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Research Article

Grass weeds control in transplanted rice with Cyhalofop-butyl

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Abstract: This experiment was performed to determine the appropriate dose of Cyhalofop-butyl (CB) for controlling grass weeds in transplanted rice. CB at four doses, including 50, 100, 150, and 200 g ai/ha was investigated and compared with current herbicides in rice at recommended doses. The results showed that CB 100, 150, and 200 g ai/ha significantly reduced the density and dry matter of *Echinochloa crusgalli* (L.) P. Beauv. and *Paspalum distichum* L. over the weedy check; the minimum control efficacy of CB at these doses was 73.3 and 88.3% for *E. crusgalli* density and dry matter reduction, respectively, and for *P. distichum*, it was 80% for density and dry matter reduction. Applying CB at all doses (50- 200 g/ha) showed no crop injury symptoms on rice plants. The highest grain yield was obtained by hand weeding, CB 150 g ai/ha, and Tiobencarb treatments, with 5180, 5106, and 5051 Kg/ha, respectively. CB 200 g ai/ha was on par with CB 150 g ai/ha, and there was no significant variation between CB 100 and 200 g ai/ha in rice grain production. Finally, it was found that the application of CB 100 g ai/ha is an efficient grass weed control practice for improving the rice yield.

Keywords: ACCase, barnyardgrass, knotgrass, herbicide, weed control

Introduction

The presence of weeds in paddy fields leads to a waste of water, sunlight, and nutrients. Weeds provide a habitat for the growth of pathogens and insect pests, adversely affecting rice productivity (Verma *et al.,* 2017). Transplanting is the primary establishment method of rice in Northern Iran. Continuous rice cultivation in the same land results in the dominance of some weeds, especially *Echinochloa* sp., which is the major weed species in rice due to its high competitiveness and widespread presence in paddy fields (Ruiz-Santaella *et al.,* 2006). One *Echinochloa* plant per m^{-2} causes negative interference and decreases the grain yield of transplanted rice fields from 4-30% (Galon *et al.,* 2007). *Echinochloa crusgalli* L. and *Paspalum distichum* L. are the most troublesome and common weeds in Northern Iran's paddy fields (Tokasi and Nouralizadeh, 2021).

Hand weeding is considered an eco-friendly weed control method but is highly costly and labor intensive. Farmers often fail to remove weeds due to high labor wages and the unavailability of labor at peak weeds.

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Sometimes, *Echinochloa* sp. and rice seedlings are grown on the same hill, and it is hard to identify them, so they cannot be separated in the early phases of rice growth by hand weeding (Samui *et al.*, 2005). Therefore, applying herbicides keeps the fields free of weeds at the critical crop growth stage, minimizes weeding costs, and reduces weeds below the threshold level. Fischer (2013) reported that *Echinochloa* sp. is the worst weed in rice fields and is poorly suppressed by flooding, and farmers have to use herbicides to control it.

Cyhalofop-butyl is an effective graminicide and controls annual and perennial grass weeds. It is a member of the aryloxyphenoxy propionate herbicides and acts by inhibiting ACCase enzyme and reducing the ability of plants to produce malonyl-coenzyme A, which is needed for the synthesis of fatty acids (Ruiz-Santaella *et al.*, 2006). Fatty acids are essential constituents of the plasma membranes of cells and organelles. The deficiency of fatty acids causes disorders of cell permeability and breaks in the structure of cell membranes (Oliveira Junior *et al.*, 2011). It has been reported that Cyhalofop-butyl is an effective herbicide for barnyardgrass control (91-98%) in rice fields when applied at 1-3 leaf stage of grass weeds (Buehring *et al.*, 2001; Ottis *et al.*, 2003; Lassiter *et al.*, 2000; Scherder *et al.*, 2001).

Herbicide selectivity depends on several factors like absorption, metabolism, and translocation of herbicide in plants, environmental conditions, and application methods (Hess 2000). Even if an herbicide is selective for a plant, the energy expenditure for detoxifying xenobiotics may cause phytotoxicity problems and impede its growth (Song *et al.*, 2007). Phytotoxicity caused by herbicides happens mainly due to the increase of reactive oxygen. These molecules are highly reactive to lipids of cell membranes, cause lipid peroxidation, and consequently form radicals, which irreversibly damage cell membranes (Fleck and Vidal, 2001). The direct response of cell membrane damage by lipid peroxidation is leakage of cellular contents, disrupting several physiological processes of plants, such as photosynthesis and defense mechanisms (Kruse *et al.*, 2006). Oxidative stress caused by a greater concentration of reactive oxygen can activate the programmed cell death due to membrane lipid peroxidation, enzyme inhibition, protein oxidation, and damage to RNA and DNA (Ma *et al.*, 2013). Nohatto *et al.* (2016) reported that Cyhalofop-butyl did not alter the antioxidant activity in the rice plant, which lowered stress in rice crops. The high selectivity of rice to Cyhalofop-butyl can be explained by the lack of esterase functionality which maintained cyhalofop acid at extremely low concentrations. It was also metabolized to inactive metabolites more quickly than grass weeds. Epicuticular waxes drastically reduce Cyhalofop-butyl absorption, and this mechanism is the basis for using Cyhalofop-butyl in paddy fields as a safe herbicide to control grass weeds (Ruiz-Santaella *et al.*, 2006). Kumar *et al.* (2012) studied the harvest residues of Cyhalofop-butyl in paddy soil and reported that Cyhalofop-butyl rapidly degraded into cyhalofop acid in the soil. The residues of Cyhalofop (ester and acid) were completely lost from harvest soil as they were below detectable levels.

The objective of the present study was to find out the effective dose of Cyhalofop-butyl in transplanted rice for efficient grass weed control in Northern Iran's paddy fields.

Materials and Methods

A field study was conducted in 2021 at Agricultural and Natural Resources Research and Education Center in Guilan province, Iran. The experiment was conducted to evaluate Cyhalofop-butyl 20 percent OD (Cleangar) in transplanted rice for grass weed control (other weeds in the plots, including *Cyperus difformis* L. were removed manually). The experimental field was situated at 49° 39´ N latitude and 37° 11´ E longitude. Land preparation, including twice tillage, was done in late April and first May and third tillage, and was done one day before transplanting of rice seedlings. Rice seedlings of Hashemi variety at 4-5 leaves stage were transplanted to plots with three to four seedlings per hill at a spacing of 20cm × 25 cm on the 24th of May. The experimental plots (4 m × 5 m) were flooded up to 10 to 15 cm deep. The distances between the plots were demarcated and covered with plastic so that the water of the different plots would not mix.

The experimental soil type was Loam (47% sand, 30% silt, 23% clay) with pH 7.24, average fertility status of 1.42% OC, available N of 0.19%, available P of 6.65 Kg/ha and available K of 255.9 Kg/ha. The recommended dose of fertilizers was applied, 120:100:100 Urea (N46%), K_2SO_4 (50% K_2O and 17.5% S), and P_2O_5 46% ha^{-1}. Half the dose of Urea and full doses of P_2O_5 and K_2SO_4 were applied during the final land preparation. The remaining half dose of Urea was applied at the active tillering stage of rice. Plant protection measures and irrigation were provided when required.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with nine treatments and three replications, and each replication was considered a block. Cyhalofop-butyl (CB) at four doses, including 50, 100, 150, and 200 g ai/ha, was investigated and compared with some current herbicides for rice in Iran (i.e., Tiobencarb 50% EC (3000 g ai/ha), Oxadiazon 12% EC (480 g ai/ha), Oxadiargyl 3% EC (1050 g ai/ha), Bispyribac sodium 40% SC (26 g ai/ha), Triafamon + Ethoxysulfuron 30% WG (45 g ai/ha)), twice hand weeding, and weedy check. Pre-emergence herbicides, including Tiobencarb, Oxadiazon, Oxadiargyl, and Triafamon + Ethoxysulfuron were applied five days after rice seedlings were transplanted (DAT) into the water. Post-emergence herbicides, including Cyhalofop-butyl, and Bispyribac sodium, were applied 15 DAT in the early growth stages of grass weeds (two- to four- leaves) using a knapsack sprayer fitted with a flat fan nozzle at a spray volume of 200 l/ha. Post-emergence herbicides were applied to the muddy soil and weeds immediately after the water in the rice paddy field was removed. Water was restored within 24 hours after spraying, and then the water was kept in the field. Hand weeding was done at 15 and 30 DAT.

The efficacy of weed control was evaluated at the time of two weeks after the post-emergence herbicide applications according to the European Weed Research Council (EWRC) rating scale for visual control (Sandral et al. 1997), Also, the number (density) and dry matter of grass weeds of each plot were measured after two, four and nine weeks after the post- emergence herbicides application using a quadrate of 50 cm × 50 cm, randomly. Grass weeds were counted by species, cut close to the ground surface and oven dried at 75°C for 48h. Weed control efficiency (WCE) of different treatments was calculated based on density or dry matter reduction in the treated plot compared to the weedy check and expressed as a percentage, with the formula (1) given below (Baghestani *et al.*, 2014).

$$WCE(\%) = \left(\frac{WDc - WDt}{WDc}\right) \times 100 \quad (1)$$

Where WCE (%) = % decrease of weed density or dry matter in the treated plot compared to the weedy check plot; WD_c = weed density (number of weeds per m^2 (no/m^2)) or weed dry matter (g/m^2) in the weedy check plot; and WD_t = weed density (no/m^2) or weed dry matter (g/m^2) in the treated plot.

The rice visual toxicity to the herbicides was recorded according to EWRC rating scale (Sandral et al. 1997). In qualitative assessment, the plants in the control treatments were used as references. Rice was harvested on 24th August. The number of rice panicles per m^2 was counted before harvesting (no/m^2). Ten panicles were randomly selected from the one-meter row in plots, and the panicle length and the height of tillers were measured with the ruler (cm). Harvesting was done manually at the full maturity stage and air-dried. The biological yield (the total dry matter produced by the crop) of rice was measured before threshing. The grain yield of rice from each plot was recorded (after adjusting moisture to 14% level) and computed as Kg/ha. The percentage of increase in rice yield (biological and grain yield) was calculated in the herbicide treatments compared to the weedy check with the formula (2) given below (Baghestani *et al.*, 2014). Finally, the weight of 1000 grains of rice was measured.

$$\%Yield = \left(\frac{Yieldspray}{Yieldnospray}\right) \quad (2)$$

Where %Yield = % increase in rice yield of the treated plot compared to the weedy check

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plot; Yieldspray = yield (Kg/ha) in the treated plot; and Yieldnospray = yield (Kg/ha) in the weedy check plot.

The data on different characters were subjected to the analysis of variance (ANOVA) performed in R-studio. Treatment means were compared using Duncan's Multiple Range Test at the 1% level of significance.

Results

Composition of weed flora

Grass weed species observed in the experimental plots, were *Echinochloa crusgalli* L., and *Paspalum distichum* L.

Weed control efficiency (WCE)

The highest density (no/m^2) and dry matter (g/m^2) of grass weeds were recorded in the weedy check. All of the herbicides significantly reduced density and dry matter of two grass weeds compared to the weedy check in all three samplings conducted at 2, 4, and 9 weeks after post-emergence herbicides application (data presented in Tables-1, 2, and 3). In the comparison between different treatments, applying Bispyribac sodium and Cyhalofop-butyl 50 g ai/ha had the lowest control efficiency of *E. crusgalli*. In applying Bispyribac sodium, the highest efficiency of control to reduce the density and dry matter of *E. crusgalli* was 47.1 and 71.3%, respectively, in the third sampling (Table 3), and the lowest efficiency of control to reduce the density and dry matter of *E. crusgalli* was 26.7 and 58.5%, respectively, in the first sampling (Table 1). In applying Cyhalofop-butyl 50 g ai/ha, the highest control efficiency to reduce the density of *E. crusgalli* was 67.8% in the third sampling (Table 3), and to reduce the dry matter of *E. crusgalli* was 58.8% in the first sampling (Table 1); the lowest control efficiency to reduce the density of *E. crusgalli* was 23.3% in the first sampling (Table 1), and to reduce the dry matter of *E. crusgalli* was 46.3% in the second sampling (Table 2). Applying Tiobencarb, Oxadiazon, Oxadiargyl, and Triafamon + Ethoxysulfuron (pre-emergence herbicides) in all samplings provided complete control of *E. crusgalli*. In applying Cyhalofop-butyl, weed control efficiency increased with the herbicide application rate. Cyhalofop-butyl achieved excellent control efficiency applied at doses of 100, 150, and 200 g ai/ha, as evidenced by a low count of *E. crusgalli* density in the range of 1-5 no/m^2 in these treatments against 14 no/m^2 in the Cyhalofop-butyl 50 g ai/ha treatment and 26 no/m^2 in the weedy check. There was no significant difference between treatments of CB 100, 150, and 200 g ai/ha. In the treatments of CB 100, 150, and 200 g ai/ha, the lowest weed control efficiency to reduce the density of *E. crusgalli* was 73.3%, and to reduce the dry matter of *E. crusgalli* was 88.3%. There was no significant difference between the treatments of CB 100, 150, and 200 g ai/ha and the pre-emergence herbicides treatments to reduce the density and dry matter reduction of *E. crusgalli*, in all samplings.

Table 1 Efficacy of herbicides in the control of *Echinochloa crusgalli* and *Paspalum distichum* four weeks after application.

Treatments	Rate (g/ha)	*E. crusgalli*				*P. distichum*			
		Density Reduction	Density (No/m^2)	Dry Matter Reduction	Dry Weight (g/m^2)	Density Reduction	Density (No/m^2)	Dry Matter Reduction	Dry Weight (g/m^2)
Cyhalofop-butyl 20% OD	50	23.3 ^{b}	14	58.8 ^{b}	34.17	91.1 ^{a}	3	98.3 ^{a}	1.41
	100	86.7 ^{a}	3	96.4 ^{a}	2.97	100 ^{a}	0	100 ^{a}	0
	150	73.3 a^b	5	95.9 ^{a}	3.39	100 ^{a}	0	100 ^{a}	0
	200	94.4 ^{a}	1	98.6 ^{a}	0.55	100 ^{a}	0	100 ^{a}	0
Bispyribac sodium 40% SC	26	26.7 ^{b}	19	47.1 ^{b}	21.48	64.4 ^{ab}	17	38.0 ^{b}	34.71
Tiobencarb	3000	100 ^{a}	0	100 ^{a}	0	95.2 ^{a}	1	99.8 ^{a}	0.16
Oxadiargil 3% EC	1050	100 ^{a}	0	100 ^{a}	0	33.3 ^{b}	37	27.6 ^{b}	69.33
Oxadiazon 12% EC	480	100 ^{a}	0	100 ^{a}	0	50.6 ^{ab}	17	74.7 ^{a}	22.17
Triafamon + Ethoxysulfuron 30% WG	45	100 ^{a}	0	100 ^{a}	0	100 ^{a}	0	100 ^{a}	0

Means followed by similar letters in each column are not significantly different by Duncan's Multiple Range Test at 1% probability level.

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Table 2 Efficacy of herbicides in the control of *Echinochloa crusgalli* and *Paspalum distichum* four weeks after application.

Treatments	Rate (g/ha)	*E. crusgalli*				*P. distichum*			
		Density reduction	Density (No/m^2)	Dry matter reduction	Dry matter (g)	Density reduction	Density (No/m^2)	Dry matter reduction	Dry matter (g)
Cyhalofop-butyl 20% OD	50	43.9 ^{b}	25	46.3 ^{b}	54.96	90.0 ^{a}	4	93.0 ^{a}	4.11
	100	77.8 ^{ab}	3	96.8 ^{a}	2.64	97.2 ^{a}	1	99.1 ^{a}	1.35
	150	93.3 ^{a}	1	99.3 ^{a}	0.65	94.4 ^{a}	3	98.5 ^{a}	2.17
	200	88.9 ^{a}	1	93.9 ^{a}	5.05	100 ^{a}	0	100 ^{a}	0
Bispyribac sodium 40% SC	26	38.9 ^{b}	13	49.3 ^{ab}	57.55	78.3 ^{a}	8	42.1 ^{b}	19.09
Tiobencarb	3000	100 ^{a}	0	100 ^{a}	0	71.7 ^{a}	7	84.5 ^{ab}	7.85
Oxadiargil 3% EC	1050	100 ^{a}	0	100 ^{a}	0	81.7 ^{a}	11	34.6 ^{b}	25.27
Oxadiazon 12% EC	480	100 ^{a}	0	100 ^{a}	0	23.9 ^{b}	21	36.2 ^{b}	42.16
Triafamon + Ethoxysulfuron 30% WG	45	100 ^{a}	0	100 ^{a}	0	94.4 ^{a}	1	99.8 ^{a}	0.08

Means followed by similar letters in each column are not significantly different by Duncan’s Multiple Range Test at 1% probability level.

Table 3 Efficacy of herbicides in the control of *Echinochloa crusgalli* and *Paspalum distichum*, nine weeks after post-emergence herbicide application.

Treatments	Dose (g/ha)	*E. crusgalli*				*P. distichum*			
		Density reduction (%)	Density (No/m^2)	Dry weight reduction (%)	Dry weight (gr)	Density reduction (%)	Density (No/m^2)	Dry weight reduction (%)	Dry weight (gr)
Cyhalofop-butyl 20% OD	50	67.8 ^{b}	33	49.4 ^{c}	185.4	67.6 ^{bc}	24	68.7 ^{abc}	22.7
	100	98.0 ^{a}	3	88.3 ^{abc}	10.1	83.6 ^{ab}	19	79.7 ^{ab}	46.8
	150	93.6 ^{a}	3	92.8 ^{ab}	23.0	95.4 a	5	95.7 ^{a}	3.2
	200	100 ^{a}	0	100 ^{a}	0	80.7 ^{abc}	11	86.9 ^{a}	6.8
Bispyribac sodium 40% SC	26	58.5 ^{b}	13	71.3 ^{abc}	52.4	33.3 ^{d}	101	16.6 ^{c}	107.7
Tiobencarb	3000	100 ^{a}	0	100 ^{a}	0	96.3 ^{a}	3	93.5 ^{a}	3.3
Oxadiargil 3% EC	1050	100 ^{a}	0	100 ^{a}	0	60 ^{c}	121	56.0 ^{abc}	75.3
Oxadiazon 12% EC	480	90.2 ^{a}	5	56.1 ^{bc}	74.2	31.5 ^{d}	61	25.8 ^{bc}	45.4
Triafamon + Ethoxysulfuron 30% WG	45	100 ^{a}	0	100 ^{a}	0	100 ^{a}	0	100 ^{a}	0

Means followed by similar letters in each column are not significantly different by Duncan’s Multiple Range Test at 1% probability level.

In the comparison between the herbicide treatments, the highest WCE of *P. distichum* was recorded in the treatments of Triafamon + Ethoxysulfuron, Cyhalofop-butyl, and Tiobencarb (Tables-1, 2, and 3). In applying Triafamon + Ethoxysulfuron, the lowest control efficiency to reduce the density and dry matter of *P. distichum* was 94.4% and 99.8%, respectively (Table 2). Applying Cyhalofop-butyl in doses of 100, 150, and 200 g ai/ha resulted in good control of *P. distichum* (Tables- 1, 2, and 3). In applying CB 100, 150, and 200 g ai/ha, the lowest control efficiency to reduce the density and dry matter of *P. distichum* was 80% (Table 3). In applying Tiobencarb, the lowest control efficiency to reduce the density and dry matter of *P. distichum* was 71.7 and 84.5%, respectively (Table 2). Oxadiazon, Bispyribac sodium, and Oxadiargyl were less effective in controlling *P. distichum* than Triafamon + Ethoxysulfuron, Cyhalofop-butyl, and Tiobencarb (Tables- 1, 2, and 3). In applying Oxadiazon, the highest control efficiency to reduce the density and dry matter of *P. distichum* was 51 and 75%, respectively, in the second sampling (Table 1). In applying Bispyribac sodium, the highest weed control efficiency to reduce the density and dry matter of *P. distichum* was 78 and 42%, respectively, in the second sampling (Table 2). Finally, in applying Oxadiargyl, the highest control efficiency to reduce the *P. distichum* density was 82% in the second sampling (Table 2), and to reduce the *P. distichum* dry matter was 56% in the third sampling (Table 3).

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EWRC rating scale of herbicides' effects on weeds

Based on the EWRC rating scale used to evaluate the herbicide effects on *E. crusgalli* and *P. distichum* control, the weed control significantly varied between treatments (Table 4). Scores of herbicide damage on weeds were correlated with WCE. In the comparison between herbicides, the lowest control of *E. crusgalli* was recorded in the treatments of Bispyribac sodium (with 50.0% control) and Cyhalofop-butyl 50 g ai/ha (with 53% control), and there was no significant difference between these two treatments (Table 4). Other herbicides, effectively controlled *E. crusgalli* (87-100%) with no significant difference. Based on the EWRC rating scale (Sandral *et al.*, 1997), Cyhalofop-butyl 150 g ai/ha (with 100% control), completely controlled *E. crusgalli*; Cyhalofop-butyl 200 g ai/ha and Triafamon + Ethoxysulfuron with 98.3% control, caused a very good control of *E. crusgalli*; Tiobencarb (with 95% control) caused good control of *E. crusgalli* and Cyhalofop-butyl 100 g ai/ha, Oxadiargil and Oxadiazon with 86.7% control, caused moderate control of *E. crusgalli*.

In the control of *P. distichum*, the highest control was recorded in the treatments of Triafamon + Ethoxysulfuron and Cyhalofop-butyl 200, 150, and 100 g ai/ha, which was 98.3, 96.7, 96.7, and 86.7%, respectively, and there was no significant difference between these treatments (Table 4). Based on EWRC rating scale (Sandral *et al.*, 1997), Triafamon + Ethoxysulfuron caused very good control of *P. distichum*; Cyhalofop-butyl 150 and 200 g ai/ha caused good control, and Cyhalofop-butyl 100 g ai/ha caused moderate control of *P. distichum*.

Crop injury

None of the herbicides caused any toxicity on the rice crop in terms of crop stand, crop growth, yellowing, necrosis, scorching, epinasty, and hyponasty. Applying Cyhalofop-butyl in all doses (50 to 200 g/ha) didn't cause any crop injury symptoms to the rice plant. Based on EWRC rating scale (Sandral *et al.*, 1997), rice crop tolerance after Cyhalofop-butyl application was "no effect".

Yield and yield components

The results indicated that the highest and lowest rice grain yield was in the treatments of twice hand weeding (5180 Kg/ha) and weedy check (3000 Kg/ha), respectively (Table 5). Applying herbicides, except Cyhalofop-butyl 50 Kg/ha, caused a significant increase in rice yield compared to the weedy check. In the comparison between herbicide treatments, the highest grain yield was in the treatments of Cyhalofop-butyl 150 Kg/ha and Tiobencarb which was 5106 and 5051 Kg/ha, respectively. There was no significant difference between hand weeding treatment and CB 150 Kg/ha, Tiobencarb, Oxadiazon, Bispyribac sodium, and Oxadiargil; these treatments increased grain yield by 72.7, 70.2, 68.4, 64.5, 54.6, 46.7%, respectively, compared to the weedy check. Cyhalofop-butyl 200 g ai/ha with 4306 Kg/ha rice yield had no statistical difference with CB 150 g ai/ha, and also, CB 100 g ai/ha with 4039 Kg/ha rice yield was on par with CB 200 g ai/ha.

Table 4 EWRC rating scale used to score the weed control following application of herbicide treatments two weeks after herbicides application.

Treatments	Dose (g/ha)	*E. crusgalli* control (%)	*P. distichum* control (%)
Cyhalofop-butyl 20% OD	50	53.3 [b]	55.0 [d]
	100	86.7 [a]	86.7 [ab]
	150	100 [a]	96.7 [a]
	200	98.3 [a]	96.7 [a]
Bispyribac sodium 40% SC	26	50.0 [b]	53.3 [d]
Tiobencarb	3000	95.0 [a]	73.3 [bc]
Oxadiargil 3% EC	1050	86.7 [a]	63.3 [cd]
Oxadiazon 12% EC	480	86.7 [a]	71.7 [bc]
Triafamon + Ethoxysulfuron 30% WG	45	98.3 [a]	98.3 [a]

Means followed by similar letters in each column are not significantly different by Duncan's Multiple Range Test at 1% probability level.
EWRC: European Weed Research Council (EWRC) scores of herbicide damages.

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Table 5 Effects of treatments on Biologic Yield (BY), Grain Yield (GY) and panicles/m^2 of rice.

Treatment	Dose (g/ha)	BY (Kg/ha)	BY increase (%)	GY (Kg/ha)	GY increase (%)	Panicles/m^2 (No/m^2)
Cyhalofop-butyl 20%OD	50	8219 bc	14	3677 ef	22.6	19 cd
	100	9664 abc	34	4039 de	34.6	21 bcd
	150	9344 bc	30	5106 ab	70.2	22 bcd
	200	10458 ab	45	4306 bcde	43.5	24 bc
Bispyribac sodium 40% SC	26	9698 abc	35	4637 abcd	54.6	22 bcd
Tiobencarb	3000	10429 ab	45	5051 ab	68.4	22 bcd
Oxadiargil 3%EC	1050	10463 ab	45	4401 abcde	39.2	26 ab
Oxadiazon12% EC	480	9515 abc	32	4936 abc	46.7	23 bcd
Triafamon + Ethoxysulfuron 30%WG	45	9543 abc	32	4177 cde	64.5	24 bc
Twice weeding	-	12236 a	70	5180 a	72.7	30 a
Weedy check	-	7205 c	-	3000 f	-	17 d

Means followed by similar letters in each column are not significant by Duncan's Multiple Range Test at 1% probability level.

The highest and lowest biological yield of rice was achieved in hand weeding (12236 Kg/ha) and weedy check treatments (7205 Kg/ha) (Table 5). In the comparison between herbicide treatments, the highest biological yield was in the treatments of Oxadiargil, Cyhalofop-butyl 200 g ai/ha, and Tiobencarb, which were 10463, 10458, and 10429 Kg/ha, respectively. There was no significant difference between hand weeding treatment, Oxadiargil, CB 200 g ai/ha, Tiobencarb, Bispyribac sodium (9698 Kg/ha), CB 100 g ai/ha (9664 Kg/ha), Tiafamon + Ethoxysulfuron (9543 Kg/ha), and Oxadiazon (9515 Kg/ha).

The results showed that there was no significant difference between the treatments in most of the rice yield components. There were no significant differences between treatments regarding rice plant height, panicle length, and weight of 1000 grains. Still, the treatments were significantly different regarding the number of panicles per m^2. Hand-weeding treatment produced the highest number of panicles (30 no/m^2), which was superior to the weedy check (17 no/m^2) (Table 5). Oxadiargil with 26 panicles per m^2 was similar to hand weeding treatment. Triafamon + Ethoxysulfuron, CB 100, 150, and 200 g ai/ha, Bispyribac sodium, Tiobencarb, and Oxadiazon (21-24 panicles per m^2) had no statistical difference with Oxadiargil.

Discussion

Weed management is one of the important operations in rice cultivation, and its failure leads to yield reduction. Weeds absorb nutrients from the soil and disrupt the rice plant's growth, and better control of weeds leaves the nutrients to be absorbed by the rice. In our experiment, weeds were almost completely controlled in the treatment of twice hand weeding, and the highest rice yield was in this treatment. This result was similar to the reports of Saha (2005), Thimme Gowda *et al.* (2009), and Prashanthi *et al.* (2017). Hand weeding promotes better air exchange; increases rooting and tillering of rice, and increases nutrient supply and production of bioactive compounds to support plant growth, but hand weeding is a very difficult, costly, and time-consuming method. If it is done late, the grain yield will decrease due to weed competition. One *Echinochloa* plant per m^{-2} causes negative interference and decreases the grain yield of transplanted rice fields from 4-30% (Galon *et al.*, 2007). In contrast, herbicide application is the fastest, easiest, and most economical method to control weeds. Applying herbicides allows the selective control of weeds right from the early stage of the crop for initiation and competitive superiority over weeds (Saha, 2005). In our experiment, almost all herbicidal treatments significantly decreased weed density and dry weight compared to the weedy check. Applying Triafamon + Ethoxysulfuron, Tiobencarb and Cyhalofop-butyl, effectively controlled both grass weed species. In the application of Cyhalofop-butyl, control efficacy rose with increasing the

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herbicide application rate. Cyhalofop-butyl achieved excellent control efficacy applied at doses of 100, 150, and 200 g ai/ha (≥ 73% density reduction and ≥ 88% dry weight reduction of *E. crusgalli*, and ≥ 87% density reduction and ≥ 80% dry weight reduction of *P. distichum*, average of three samplings). The more efficient control of *Echinochloa* species with increasing Cyhalofop-butyl application rates agrees with the results reported by other researchers (Ntanos *et al.*, 2000; Damalas *et al.*, 2006; Buehring *et al.* (2001); Ottis *et al.* (2003); Lassiter *et al.* (2000) and Scherder *et al.* (2001)). Higher rates of this herbicide are required for adequate and consistent control of *Echinochloa* species in rice fields (Damalas *et al.*, 2006).

The choice of herbicide for weed control depends on the major weed flora in crops. Smith (1981) reported that Poaceae is rice's most important and troublesome weed family, and *E. crusgalli* is the predominant species in paddy fields and thrives well in flooded situations. Herbicides commonly used in Iran in transplanted rice, include Thiobencarb, Pretilachlor, Bispyribac sodium, Triafamon + Ethoxysulfuron, Bensulfuron methyl, *etc.* Continuous application of herbicides with a similar mode of action has to be restricted to avoid undesirable weed shift. For example, the continuous application of some of these herbicides in Northern Iran has led to the predominance of perennial weeds such as *P. distichum*, which is a troublesome perennial grass weed in paddy fields (Tokasi and Nouralizadeh, 2021). Cyhalofop-butyl is an effective graminicide that controls annual and perennial grass weeds (Ruiz-Santaella *et al.*, 2006; Buehring *et al.*, 2001; Ottis *et al.*, 2003; Lassiter *et al.*, 2000; Scherder *et al.*, 2001). Cyhalofop-butyl is a new herbicide in Iran, and the results of this experiment indicated that the tolerance of rice after applying Cyhalofop-butyl was "no effect". Nohatto *et al.* (2016) reported that Cyhalofop-butyl did not alter the antioxidant activity of the rice plant, indicating that it induced no stress in rice crop. The higher selectivity of rice to Cyhalofop-butyl can be explained by the lack of esterase functionality which maintained cyhalofop acid at deficient concentrations. It was also metabolized to inactive metabolites in rice more quickly than in grass weeds. Epicuticular waxes drastically reduced the absorption of Cyhalofop-butyl, which was the basis for using Cyhalofop-butyl in paddy fields as a safe herbicide to control grass weeds and maintain the selectivity in the crop (Ruiz-Santaella *et al.*, 2006).

Considering the weed control results and rice yield production in Cyhalofop-butyl treatments, it was found that applying Cyhalofop-butyl 100 g ai/ha is an efficient grass weed control practice for improving the rice grain yield in Northern Iran. This treatment should be applied as a post-emergence application to control annual and perennial grass weeds in the early growth stages of grass weeds (two- to four-leaves or 5-10 cm tall) in transplanted rice fields which heavily infested with grass weeds. Ito *et al.* (1998) reported that most species belonging to the Poaceae family were highly susceptible to Cyhalofop-butyl and were ultimately killed at the dose of 100 g ai/ha. These findings were in line with those of Kumar *et al.* (2012), that reported grass weeds were effectively controlled by Cyhalofop-butyl 100 g ai/ha.

Conclusions

Our results indicated that Cyhalofop-butyl application achieved excellent control efficacy at doses of 100, 150, and 200 g ai/ha. So, regarding rice yield and production costs, it can be concluded that applying Cyhalofop-butyl at 100 g ai/ha can effectively control the annual and perennial grass weed species in transplanted rice.

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Disclosure statement
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ارزیابی کارایی علفکش سای‌هالوفوپ-بوتیل در کنترل علف‌های-هرز باریک‌برگ در کشت نشایی برنج (*Oryza sativa* L.)

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چکیده: این آزمایش با هدف تعیین دوز مناسب کاربرد علفکش سای‌هالوفوپ-بوتیل برای کنترل مؤثر علف‌های‌هرز باریک‌برگ در مزرعه برنج انجام شد. علفکش سای‌هالوفوپ-بوتیل در مقادیر ۵۰، ۱۰۰، ۱۵۰ و ۲۰۰ گرم ماده مؤثره در هکتار ارزیابی و با کارایی چند علفکش رایج در برنج در مقدار توصیه شده مقایسه گردید. نتایج نشان داد که کاربرد سای‌هالوفوپ-بوتیل در مقادیر ۱۰۰، ۱۵۰ و ۲۰۰ گرم ماده مؤثره در هکتار به‌طور معنی‌داری تراکم و زیستتوده علف-های‌هرز سوروف (*Echinochloa crusgalli*) و بندواش (*Paspalum distichum*) را نسبت به شاهد بدون کنترل علف‌هرز کاهش داد، کم‌ترین کارایی سای‌هالوف-بوتیل در این مقادیر به‌ترتیب ۷۳/۳ و ۸۸/۳ درصد کاهش تعداد و زیستتوده سوروف و ۸۰ درصد کاهش تعداد و زیستتوده بندواش بود. بالاترین عملکرد برنج در کاربرد تیمارهای دوبار وجین دستی، سای‌هالوفوپ-بوتیل ۱۵۰ گرم ماده مؤثره در هکتار و تیوبنکارب به‌دست آمد که به‌ترتیب ۵۱۸۰، ۵۱۰۶ و ۵۰۵۱ کیلوگرم در هکتار بود. تیمارهای سای‌هالوفوپبوتیل در مقادیر ۱۵۰ و ۲۰۰ گرم ماده‌مؤثره در هکتار و همچنین در مقادیر ۱۰۰ و ۲۰۰ گرم ماده مؤثره در هکتار در تولید عملکرد برنج اختلاف آماری معنی‌دار با هم نداشتند. در نهایت، کاربرد علفکش سای-هالوفوپ-بوتیل ۱۰۰ گرم ماده مؤثره در هکتار برای کنترل مؤثر علف‌های‌هرز باریک‌برگ گرامینه شالیزار برای بهبود عملکرد برنج مناسب ارزیابی شد.

واژگان کلیدی: استیل‌کوآنزیم‌آکربوکسیلاز، بندواش، سوروف، علفکش، کنترل شیمیایی

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