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Research Paper

Bio-efficacy of post-emergence herbicides for control of complex weed flora in drum-seeded rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted during the rainy season of 2012 and 2013 at Gambharipali, Bargarh Odisha, to study the bio-efficacy of various herbicides on weeds, yield and economics of drum-seeded rice (*Oryza sativa* L.). Sole application of chlorimuron ethyl + metsulfuron methyl @ 4 g/ha, ethoxysulfuron @ 18 g/ha and 2, 4-D ethyl ester @ 400 g/ha showed selectivity towards broad-leaf weeds, whereas fenoxaprop-p-ethyl @ 60 g/ha showed selectivity towards grasses. Tank-mix application of chlorimuron ethyl + metsulfuron methyl with fenoxaprop-p-ethyl (4+60 g/ha) proved to be the most effective in minimizing the density (10.57/m^2), biomass (4.07 g/m^2) of weeds and enhancing the weed-control efficiency (95.7%), grain yield (5.68 t/ha), N, P and K uptake by crop, net returns (₹30,439/ha) and benefit: cost ratio (0.61).

Key words : Chlorimuron + metsulfuron, Drum seeded rice, Ethoxysulfuron, Fenoxaprop-p-ethyl, Herbicide mixture, Weeds

Transplanted rice is a labour-intensive and costly practice of rice cultivation. Drum seeding is an alternative to transplanting in medium lands. It requires 40% less labour (66 man-days) for pre-harvest operations than the transplanted rice (112 man-days) by reducing the labour engagement in transplanting and nursery raising (Pandey and Velasco, 2002). Drum seeding, however, is subjected to more weed infestation because both weeds and crop seeds emerge at the same time and compete with each other from beginning itself resulting in less grain yield (Singh and Singh, 2010). Timely availability of labour for manual weeding is also a problem. Delayed weeding hampers the application of nutrients and reduces production of effective tillers causing loss in yield by 96% in dry-seeded rice and 61% in wet-seeded rice (Maity and Mukherjee, 2008).

Weed shift from grasses to broad leaf and annual sedges is being observed in drum-seeded rice fields due to continuous use of butachlor and pretilachlor. Such changes beyond a certain level may become unmanageable. Therefore, there is a necessity to supplement the commonly used post-emergence herbicide (fenoxaprop-p-ethyl) with other herbicides as tank-mixture to widen the weed-control spectrum. Ready-mix available formulation of metsulfuron methyl and chlorimuron ethyl has been found to be effective against sedges and broad-leaf weeds in transplanted rice with some effect on annual grass control (Mandal *et.al.* 2013). In the light of these facts, the present investigation was proposed to examine the possibility of suitable broad-leaf herbicides to be used as tank-mixture with fenoxaprop-p-ethyl to widen the weed-control spectrum in drum-seeded rice.

MATERIALS AND METHODS

The study was undertaken at Seed Research Farm, OUAT, Gambharipali, Bargarh, Odisha, during the rainy (*kharif*) season of 2012 and 2013. The soil of the experimental field was sandy clay loam with *p*H 6.6, organic carbon 0.43% and available N ($KMnO_4$ method), P (Olsen) and K (NH_4OHC method) content of 268, 13.4 and 132 kg/ha respectively. Nine treatments, consisting of T_1, chlorimuron ethyl + metsulfuron methyl + fenoxaprop-p-ethyl (4 + 60 g/ha); T_2, ethoxysulfuron + fenoxaprop-p-ethyl (18 + 60 g/ha); T_3, 2,4 -D ethyl ester + fenoxaprop-p-ethyl (400 + 60 g/ha); T_4, chlorimuron ethyl + metsulfuron methyl (4 g/ha); T_5, ethoxysulfuron (18 g/ha); T_6, 2, 4-D ethyl ester (400 g/ha); T_7, fenoxaprop-p-ethyl (60 g/ha); T_8, weed-free; and T_9, weedy check, were tried in a randomized block design with 3 replications. All the herbicides were applied at 15 days after sowing. The pre-

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germinated seeds of rice cultivar 'MTU 1001' of 135 days were sown in puddle field using 8-row drum seeder, spaced at 20 cm. The total rainfall received during crop season was 865 and 925 mm during 2012 and 2013 respectively. A common fertilizer dose of 80 kg N + 18.2 kg P + 33.3 kg K/ha was applied. Full dose of P and half dose of K and N were applied basal and remaining N and K were top-dressed in 2 equal splits, at maximum tillering and panicle-initiation stages of the crop. The required quantity of herbicides were applied with manually-operated knapsack sprayer fitted with flat-fan nozzle using a spray volume of 500 *l* of water/ha. Water in the field was drained before application of herbicides and irrigated one day after application. Weed counts (numbers/m^2) and biomass (g/m^2) were taken from random samples at 2 places in the field with the help of 1 m^2 quadrate 50 days after sowing (DAS).

The weed samples were air-dried in shade initially followed by oven drying at 65^{o}C for 48 hours till they attain constant weight. Data on weed density and biomass were subjected to square-root transformation. Weed-control efficiency (WCE) and weed index (WI) are calculated based on the weed biomass and rice grain yield respectively. The N, P and K uptake by crop was recorded at harvesting using standard procedures. Economics was computed using the prevailing market prices for inputs and outputs.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora in the experimental field comprised grasses, viz. *Echinochloa crus-galli*, *Echinochloa colona*, *Digitaria sanguinalis*, *Panicum repens*, and *Leptochloa chinensis*; sedges, viz. *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus*, *Fimbristylis miliacea;* and broad-leaf weeds, viz. *Ludwigia paraviflora*, *Ammania baccifera*, *Eclipta prostrata*, *Eclipta alba*, *Lippa nodiflora*, *Marsilea quadrifolium*, *Sphenoclea zeylanica*, *Commelina benghalensis*. The composition of grasses, sedges and broad-leaf weeds in weedy check plot was 28.3, 36.5 and 35.1%, respectively. Emergence of sedges and broad-leaf weeds were noticed earlier as compared to grasses.

The herbicides used in the experiment are broad spectrum in nature. But in their sole applications, fenoxaprop-p-ethyl was the best in controlling grasses (15.8/m^2), whereas ethoxysulfuron was the most effective in controlling sedges followed by chlorimuron + metsulfuron (17.2/m^2). Broad leaf weeds were effectively controlled by 2, 4 -D ethyl ester followed by chlorimuron + metsulfuron (Table 1). This may be due to differential selectivity towards grassy and broad-leaf weeds. The results are in agreement with Yadav *et al*. (2011). Weed density was the lowest (47.7/m^2) with sole application of chlorimuron + metsulfuron, followed by ethoxysulfuron (52.6/m^2).

Tank-mix application of chlorimuron + metsulfuron with fenoxaprop-p-ethyl was the most effective in controlling all the weeds. But the control of grasses by this tank mixture was inferior to ethoxysulfuron + fenoxaprop-p-ethyl.

Among sole application of the herbicides, the lowest biomass of grasses was found with fenoxaprop-p-ethyl (7.8 g/m^2), whereas the lowest sedge biomass was found with sole application of ethoxysulfuron (1.8 g/m^2), followed by chlorimuron + metsulfuron and the lowest broad-leaved biomass in 2, 4 -D ethyl ester, followed by chlorimuron + metsulfuron.

The tank-mix application of chlorimuron + metsulfuron, ethoxysulfuron and 2, 4-D ethyl ester with fenoxaprop ethyl produced lower weed biomass than that of sole application. The lowest grass and broad-leaf weeds were recorded by 2, 4 -D ethyl ester + fenoxaprop-p-ethyl and the lowest sedge biomass were recorded with both chlorimuron + metsulfuron + fenoxaprop-p-ethyl and ethoxysulfuron + fenoxaprop-p-ethyl. On the whole, total biomass production was the lowest with chlorimuron +metsulfuron+ fenoxaprop-p-ethyl, which was on a par with application of ethoxysulfuron + fenoxaprop-p-ethyl and 2, 4 -D ethyl ester + fenoxaprop-p-ethyl. All these combinations were significantly superior to the sole application of the herbicides and over weedy check. Sole application of chlorimuron + metsulfuron at 4 g/ha, ethoxysulfuron at 18 g/ha and 2,4 D ethyl ester at 400 g/ha was the least effective as compared to their tank-mixture application due to the fact that field was infected with complex weed flora and these being basically herbicides for broad-leaf weeds, failed to manage grassy weeds. However, all the herbicides were effective over weedy check in this respect. Singh *et al.* (2004) also recorded lower biomass of weed with tank-mix of chlorimuron + metsulfuron with butachlor.

Weed control efficiency of the herbicide tank-mixture were superior to sole applications. The highest weed-control efficiency (95.7%) was found with chlorimuron + metsulfuron + fenoxaprop-p-ethyl followed by ethoxysulfuron + fenoxaprop-p-ethyl (95.5%) and 2, 4 -D ethyl ester + fenoxaprop-p-ethyl (95.2%). This showed that all the herbicide tank-mixture taken in this experiment were compatible, which increased their efficiency over sole application (55.1 to 79%) without any phytotoxic effect causing adversity.

Data on weed index showed the least yield reduction (3.3%) with tank-mix of chlorimuron +metsulfuron+ fenoxaprop-p-ethyl, followed by ethoxysulfuron + fenoxaprop-p-ethyl (7.4%) and 2,4 -D ethyl ester +

fenoxaprop-p-ethyl (9.1%), whereas yield reduction varied from 14.4 to 25% in the sole herbicide applied plots as compared to weed-free treatment. The weed-index was lower in all the treatment as compared to weedy check.

Yield attributes and yield

The effect of herbicide was not significant with respect to panicle length. But the herbicide treatments affected the number of effective tiller, grains/panicle and test weight. Effective tillers /m^2, panicle length, grains/panicle were the highest with chlorimuron + metsulfuron + fenoxaprop-p-ethyl and were at par with that of weed-free treatment (Table 2). With respect to effective tillers, all the tank-mixtures of herbicides chlorimuron + metsulfuron + fenoxaprop-p-ethyl, ethoxysulfuron + fenoxaprop-p-ethyl and 2, 4 -D ethyl ester + fenoxaprop-p-ethyl were at par, whereas their effect was significantly superior to sole application of all the herbicides. Data on grains/panicle showed that chlorimuron + metsulfuron + fenoxaprop-p-ethyl and ethoxysulfuron + fenoxaprop-p-ethyl were at par followed by 2, 4 -D ethyl ester + fenoxaprop-p-ethyl, whereas all the tank-mix applications were superior to sole application of the herbicides.

The complex weed flora comprised grasses, sedges and broad-leaf weeds showed reduction of 29.3% in grain yield in the weedy check compared to weed-free treatment (5.87 t/ha). The highest grain yield (5.68 t/ha) was recorded with chlorimuron + metsulfuron + fenoxaprop-p-ethyl which was at par with weed-free check. Chlorimuron + metsulfuron + fenoxaprop-p-ethyl, ethoxysulfuron + fenoxaprop-p-ethyl, 2, 4 -D ethyl ester + fenoxaprop-p-ethyl resulted in an average increase of 26.9, 23.7 and 22.1% in the grain yield as compared to weedy check. Sole application of chlorimuron + metsulfuron, ethoxysulfuron and 2, 4 -D ethyl ester recorded lower grain yield as compared to their tank-mix application with fenoxaprop-p-ethyl which was possibly owing to their in-effectiveness in controlling grassy weeds, resulting lower weed-control efficiency (Tables 1, 2). Since ethoxysulfuron and 2,4 -D ethyl ester were highly effective towards sedges and broad-leaf weeds, the significant reduction of 12.9 and 14.8% of grain yield in these treatments was noticed compared to tank-mix of ethoxysulfuron and 2,4 -D ethyl ester with fenoxaprop-p-ethyl. Sharma *et al.* (2003) also reported that fenoxaprop-p-ethyl did not provide any control of broad-leaf weeds. Tank-mix application of fenoxaprop-p-ethyl with chlorimuron + metsulfuron, ethoxysulfuron and 2,4 -D ethyl ester resulted in significantly higher yield than their sole application, which may be owing to control of all grasses, sedges and broad leaf weeds. Grain yield of fenoxaprop-p-ethyl with ethoxysulfuron and 2, 4 -D ethyl ester remained statistically at par among themselves, lower than fenoxaprop-p-ethyl with chlorimuron + metsulfuron. Ethoxysulfuron, 2, 4 -D ethyl ester and chlorimuron + metsulfuron were compatible with fenoxaprop-p-ethyl, as there site of action is different in the plant. Fenoxaprop-p-ethyl inhibits the synthesis of lipid, whereas chlorimuron + metsulfuron and ethoxysulfuron inhibits the synthesis of amino acids and 2, 4-D ethyl ester affect cell-wall plasticity and nucleic acid metabolism in plant. Better performance of these treatments in terms of yield could be owing to better control of complex weed flora tilting the crop-weed competition in favour of the crop. Singh *et al.* (2006) observed that post- emergence application of fenoxaprop-p-ethyl + ethoxysulfuron was as effective as

Table 1. Effect of weed-management practices on weed density and biomass at 50 days after transplanting in rice (mean data of 2 years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				Weed control efficiency (%)	Weed index (%)
	Grasses	Sedges	BLWs	Total	Grasses	Sedges	BLWs	Total		
T_1	2.68 (6.2)	1.00 (0.00)	2.29 (4.3)	3.40 (10.57)	1.97(2.9)	1.00 (0.00)	1.45 (1.1)	2.25 (4.07)	95.7	3.3
T_2	2.52 (5.4)	1.00 (0.00)	2.73 (6.5)	3.60 (11.97)	1.81(2.3)	1.00 (0.00)	1.70 (1.9)	2.29 (4.27)	95.5	7.4
T_3	2.60 (5.8)	2.38 (4.7)	2.36 (4.6)	4.02 (15.20)	1.67(1.8)	1.34 (1.8)	1.38 (0.9)	2.37 (4.60)	95.2	9.1
T_4	4.60 (20.1)	4.27 (17.2)	3.36 (10.3)	6.98 (47.70)	3.34(10.2)	2.46 (6.1)	2.14 (3.6)	4.58 (20.00)	79.0	14.4
T_5	5.34 (27.5)	2.31 (4.4)	4.65 (20.6)	7.32 (52.60)	3.91(14.3)	1.64 (1.8)	2.48 (5.2)	4.73 (21.40)	77.6	18.0
T_6	5.89 (33.7)	6.47 (40.9)	3.13 (8.8)	9.19 (83.50)	4.15(16.2)	4.08 (15.6)	1.76 (2.1)	5.92 (34.00)	64.3	21.0
T_7	4.10 (15.8)	6.69 (43.7)	7.68 (57.9)	10.89(117.50)	2.97(7.8)	4.18 (16.5)	4.40 (18.4)	6.62 (42.80)	55.1	25.0
T_8	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00(0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	100	0
T_9	7.99 (62.8	9.04 (80.7)	8.87 (77.6)	14.91(221.20)	5.58(30.2)	6.03 (35.3)	5.54 (29.8)	9.82 (95.40)	0	29.3
SEm±	0.06	0.52	0.07	0.90	0.03	0.11	0.09	0.58	-	-
CD(P=0.05)	0.18	1.56	0.20	2.70	0.07	0.33	0.27	1.74	-	-

Data subjected to square-root transformation ($\sqrt{x+1}$), original value are in parentheses

T_1, chlorimuron + metsulfuron + fenoxaprop-p-ethyl (4 + 60 g/ha); T_2, ethoxysulfuron + fenoxaprop-p-ethyl (18 + 60 g/ha); T_3, 2,4 -D ethyl ester + fenoxaprop-p-ethyl (400 + 60 g/ha); T_4, chlorimuron + metsulfuron (4 g/ha); T_5, ethoxysulfuron (18 g/ha); T_6, 2, 4-D ethyl ester (400 g/ha); T_7, fenoxaprop-p-ethyl (60 g/ha); T_8, weed-free; T_9, weedy check hand-weeding twice.

Nitrogen, phosphorus and potassium

The N, P and K uptake by crop was significantly influenced by weed-management practices (Table 3). The highest total nitrogen, phosphorus and potassium uptake in grain was recorded in weed-free check, followed by chlorimuron + metsulfuron + fenoxaprop-p-ethyl. This was mainly owing to better grain yields observed under these treatments. The lowest N, P and K uptake in grain and straw was found in weedy check. Similar results were reported by Singh and Singh (2010).

Economics

All the herbicides in tank-mix application recorded higher monetary returns than their sole application and weedy check (Table 2). Among the chemical weed-control treatments, chlorimuron + metsulfuron + fenoxaprop-p-ethyl gave the maximum net returns (₹30,439/ha) and benefit: cost ratio (0.61), followed by ethoxysulfuron + fenoxaprop-p-ethyl owing to low cost and higher grain yield as compared to other post- emergence herbicides (Table 2). Dewangan *et al.* (2013) also reported similar findings with tank-mix application of herbicides. Weed-free treatment though registered higher grain yield (5.87 t/

Table 2. Effect of different weed-management practices on yield attributes, yield and economics of rice (mean data of 2 years)

Treatment	Effective tillers (No./m^2)	Panicle length (cm)	Grains/ panicle	Test weight (g)	Grain yield (t/ha)			Cost of cultivation (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	Benefit: cost ratio
					2012	2013	Pooled			
T_1	386	23.6	81.1	23.5	5.47	5.89	5.68	49.6	30.4	0.61
T_2	379	23.5	80.2	23.6	5.23	5.64	5.44	49.8	26.9	0.54
T_3	365	23.3	76.4	23.5	5.13	5.53	5.33	49.4	25.7	0.52
T_4	349	22.5	74.4	23.4	4.83	5.21	5.02	48.6	22.2	0.45
T_5	337	23.4	70.4	23.5	4.63	5.00	4.82	48.7	19.2	0.39
T_6	323	22.9	73.5	23.2	4.47	4.82	4.64	48.4	17.0	0.35
T_7	312	22.6	70.5	22.8	4.23	4.57	4.40	49.0	12.9	0.26
T_8	409	23.7	82.6	23.6	5.65	6.09	5.87	57.6	25.2	0.44
T_9	298	20.8	66.8	23.2	3.70	4.60	4.15	47.6	10.9	0.22
SEm±	7.67	0.59	0.55	0.05	0.06	0.09	0.08	-	-	-
CD (P=0.05)	24.01	1.78	1.66	0.15	0.18	0.26	0.25	-	-	-

T_1, Chlorimuron + metsulfuron + fenoxaprop-p-ethyl (4 + 60 g/ha); T_2, ethoxysulfuron + fenoxaprop-p-ethyl (18 + 60 g/ha); T_3, 2,4 -D ethyl ester + fenoxaprop-p-ethyl (400 + 60 g/ha); T_4, chlorimuron + metsulfuron (4 g/ha); T_5, ethoxysulfuron (18 g/ha); T_6, 2,4 -D ethyl ester (400 g/ha); T_7, fenoxaprop-p-ethyl (60 g/ha); T_8, weed-free; T_9, weedy check

Input price (₹/kg) rice seed, 22; urea, 5.52; diammonium phosphate, 24.45; muriate of potash, 17.44; fenoxaprop-p-ethyl, ₹180/100 ml; chlorimuron + metsulfuron, ₹220/8 g, ethoxysulfuron ₹270/50 g, 2, 4 -D ethyl ester, ₹174/500 ml; sale rate of rice grain (₹14,100/t), rice straw (₹800/t) and manual labour (₹127/day).

Table 3. Effect of weed management on N, P, K uptake (kg/ha) by rice at harvesting (mean data of 2 years)

Treatment	Nitrogen			Phosphorus			Potassium		
	Grain	Straw	Total	Grain	Straw	Total	Grain	Straw	Total
T_1	67.0	41.5	108.5	20.6	2.8	23.4	24.4	121.8	146.2
T_2	64.4	40.4	104.8	19.9	2.6	22.5	23.8	115.0	138.8
T_3	63.6	35.7	99.3	18.5	2.0	20.5	22.8	107.2	130
T_4	59.2	35.2	94.4	17.3	1.9	19.2	21.2	103.3	124.5
T_5	58.2	33.0	91.2	17.1	1.8	18.9	21.1	102.2	123.3
T_6	53.4	29.9	83.3	15.7	1.7	17.4	19.0	96.8	115.8
T_7	52.4	29.5	81.9	14.9	1.6	16.5	18.5	90.1	108.6
T_8	68.7	37.6	106.3	20.7	2.1	22.8	24.6	126.7	151.3
T_9	48.8	29.0	77.8	12.1	1.2	13.3	14.8	86.4	101.2
SEm±	0.72	0.12	0.26	0.13	0.01	0.06	0.11	2.32	0.82
CD (P=0.05)	2.14	0.36	0.76	0.39	0.03	0.17	0.33	6.96	2.44

T_1, Chlorimuron + metsulfuron + fenoxaprop-p-ethyl (4 + 60 g/ha); T_2, ethoxysulfuron + fenoxaprop-p-ethyl (18 + 60 g/ha); T_3, 2,4 -D ethyl ester + fenoxaprop-p-ethyl (400 + 60 g/ha); T_4, chlorimuron + metsulfuron (4 g/ha); T_5, ethoxysulfuron (18 g/ha); T_6, 2, 4 –D ethyl ester (400 g/ha); T_7, fenoxaprop-p-ethyl (60 g/ha); T_8, weed-free; T_9, weedy check ha), recorded lower monetary returns (₹25,185/ha) than tank-mix application of herbicide mixture, due to high cost incurred on manual weeding to keep the crop-weed free.

It can be concluded that chlorimuron + metsulfuron, ethoxysulfuron and 2, 4 -D ethyl ester were compatible with fenoxaprop-p-ethyl and there was no adverse effect on crop growth. It successfully controlled the complex weed flora in rice. Fenoxaprop-p-ethyl with chlorimuron + metsulfuron was the most remunerative and effective herbicide mixtures for controlling the complex weed flora in drum-seeded rice.

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