	0.0	0.0^{B}	4.3^{B}	757.3^{A}	0.02^{E}
Azimsulfuron	35	70.1^{B}	63.3^{C}	84.5^{A}	0.0^{B}	0.2^{C}	0.0^{B}	0.0	0.0^{B}	0.0^{B}	218.2^{C}	2.14^{B}
Cyhalofop-p- butyl	80	455.3^{A}	88.8^{C}	1.9^{CD}	3.5^{A}	(5.0^{A}	10.7^{A}	2.8	1.3^{A}	17.9^{A}	587.1^{AB}	0.17^{DE}
Weed free	-	0.0^{C}	0.0^{D}	0.0^{D}	0.0^{B}	0.0^{C}	0.0^{B}	0.0	0.0^{B}	0.0^{B}	0.0^{D}	7.18^{A}
Weedy check	-	506.4^{A}	203.3^{B}	5.1^{BCD}	0.5^{B}	2.3^{B}	0.0^{B}	0.7	0.0^{B}	11.6^{A}	730.0^{A}	0.02^{E}
p-Value		<.0001	<.0001	0.0055	<.0001	.0001	0.0023	0.0553	0.0007	0.0001	0.0001	<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

effectiveness of bispyribac for control of *Echinochloa* spp. and *Cyperus* spp.

Flucetosulfuron was inferior to standard herbicide azimsulfuron in DSR conditions but was at par under PTR in respect of weed control and producing rice grain yield. This differential response was due to different weed flora. Earlier also the differential weed flora and grain yield have been observed under DSR and PTR plots (Chhokar *et al.*, 2014). Results of these field studies are in confirmation with those of previous studies where the effectiveness of bispyribac sodium as a post-emergence herbicide for DSR and TPR has been also reported (Singh *et al.*, 2009; Khaliq *et al.*, 2011; Yadav *et al.*, 2009; Rao *et al.*, 2015).

Satapathy *et al.* (2017) also observed effectiveness of flucetosulfuron at 25 g ha^{-1} for control of grasses, sedges and broadleaved weeds. They reported that application of flucetosulfuron at 25 g ha^{-1} (5.42 t ha^{-1}), bispyribac sodium at 30 g ha^{-1} (5.40 t ha^{-1}) and azimsulfuron at 35 g ha^{-1} (5.38 t ha^{-1}) recorded grain yield on par with the hand weeding twice (5.64 t ha^{-1}).

Kim *et al.* (2003) observed that at the whole plant level, the GR_{50} values (the dose rate required for 50% growth inhibition) of flucetosulfuron for *E. crus-galli* were 0.6 and 4.6 g ha^{-1} by soil and foliar application, respectively, while those for rice were 183 and 223 g ha^{-1} respectively, demonstrating high activity of flucetosulfuron against *E. crus-galli* with good safety to rice.

3.2. Evaluation of penoxsulam + bentazone against weeds

3.2.1 Direct seeding rice

The performance of pre-mix of penoxsulam + bentazone (1:36) against major weeds in DSR is given in Table 7. The dominant grass weeds in the experimental

Table 8: Performance of penoxsulam + bentazone against weeds in transplanted rice.

Treatments	Dose (g a.i. ha^{-1})	*Weed dry weight g m^{-2} E. crus-galli	*E. colona*	*E. alba*	*C. difformis*	*Ammenia bacciferra*	Total weeds	Weed Control Efficiency (WCE)%	Rice Grain Yield (t ha^{-1})
Penoxsulam + Bentazone (1:36)	840	3.7^{C}	6.9^{B}	0.2^{C}	3.6^{B}	0.2^{B}	14.5^{CD}	94.3	8.20^{A}
Penoxsulam + Bentazone (1:36)	925	1.1^{C}	0.1^{B}	0.1^{C}	1.9^{B}	0.2^{B}	3.4^{DE}	98.7	8.45^{A}
Penoxsulam + Bentazone (1:36)	1110	1.2^{C}	0.0^{B}	0.0^{C}	1.0^{B}	0.0^{B}	2.2^{E}	99.1	8.31^{A}
Penoxsulam	22.5	4.5^{C}	1.1^{B}	0.1^{C}	0.8^{B}	0.4^{B}	6.9^{DE}	97.3	8.22^{A}
Bentazone	960	162.3^{A}	29.6^{A}	0.0^{C}	1.5^{B}	0.0^{B}	193.4^{A}	23.7	5.83^{C}
Azimsulfuron	35	33.1^{B}	0.4^{B}	0.0^{C}	0.0^{B}	0.1^{B}	33.7^{C}	86.7	8.21^{A}
Cyhalofop butyl	80	60.0^{B}	0.0^{B}	4.7^{A}	56.1^{A}	5.5^{A}	126.3^{B}	50.2	7.33^{B}
Weed free	-	0.0^{C}	0.0^{B}	0.0^{C}	0.0^{B}	0.0^{B}	0.0^{E}	100.0	8.22^{A}
Weedy check	-	176.4^{A}	20.0^{A}	2.6^{B}	50.2^{A}	4.1^{A}	253.3^{A}	0.0	5.36^{C}
p-value		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		<.0001

*Original weed dry weight values were square root transformed (√x+1) before statistical analysis and based on the analysis of the transformed data, the upper-case letters have been assigned to original values for interpretation; Means at least one letter common within a column are not significantly different using Fisher's LSD at 5% level of significance

fields were *D. aegyptium, E. crus-galli, D. sanguinalis* and among broad-leaved and sedges weeds major were *E. alba, P. minima, P. niruri, A. baccifera, C. difformis, and F. miliacea*.

The perusal of data (Table 7) showed that the maximum total weed dry weight was in application of bentazone and untreated weedy check. The higher weed dry weight in bentazone treatment was due to its ineffectiveness in controlling the grass weeds as it was only effective against broad-leaved weeds and sedges. The total weed dry weight in weedy check was 730 g m^{-2}.

Amongst the herbicide treatments, azimsulfuron caused the maximum reduction in total weed dry weight. Penoxsulam alone and in combination with bentazone provided the very good control of dominant grass weed *Echinochloa crus-galli.* However, penoxsulam alone and in combination with bentazone was ineffective in controlling the other grass weeds namely *D. aegyptium and D. sanguinalis*. Whereas, azimsulfuron provided better control of *D. aegyptium.* Except bentazone and cyhalofop-p-butyl, all the weed control treatments caused significant reduction in total weed dry weight.

The weed free treatment recorded significant higher grain yield (7.18 t ha^{-1}) than other treatments (Table 7). Among various herbicide treatments, azimsulfuron at 35 g ha^{-1} recorded significantly better yield but was significantly inferior to weed free check. The weed control efficiency based on weed dry weight with azimsulfuron application was 70.1%. The performance of the commercially available herbicide cyhalofop-p-butyl at 80 g ha^{-1} was also poor compared to the azimsulfuron and the weed dry weight accumulation was 587.1 g m^{-2}. None of the herbicide treatment produced the yield at par with the weed free check and this reflects that we need to have sequential or tank mix application of herbicides having different weed control spectrum for broad range weed control.

3.2.2. Transplanted rice

Pre-mix penoxsulam + bentazone was also evaluated against grass and broad-leaved weeds in PTR. The results regarding bio-efficacy of penoxsulam + bentazone against weeds under puddle transplanted conditions are given in Table 8. *E. crus-galli* was the most dominant grass weed in the experimentation. Similar to flucetosulfuron studies, some of the grass weeds (*D. aegyptium, D. sanguinalis)* that infested the DSR conditions failed to establish under puddled conditions. Penoxsulam + bentazone at the tested doses provided excellent control of dominant weed (*E. crus-galli).* Bentazone alone at 960 g ha^{-1} provided good control of broad-leaved and sedge group of weeds. Azimsulfuron alone also provided the good control of grasses and broad-leaved weeds (Table 8). Ready mix combination penoxsulam + bentazone at 1110 g ha^{-1} was significantly superior to azimsulfuron at 35 g ha^{-1} and cyhalofop-p-butyl at 80 g ha^{-1} in reducing the weed dry weight. The rice grain yields (Table 8) under various doses of ready mix combinations of penoxsulam + bentazone were statistically similar to season long weed free situations as well as the recommended treatment of azimsulfuron 35 g ha^{-1} but significantly better than the application of cyhalofop-p-butyl at 80 g ha^{-1}. The better grain yields in these treatments were due to better weed control. The WCE in various treatments of penoxsulam + bentazone was more than 94%.

Our results are also in confirmation with those of previous studies where penoxsulam was observed effective for control of grasses, sedges and broad-

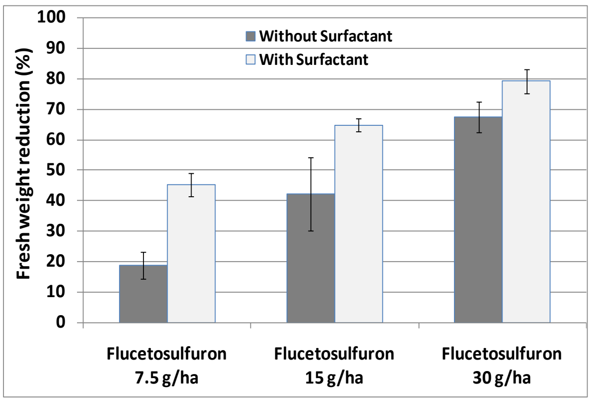

Fig 1a

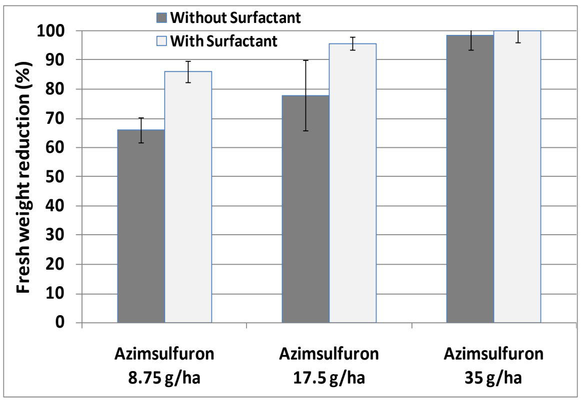

Fig 1b

Fig. 1: Effect of surfactant on flucetosulfuron (Fig 1a) and azimsulfuron (Fig. 1b) efficacy against *D. aegyptium.* The vertical error bars above means represent the ± SEM

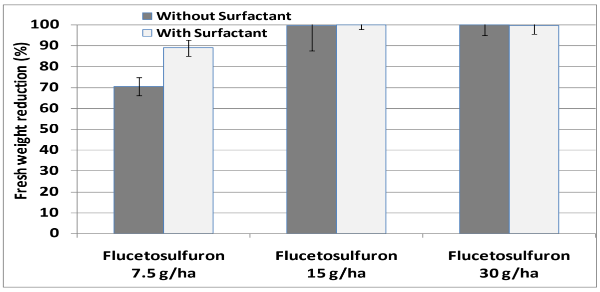

Fig 2a

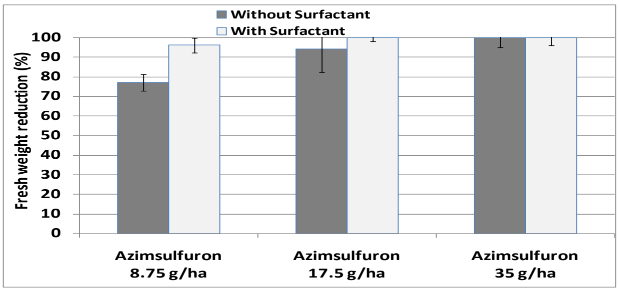

Fig 2b

Fig. 2: Effect of surfactant on flucetosulfuron (Fig. 2a) and azimsulfuron (Fig. 2b) efficacy with surfactant against *E. crus-galli*. The vertical error bars above means represent the ± SEM.

leaved weeds (Mahajan and Chauhan, 2008; Singh *et al.*, 2009).

3.3. Effect of surfactant on efficacy of flucetosulfuron and azimsulfuron

The effect of surfactant in improving the efficacy of flucetosulfuron and azimsulfuron was evaluated against three weed species (*D. aegyptium, E. crus-galli, T. portulacastrum*). There was significant improvement in the efficacy of these herbicides at lower doses against grass weeds (Fig. 1 - 2). Flucetosulfuron applied at 7.5, 15 and 30 g ha^{-1} with cationic surfactant (1000 ml ha^{-1}) resulted in 45.1, 64.7 and 79.1%, respectively reductions in fresh weight of *D. aegyptium,* whereas, when respective doses were applied without surfactant caused only 18.7, 42.2 and 67.3 % reductions. Similarly, azimsulfuron at 8.75, 17.5 and 35 g ha^{-1} with surfactant reduced the fresh weight of *D. aegyptium by* 86.1, 95.7 and 100%, respectively and without surfactant reductions were 65.9, 77.9 and 98.4%, respectively. In another trial, flucetosulfuron at 7.5 g ha^{-1} without and with surfactant caused 70.6 and 89.0% reductions in *E. crus-galli* fresh weight, respectively, in comparison to fresh weight of control pots (Fig. 2). Whereas, the fresh weight reductions with application of azimsulfuron at 8.75 and 17.5 g ha^{-1} without surfactant and with surfactant were 76.8 and 94.1% and 95.9 and 100%, respectively. However, the efficacy of flucetosulfuron against broad-leaved weed, *T. portulacastrum* did not differ significantly whether applied without or with surfactant (Fig. 3). These results indicate that for better efficacy particularly against grass weeds, flucetosulfuron and azimsulfuron should be applied with cationic surfactant. These results are in conformity with the findings of Singh *et al.* (2016) that surfactant (0.2%) improved the efficacy of azimsulfuron for control of sedges group of weeds.

In earlier studies also, surfactants have been found to increase the efficiency and spectrum of weed control resulting in the possibility of reductions in the dose of herbicides (Chhokar *et al.,* 2015).

In our studies, *E. crus-galli* was the major weed in DSR as well as PTR. This weed is highly competitive and has wider adaptability. Among various herbicide tested against this weed, penoxsulam was the most effective for its control. Earlier studies have also reported the effective control of *E. crus-galli* in the DSR fields by the early post-emergence application of penoxsulam (Jabran *et al.*, 2012). However, its continuous use may result in weed shift dominated by *D. aegyptium* and *D. sanguinalis* as penoxsulam is not effective against these weeds. Therefore, it is important to use a broad-spectrum herbicides including pre and post herbicides for season long effective weed control and to avoid shift towards problematic weed species (Singh *et al.*, 2009; Chauhan, 2012; Yadav *et al.*, 2009) or evolution of herbicide resistant weed biotypes. Herbicide combinations chosen judiciously give effective weed control than single herbicide application.

In the present field studies (flucetosulfuron and penoxsulam + bentazone evaluation), DSR suffered more due to weed infestation which caused yield losses between 86 to 100 per cent. The application of single herbicide either flucetosulfuron or penoxsulam or bispyribac or azimsulfuron proved equally effective in

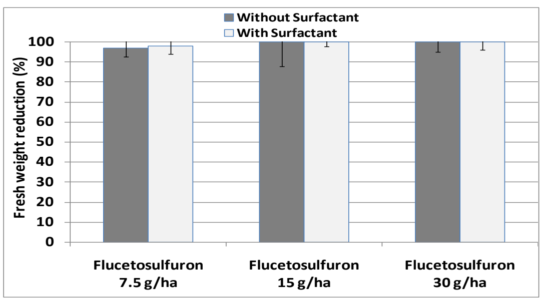

Fig. 3: Effect of surfactant on flucetosulfuron and azimsulfuron efficacy against *T. portulacastrum.* The vertical error bars above means represent the ± SEM

reducing the weed abundance and improving the rice grain yield under puddle transplanting conditions. Rice grain yield under these herbicides were statistically at par with season long weed free conditions. However, under direct sown aerobic conditions, weed infestation caused huge yield losses as high as 100 per cent and all the herbicides tested were inferior to weed free control with regard to producing rice grain yield. The more diversity and intensity of weed flora was responsible for this huge yield decline. Similarly, earlier also yield losses between 30 and 100 per cent in direct sown aerobic rice had been reported by various research workers (Oerke and Dehne, 2004; Rao *et al.*, 2007; Kumar and Ladha, 2011; Jabran *et al.*, 2012; Chhokar *et al.*, 2014).

The use of single herbicide for weed management in DSR is less effective against wider range of weed flora in abundance. To check the diverse weed flora, combination of herbicides or sequential applications of herbicides are required. The findings of Awan *et al.* (2015) also indicated that application of a single herbicide in dry seeded rice systems often provides sub-optimal weed control because of complex weed flora and long critical periods. Therefore, the best weed control option in dry seeded rice is the application of a pre-emergent herbicide followed by a post-emergent herbicide (Singh *et al.*, 2009; Chauhan and Opena, 2012) or a pre-emergent herbicide followed by a hand weeding. Mahajan and Chauhan (2013) also reported that the sequential application of herbicides is better than single application in DSR. They observed 228% more grain yield with the sequential application of pre-emergence pendimethalin followed by post-emergence azimsulfuron over non-treated control. Similarly, Wallia *et al.* (2008) reported effective weed control with integration of pre-emergence application of pendimethalin with post-emergence application of azimsulfuron.

In DSR, the increased herbicide use, and continuous use of similar herbicides may result in evolution of herbicide resistance in weeds. Therefore, besides proper sequential or tank mix application of suitable herbicides (Khaliq *et al.*, 2011), integration of varied non-chemical weed management strategies such as tillage, weed-competitive cultivars, row spacing, higher seeding rates, green and/or brown manuring, stale seed bed, appropriate water management and mechanical practices (hand weeding) are required for long-term effective weed control.

4. Conclusions

Based on the present studies, it can be concluded that penoxsulam + bentazone at 925-1110 g ha^{-1} and flucetosulfuron at 25-30 g ha^{-1} are effective for control of grass weed *Echinochloa* spp. and many broad-leaved weeds but were not effective against *D. aegyptium and D. sanguinalis* found in DSR. Whereas, flucetosulfuron 25-30 g ha^{-1} performed similar to bispyribac-Na 20 g ha^{-1} and azimsulfuron 35 g ha^{-1} under puddle transplanted conditions. Penoxsulam + bentazone performed significantly better to cyhalofop-p-butyl 80 g ha^{-1} but similar to azimsulfuron 35 g ha^{-1} under puddle transplanted conditions. However, the performance of ready-mix of penoxsulam + bentazone as well as flucetosulfuron in the DSR was inferior to azimsulfuron. The cationic surfactant was found effective in improving the efficacy of flucetosulfuron and azimsulfuron against grass weeds.

5. References

1. Awan TH, PC Sta Cruz and BS Chauhan. 2015. Agronomic indices, growth, yield contributing traits, and yield of dry-seeded rice under varying herbicides. *Field Crops Research* **177**: 15-25.
2. Chauhan BS and J Opena. 2012. Effect of tillage systems and herbicides on weed emergence, weed growth, and grain yield in dry-seeded rice systems. *Field Crops Research* **137**: 56-69.
3. Chauhan BS. 2012. Weed ecology and weed management strategies for dry seeded rice in Asia. *Weed Technology* **26**: 1-13.
4. Chhokar RS, RK Sharma and I Sharma. 2015. Improving the herbicide efficacy with tank mix adjuvant usage. *Pestology* **XXXIX No. 5**: 15-34.
5. Chhokar RS, RK Sharma, MK Gathala and AK Pundir. 2014. Effect of crop establishment techniques on weeds and rice yield. *Crop Protection* **64**: 7-12.
6. Dhillon BS and MS Bhullar. 2016. Effective post-emergence herbicides for weed control in rice nurseries. *Indian Journal of Weed Science* **48(3)**: 272–274.
7. Diarra ARJ, RJ Smith and RE Talbert. 1985. Red rice (*Oryza sativa*) control in drill seeded rice (*Oryza sativa*). *Weed Science* **33**: 703-707.
8. Eleftherohorinos IG, KV Dhima and IB Vasilakoglou. 2002. Interference of red rice in rice grown in Greece. *Weed Science* **50**: 167-172.
9. FAO- Food and Agriculture Organization. 2019. FAO STAT Database FAO, Rome, http://www.fao.org/faostat/en/#data/QC accessed December, 2019.
10. Fischer AJ and A Ramirej. 1993. Red rice (*Oryza sativa*): competition studies for management decisions. *International Journal of Pest Management* **39**: 133-138.
11. Gharde Yogita, PK Singh, RP Dubey and PK Gupta. 2018. Assessment of yield and economic losses in

agriculture due to weeds in India. *Crop Protection* **107**: 12-19.

12. IRRI. 2019. World Rice Statistics. http://ricestat.irri.org:8080/wrsv3/entrypoint.htm.

13. Jabran K, M Farooq, M Hussain, Ehsanullah, MB Khan, M Shahid and DJ Lee. 2012. Efficient weeds control with penoxsulam application ensures higher productivity and economic returns of direct seeded rice. *International Journal of Agriculture and Biology* **14**: 901-907.

14. Khaliq A, A Matloob, HM Shafique, M Farooq and A Wahid. 2011. Evaluating sequential application of pre and post emergence herbicides in dry seeded finer rice. *Pakistan Journal of Weed Science Research* **17**: 111-123.

15. Kim DS, SJ Koo, JN Lee, KH Hwang, TY Kim, KG Kang, KS Hwang, GH Joe, JH Cho and DW Kim. 2003. Flucetosulfuron: a new sulfonylurea herbicide. pp. 87-92. *In: Proceedings of the BCPC International Congress: Crop Science and Technology,* 10-12 November 2003, SECC, Glasgow, Scotland, UK.

16. Kumar V and JK Ladha. 2011. Direct-seeding of rice: recent developments and future research needs. *Advances in Agronomy* **111**: 297-413.

17. Mahajan G and BS Chauhan. 2008. Performance of penoxsulam for weed control in transplanted rice. *Pest Technology* **2(2)**: 114-116.

18. Mahajan G and BS Chauhan. 2013. Herbicide options for weed control in dry seeded aromatic rice in India. *Weed Technology* **27**: 682-689.

19. Menzes VG, PRF Da Silva, R Carmona, F Rezera and CH Mariot. 1997. Red rice interference on million yield of irrigated rice cultivars. *Laboure Arrozeria* **50**: 3-6.

20. Oerke EC and HW Dehne. 2004. Safe guarding production losses in major crops and the role of crop protection. *Crop protection* **23**: 275-285.

21. Oerke EC. 2006. Crop losses to pests. *Journal of Agricultural Science* **144**: 31-43.

22. Rao AN, DE Johnson, B Sivaprasad, JK Ladha and AM Mortimer. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153-255.

23. Rao AN, SP Wani, M Ramesha and JK Ladha. 2015. Weeds and weed management of rice in Karnataka state, India. *Weed Technology* **29**: 1-17.

24. Satapathy BS, B Duary, S Saha, KB Pun and T Singh. 2017. Effect of weed management practices on yield and yield attributes of wet direct seeded rice under lowland ecosystem of Assam. *Oryza* **54(1)**: 29-36.

25. Singh Rohitashav, Rekha, A Gupta, Tej Pratap, S Kumar and A Kumar. 2016. Azimsulfuron as an effective herbicide against sedges in transplanted rice. *Indian Journal of Weed Science* **48**(3): 251–253.

26. Singh S, RS Chhokar, R Gopal, JK Ladha, RK Gupta, V Kumar and M Singh. 2009. Integrated weed management: a key to success for direct seeded rice in Indo-Gangetic plains. In JK Ladha, Yadvinder Singh, O Erenstein and B Hardy (Editors) I*ntegrated crop and resource Management in the Rice-Wheat System of Southern Asia.* Los Banos (Philippines): International Rice Research Institute, pp261-278.

27. Wallia US, MS Bhullar, Shelly Nayyar and SS Wallia. 2008. Control of complex weed flora of dry-seeded rice (*Oryza sativa* L.) with pre- and post-emergence herbicides. *Indian Journal of Weed Science* **40**(3-4): 161-164.

28. Yadav DB, A Yadav and SS Punia. 2009. Evaluation of bispyribac sodium for weed control in transplanted rice. *Indian Journal of Weed Science* **41**: 23-27.