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Efficacy of pre- and post-emergence herbicides on weed dynamics, yield and economics in direct seeded rice on Inceptisols and their residual effect on Indian mustard

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ABSTRACT

In India, there is a growing shift towards direct-seeded rice (DSR) production methods, largely due to their numerous benefits. However, one significant challenge that accompanies the advantages of DSR production is the issue of weed management. In this context a field investigation was conducted during rainy (Kharif) season at the Agricultural Research Farm, Banaras Hindu University, Varanasi. The field trial consisting eight treatments which were replicated thrice in Randomized Block Design. Rice cultivar 'HUR 1304' was taken as a test crop. Post emergence application of cyhalofop-butyl 10% EC @ 75 ml ha^{-1} suppressed weed density, weed dry weight and higher weed control efficiency at 60 days after sowing over the control. Growth and yield attributes, viz., plant height, tillers running meter^{-1}, dry-matter accumulation running meter^{-1}, leaves plant^{-1}, effective panicles m^{-2}, grains panicle^{-1}, panicle length, panicle weight, and test weight were improved significantly with post emergence application of cyhalofop-butyl 10% EC @ 75 ml ha^{-1}. Two hand weeding exhibited higher nutrients (NPK) uptake by the crop followed by cyhalofop-butyl 10% EC @ 75 ml ha^{-1}. Similarly, higher rice grain, straw yields, maximum net returns and higher benefit-cost ratio were also associated with post-emergence application of cyhalofop-butyl 10% EC @ 75 ml in comparison to fenoxaprop-p-ethyl 6.7% w/w EC @ 54.50 ml and oxyfluorfen 23.5% EC @ 152.80 ml ha^{-1}. Post-emergence application of cyhalofop-butyl 10% EC ml ha^{-1} appeared a viable strategy for weed control in DSR with higher economic returns. Residual effect of herbicidal treatments in rice did not show marked variation in per cent crop germination, plant population, siliqua/ plant, test weight and seed yield of Indian mustard.

Keywords: Bio-efficacy, Cyhalofop-butyl, Direct-sown rice, Economics, Fenoxaprop

INTRODUCTION

Rice (*Oryza sativa* L.) is a vital staple food for over 60% of the global population, contributing significantly to economic and social stability. Unfortunately, due to water scarcity, this most important rice ecosystem is becoming increasingly endangered, threatening global food security (Singh *et al.,* 2016). In many Asian countries, including India, increased production costs, farmworker shortages, higher wages, and decreased groundwater availability have resulted in the transition from traditional paddy nursery transplanting to dry direct seeding of rice (Mahajan *et al.,* 2013). Weeds pose a significant challenge to rice production in direct-seeded systems, leading to increased production costs and reduced yields. The yield was reduced by 61% in wet DSR and 96% in dry DSR due to uncontrolled weeds. When rice is directly sown, weeds can reduce output by 40–100% (Rathika *et al.,* 2020). Weed infestation in direct-seeded rice (DSR) remains the primary constraint on its productivity. Recent estimates indicate that weed-related yield reductions in DSR can range from 12% to 72%, depending on the weed species and the level of competition they pose to the crop (Ramachandra *et al.,* 2014). Since weeds and rice emerge simultaneously in DSR, effectively managing weeds at the right time and using appropriate methods is a complex challenge. Effective early weed management is essential for enhancing productivity and profitability in DSR. Although manual weeding is efficient in weed control, it is limited by economic and technological factors. Over time, chemical weed control in DSR has become a promising solution due to its ease, speed, cost-effectiveness, and feasibility. In this context, post-emergence herbicides offer a viable alternative. In India, several herbicides have been developed for weed control in rice. However, none of them can effectively and economically control a wide range of rice weeds when used alone. Additionally, the currently available rice herbicides have a limited range of selectivity, and prolonged use of a specific herbicide may lead to shifts in weed species that

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compete with rice. Therefore, continuous development and evaluation of new herbicide chemistry are crucial to addressing emerging challenges related to weed shifts and herbicide resistance. Cyhalofop-butyl, a post-emergence herbicide, is commonly used to control a broad range of weeds, particularly broadleaf weeds. Consequently, the present study aims to assess the effectiveness of herbicides on weed species, crop yield, and the economic aspects of direct-seeded rice cultivation.

MATERIALS AND METHODS

A field experiment was carried out during the rainy (*Kharif*) season of 2020 at the Agricultural Research Farm, Banaras Hindu University, Varanasi (25º 18'N, 83º 03'E and 75.7 m above the mean sea-level), Uttar Pradesh. The site was well-drained sandy clay loam soil, *p*H 7.32 (1: 2.5 soil: water), and contained 0.33% organic carbon, low in available nitrogen (176 kg ha^{-1}), medium in available phosphorus (23.43 kg ha^{-1}), and medium in available potassium (207 kg ha^{-1}). The weekly mean minimum and maximum temperature during the period of crop growth was 25.5 to 22.0ºC and 31.3 to 33.6ºC, respectively. The total rainfall received was 118.6 mm. The experiment was laid out in a randomized block design, replicated four times, comprising seven treatments *viz*., cyhalofop-butyl 10% EC @ 75.0 ml ha^{-1} as post-emergence application (PoE), cyhalofop-butyl 10% EC @ 80.0 ml ha^{-1} PoE, cyhalofop-butyl 10% EC @ 85.0 ml ha^{-1} PoE, fenoxaprop-p-ethyl 6.7% w/w @ 54.5 ml ha^{-1} PoE, oxyfluorfen 23.5% EC @ 152.8 ml ha^{-1} PoE, hand weeding at 20 and 40 DAS and untreated control (weedy check). The desired quantities of herbicides were applied using 500 liters ha^{-1} of water through a knap-sack sprayer fitted with a flat-fan nozzle. The field was ploughed and leveled before the start of the monsoon, and rice seeds of cultivar 'HUR 1304' were sown on 25 June with seed rate 30 kg ha^{-1}. Irrigation was applied for proper germination after sowing the rice seeds. The crop was provided with 150 kg N+60 kg P+60 kg K ha^{-1}. Species-wise weed density and their dry weight were measured at 60 DAS by placing a quadrate of 0.50 m × 0.50 m randomly at 2 places in each plot. Weed biomass data were subjected to square root transformation (x+0.5) before statistical analysis. Weed control efficiency (WCE) was calculated using the weed biomass data in various treatments as suggested by Mani *et al.* (1973). Indian mustard was taken as succeeding crop. Analysis of variance and mean separation tests were used following the randomised block design test as given by Gomez and Gomez (1984).

RESULTS AND DISCUSSIONS

Effect on weeds

The major weed flora observed in the experimental field consisted of three grass species, six of broad-leaved weeds (BLW) and three sedges. The grassy weeds were *Echinochloa colona, Echinochloa crus-galli,* and *Cynodon dactylon*. The sedge weeds *Cyperus rotundus, Cyperus irria, Cyperus haspan*, and *Lindernia crustacea*, *Lindernia procumbens*, *Eclipta alba*, *Phyllanthus niruri*, *Spilanthes acmella*, and *Paspalum conjugatam* were the BLW.

Effect on density and dry weight of weeds

The study investigated the effectiveness of various herbicidal treatments on weed density, total weed dry weight, and weed control efficiency in direct-sown rice at 60 days after sowing (DAS). The results obtained from Table 1 reveal significant variations among the different herbicidal treatments. The data on weed density of different weeds as affected by various treatments envisaged significant reduction in weed density of *Echinochloa spp., Phyllanthus niruri,* and *Paspalum conjugatum* compared to the weedy check. The application of cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} recorded the maximum reduction of weed density at 60 DAS as compared to rest of the herbicidal treaments. This result was also reported by Singh *et al.* (2017) where they concluded that application of cyhalofop-butyl controlled grassy weeds better than the non-grassy weeds and recorded maximum weed control efficiency, higher yield attributes and yield. Application of cyhalofop-butyl in rice did not show any phytotoxic effect on succeeding Indian mustard. At 60 DAS, cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} recorded lower total weed dry weight than cyhalofop butyl 10% EC @ 80 ml ha^{-1}, cyhalofop

Table 1: Effect of herbicidal treatment on weed density (No. m^{-2}), total weed dry weight (g m^{-2}) and total weed control efficiency (%) at 60 DAS in direct-sown rice on Inceptisols

Treatments	Dosage (ml a.i.ha^{-1})	*Echinochloa spp.*	*Phyllanthus niruri*	*Paspalum conjugatum*	Total weed dry weight (g/m^2)	Total weed control efficiency (%)
Cyhalofop-butyl 10% EC	75.0	0.71 (0.00)	1.83 (5.33)	0.71 (0.00)	2.24 (0.20)	80.44
Cyhalofop-butyl 10% EC	80.0	3.65 (17.33)	1.44 (2.67)	0.71 (0.00)	4.58 (10.3)	62.67
Cyhalofop-butyl 10% EC	85.0	3.24 (13.33)	0.71 (0.00)	0.71 (0.00)	4.1 (7.88)	66.58
Fenoxaprop-p-ethyl 6.7% w/w EC	54.5	0.71 (0.00)	1.44 (2.67)	0.71 (0.00)	2.71 (1.84)	77.91
Oxyfluorfen 23.5% EC	152.8	4.38 (18.67)	0.71 (0.00)	7.11 (50.00)	8.75 (31.5)	28.68
Hand weeding at 20 and 40 DAS	-	4.21 (17.00)	0.71 (0.00)	0.71 (0.00)	3.22 (5.13)	73.75
Untreated control (Weedy check)	-	5.80 (48.00)	5.69 (32.00)	6.39 (40.33)	12.27 (78.53)	0.00
SEm±		1.37	0.42	0.68	0.48	-
CD(*p*=0.05)		3.11	1.31	2.01	1.57	-

Data transformed to square root values $\sqrt{x} + 0.5$*, Original values are given in parentheses*

butyl 10% EC @ 85 ml ha^{-1}, fenoxaprop-p-ethyl 54.5 ml ha^{-1}, and oxyfluorfen 152.8 ml ha^{-1} (Table 1). These results were in line with those reported by Singh *et al.* (2019), where they found that dry weight reduction of 35% in *E. japonica* was recorded as cyhalofop-butyl + penoxsulam rate doubled from 32.5 to 65 g ha^{-1}, but further doubling the rate resulted in a further decrease of only 5% dry weight. These treatments, along with hand-weeding twice, resulted in significantly reduced weed dry weight, leading to improved yield attributes and higher rice yields compared to all other treatment methods. Among the herbicidal treatments, cyhalofop butyl 10% EC @ 75.00 ml ha^{-1} resulted in higher weed control efficiency (80.44%), followed by cyhalofop butyl 10% EC @ 80.0 ml ha^{-1} (62.67%), cyhalofop butyl 10% EC @ 85 ml ha^{-1} (66.58%), fenoxaprop-p-ethyl 54.5 ml ha^{-1}, and oxyfluorfen 152.8 ml ha^{-1}. This might be due to lower total weed dry weight under these treatments. Sen *et al.* (2020) highlighted that the sequential application of pendimethalin (1 kg a.i. ha^{-1}) as pre-emergence followed by a mixture of penoxsulam + cyhalofop butyl (130 g a.i. ha^{-1}) as post-emergence exhibited significant reduction in weed density and dry-biomass accumulation, resulting in a considerable increase in weed-control efficiency (84.49%) and productivity (3.92 t ha^{-1}).

Effect on growth parameters of crop

Data presented in Table 2 revealed that at 60 days after sowing (DAS), among different herbicidal treatments, cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} resulted in higher plant height, tillers per running meter, dry-matter accumulation (g running $meter^{-1}$), and the number of leaves per plant compared to rest of the treatments. Singh *et al.* (2017) found that the application of cyhalofop-butyl at 90 and 80 g ha^{-1} during the two respective years produced the highest number of grains $panicle^{-1}$.

Effect on yield attributes and yield

Herbicidal treatments resulted in a marked increase in yield attributes, with significantly higher grain and straw yields compared to the weedy check (Table 3). Among the herbicidal treatments, cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} resulted in higher numbers of effective panicles, grains per panicle, panicle length (cm), panicle weight, test weight (g), grain yield, and straw yield, followed by cyhalofop butyl at 80 ml ha^{-1} and cyhalofop butyl at 85 g ha^{-1}. The increased grain yield in these treatments was due to a significant reduction in dry matter accumulation by the weeds and a higher number of effective tillers, panicle length, and plant height compared to other treatments.

Table 2: Effect of herbicidal treatment on plant height (cm), tillers running meter^{-1}, leaves plant^{-1}, plant dry matter running meter^{-1} at 60 DAS and NPK uptake by crop at harvest

Treatment	Dosage (ml a.i. ha^{-1})	Plant height (cm)	Tillers running meter^{-1}	Leaves plant^{-1}	Plant dry matter running meter^{-1} (g)	Nutrient uptake by crop at harvest		
						N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Cyhalofop-butyl 10% EC	75.0	58.87	22.00	5.50	75.21	53.16	6.27	14.43
Cyhalofop-butyl 10% EC	80.0	56.56	20.67	5.42	69.77	48.88	5.7	13.41
Cyhalofop-butyl 10% EC	85.0	58.87	21.42	5.42	73.19	47.94	5.28	12.76
Oxyfluorfen23.5% EC	152.8	57.20	20.00	5.42	60.11	53.72	5.06	12.19
Hand weeding at 20and40 DAS	-	57.59	22.83	5.50	75.19	64.61	6.8	13.30
Untreated control (Weedy check)	-	55.39	17.67	5.33	47.48	43.39	5.29	8.25
SEm±		2.31	1.40	0.15	1.29	0.71	0.34	0.84
CD (*p*=0.05)		NS	NS	NS	4.00	2.14	1.10	2.51

NS: Non-significant

Similar results were reported by Sen *et al.* (2020), where they observed that all weed control treatments significantly impacted weed interference, crop growth, and yield. Sequential applications of pendimethalin (1.0 kg ha^{-1}) as pre-emergence and a ready mixture of penoxsulam + cyhalofop-butyl (130 g ha^{-1}) at 25 days after sowing (DAS) significantly reduced weed dry weight by 87.6% at harvest, and it was superior to other treatments.

Effect on nutrient uptake by crop

A critical analysis of data presented in Table 2 and depicted in figure1 revealed that among herbicidal treatments, cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} recorded higher nutrient uptake (N, P, and K) by the crop compared to the rest of the treatments. Whereas, the highest and the lowest nutrient uptake were found in weed-free and weedy check plots, respectively. This might be due to lower weed density, lower weed dry matter, and higher weed control efficiency, resulting in less crop-weed competition for minerals, moisture, light, and space, leading to better growth and development of the crop.

Table 3: Effect of herbicidal treatments on yield attributes, yield and economics of direct-seeded rice

Treatments	Dosage (ml a.i. ha^{-1})	Effective panicles m^{-2}	Grains panicle^{-1}	Panicle length (cm)	Fresh weight of panicle (g)	Test weight (g)	Grain yield (kgha^{-1})	Straw yield (kg ha^{-1})	Gross income (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B-C Ratio
Cyhalofop-butyl 10% EC	75.0	239	100	20.4	35.4	21.6	3692	4632	113313	69198	1.5
Cyhalofop-butyl 10% EC	80.0	234	96	20.4	34.6	20.4	3568	4436	109144	64826	1.4
Cyhalofop-butyl 10% EC	85.0	232	98	20.3	35.9	20.4	3525	4425	108210	63688	1.4
Fenoxaprop-p-ethyl6.7%w/w EC	54.5	213	96	20.7	35.3	19.6	3499	4367	107184	62126	1.3
Hand weeding at 20 and 40 DAS	-	248	103	21.5	35. 5	21.4	4251	5300	130170	76278	1.4
Untreated control (Weedy check)	-	218	88	20.7	31.2	20.3	2646	3307	81096	40044	0.97
SEm±		2.19	1.20	0.31	0.76	0.55	54.6	70.4	-	-	-
CD(*p*=0.05)		6.61	3.73	NS	2.21	1.50	168.3	212.1	-	-	-

Market cost of produce: Grain @ Rs. 19.4 kg^{-1}; Straw @ Rs. 9 kg^{-1}; NS: Non-significant

Economics

A critical analysis of data revealed that among different herbicidal treatments, hand weeding at 20 and 40 DAS generated the highest gross income of ₹1,30,170 ha^{-1}, followed by the cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} treatment with ₹1,13,313 ha^{-1} (Table 3). The cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} treatment showed the highest net returns of ₹ 69,198 ha^{-1}. The B-C ratio, which indicates the profitability of each treatment, was highest for cyhalofop-butyl 10% EC at 75.0 ml ha^{-1} treatment, showing a B-C ratio of 1.5. Thus, the

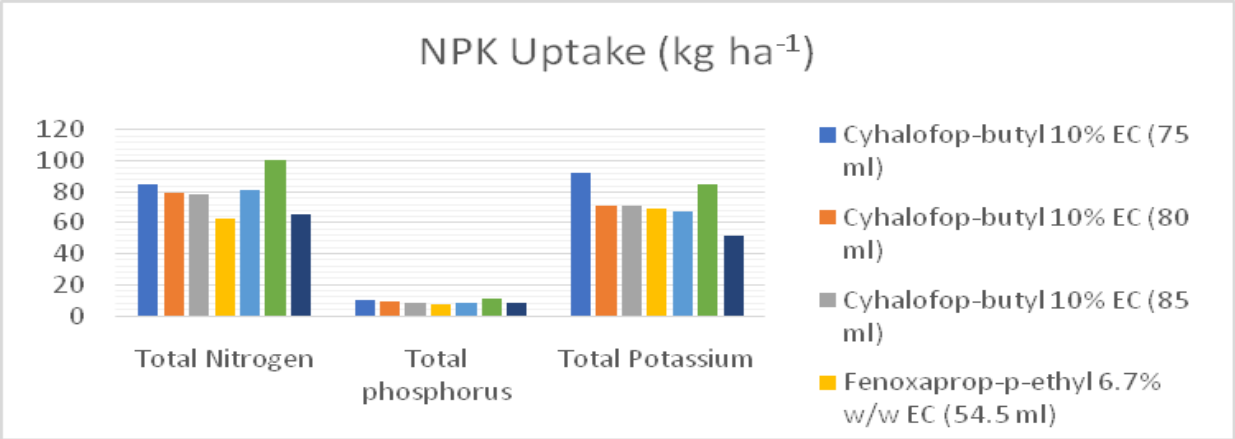

Figure 1: Effect of the treatments on NPK uptake by rice on Inceptisols

treatment cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} was the most economically beneficial. Similar findings were also reported by Jacob *et al.,* 2017, as the best herbicide for the control of grass weeds was either fenoxaprop-p-ethyl at 60 g a.i. or cyhalofop butyl at 80 g a.i. ha^{-1}, both applied at 20 DAS. Broad-spectrum weed control can be made possible by spraying herbicide combinations that could give higher yield and B-C ratio.

Table 4: Residual effect of cyhalofop-butyl 10% EC on crop germination, plant population, yield attributes and yields of Indian mustard

Treatments (applied in preceding rice crop)	Dosage (ml a.i. ha^{-1})	% crop germination	Mean plant Population m^{-2} (at 30 DAS)	Plant height (cm)	Yield attributes						Grain yield (kg ha^{-1})
					Primary branches plant^{-1}	Secondary branches plant^{-1}	Siliquae on main shoot (/shoot)	Siliquae plant^{-1}	Length of siliqua (cm)	1000-seed weight (g)	
Cyhalofop-butyl 10% EC	75.0	96	15.6	193	2.93	4.20	46.5	161	26.4	3.83	898
Cyhalofop-butyl 10% EC	80.0	96	14.8	183	2.93	5.13	54.6	174	25.8	4.00	950
Cyhalofop-butyl 10% EC	85.0	97	13.6	173	2.87	3.93	49.1	165	26.9	3.91	953
Oxyfluorfen 23.5% EC	152.8	95	13.1	177	3.00	4.80	49.3	166	26.2	3.40	944
Hand weeding at 20 & 40 DAS	-	98	14.0	192	3.33	4.27	51.3	179	26.3	3.87	889
Untreated control (Weedy check)	-	97	15.4	189	3.00	3.07	51.2	157	27.0	3.93	931
Cyhalofop-butyl 10% EC (only for phytotoxicity study)	1600	95	13.2	-	-	-	-	-	-	-	-
SEm±		0.75	0.12	3.40	0.20	0.22	3.84	12.1	0.43	0.06	23
CD(*p*=0.05)		NS	NS	9.12	0.63	0.65	11.12	NS	NS	NS	NS

NS: Non-significant

Effect of the treatments on succeeding crop of Indian Mustard

There was not significance differences on crop germination percentage of among the treatments applied in preceding rice crop (Table 4). However, plant height of Indian mustard at harvest was recorded the maximum value (193.13 cm) with the application of cyhalofop-butyl 10% EC @ 75.00 ml ha^{-1} among the herbicidal treatment. The residual effect of different treatments applied in preceding rice crop was tested in succeeding yield of Indian mustard crop, regarding this data of different yield attributing characters were analysed, and found that there was not significance differences in number of siliqua plant^{-1}, length of siliqua, 1000-seed weight and grain yield. However, primary and secondary branches plant^{-1} were higher under the application of fenoxaprop-p-ethyl 6.7% w/w EC @ 54.5 ml ha^{-1} and number of siliquae on main shoot (per shoot)

recorded higher with cyhalofop-bytul 10% EC @ 80.0 ml ha^{-1} applied in preceding rice crop over rest of the treatments.

Based on the study, it is advised to apply cyhalofop-butyl 10% EC as a post-emergence herbicide, at the rate of 75.00 ml ha^{-1}, around 17 days after sowing. This approach not only provides effective broad-spectrum weed control on Inceptisols but also serves as an economically viable strategy for managing weeds in the cultivation of direct-seeded rice.

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