



RESEARCH ARTICLE

Evaluation of herbicides efficacy and selectivity for weed management in transplanted rice and the response of succeeding cowpea to herbicide residues

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ABSTRACT

A field experiment was undertaken in India's eastern sub-Himalayan plain during the *Kharif* seasons of 2021 and 2022 to evaluate various weed management options in transplanted rice and examine herbicides residual effects on succeeding cowpea crop. Among the treatments evaluated, early post-emergence application (EPoE) of bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha with a silicon-based non-ionic surfactant at 5 ml/l, recorded significantly higher reduction of weed density (83.3%), weed biomass (83.0%) with higher weed control efficiency (WCE) (85.3%) at 60 days after application (DAA). Bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha EPoE recorded higher benefit:cost ratio of 2.11 and outperformed manual weeding twice in terms of rice grain yield, straw yield, and net returns. Pyrazosulfuron-ethyl 15 g/ha EPoE was effective against broad-leaved weeds, while bispyribac-sodium 25 g/ha EPoE performance was better against grasses and sedges (WCE of 65-66%). The emergence, plant stand, growth, or yield of subsequently grown cowpea was unaffected by residues of herbicides sprayed in transplanted rice proving that all herbicide treatments tested were safe to crops in rice-cowpea cropping system.

Keywords: Bispyribac-sodium, Herbicide residues, Penoxsulam, Pyrazosulfuron-ethyl, Transplanted rice, Weed management, Cowpea

INTRODUCTION

Rice (*Oryza sativa* L.) is a crucial cereal crop worldwide and serves as a major staple for about half of the global population, with around 90% of its production occurring in Asia. In India, the saying "Rice is life" truly reflects its role in ensuring national food security and sustaining rural livelihoods, contributing nearly 70% of the daily caloric intake (Yogi *et al.* 2023). With an output of 124 million tons over an area of around 44 million hectares, the crop accounts for 21.5% of the world's rice production (DES 2024). However, to feed the world's anticipated 1.64 billion people by 2050, rice production must rise significantly while limiting environmental damage and making wise use of scarce resources like labour, water, land, and agrochemicals (Rao 2022; Ahmad *et al.* 2021). The weeds are major constraints in direct-

seeded rice (DSR) causing higher (14 to 100%) than in transplanted rice (TPR) (7 to 80%) (Rao *et al.* 2017). Although TPR provides partial weed suppression through standing water and improved nutrient availability (Choudhary *et al.* 2021), repeated weed flushes during the crop growth period result in severe competition for nutrients, moisture and light. Manual weeding, though effective, has become increasingly impractical due to labour scarcity, frequent rains and escalating wage rates during the critical period of crop-weed competition (Choudhary and Dixit 2018). Under these circumstances, the use of herbicides, either as premixes or as tank-mix combinations with different modes of action, has emerged as an efficient and cost-effective weed management strategy. Such combinations were reported to provide broader weed control, reduce herbicide load and improve economic returns. However, location-specific information on their efficacy remains limited. Thus, this study was conducted with an objective to assess the early post-emergence application (EPoE) of premix herbicide combinations efficacy to control weeds in transplanted rice and to examine herbicides residual effects of herbicides used in rice on succeeding cowpea.

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MATERIALS AND METHODS

A field experiment was carried out during the *Kharif* seasons of 2021 and 2022 at the Instructional Farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal (26°N latitude, 89°E longitude, and 43 m above mean sea level). The experimental soil had a sandy loam texture, a neutral response, and a medium fertility condition. A randomized block design (RBD), with nine treatments and three replications was used.

The tested treatments include: bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 18.75 g/ha + silicon-based non-ionic surfactant 5 ml/l; bispyribac-sodium 30 g/ha + pyrazosulfuron-ethyl 22.5 g/ha + silicon-based non-ionic surfactant 5 ml/l; bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha + silicon-based non-ionic surfactant 5 ml/l; bispyribac-sodium 25 g/ha; pyrazosulfuron-ethyl 15 g/ha; triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha; penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha; untreated control and hand weeding twice. The rice variety MTU-7029 was grown under puddled and transplanted conditions. The cowpea variety Bidhan Sadabahar was cultivated as succeeding crop to assess residual effects of herbicides used in rice. Thirty days after seeding in a wet nursery, rice seedlings were transplanted with a spacing of 20 cm × 15 cm. At 14 days after transplanting (DAT), herbicides were sprayed as per the treatments using a backpack knapsack sprayer equipped with a flat-fan nozzle and a spray volume of 300-400 l/ha. Fertilizers at 120: 60: 60 kg/ha N: P: K were used. At the active tillering and panicle initiation stages, the remaining nitrogen was top-dressed in two equal splits, while full dosages of phosphorus, potassium, and half of the nitrogen were applied as basal. At 30, 45, and 60 days after application (DAA), weed density and weed dry weight (weed biomass) were measured by randomly placing three 0.25 m² quadrats in each plot. To quantify weed biomass, the weeds were identified based on their taxonomic characteristics, trimmed at ground level, sun-dried for 3-5 days, and then oven-dried at 70 ± 2°C until their weight remained constant. Weed control efficiency (WCE) and weed control index (WCI) were determined using weed biomass and grain yield data (Das 2008).

$$\text{WCE (\%)} = \frac{\text{Weed density in untreated plot} - \text{Weed density in treated plot}}{\text{Weed density in untreated plot}} \times 100$$

$$\text{WCI (\%)} = \frac{\text{Weed biomass in control} - \text{Weed biomass in treated plot}}{\text{Weed biomass in control}} \times 100$$

Data on weed density and biomass were subjected to square-root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize the variance. Yield attributes and grain yield were recorded at harvest. The cowpea (*Vigna unguiculata* L.) variety Bidhan Sadabahar was grown during the *rabi* seasons of both experimental years, following the harvest of *Kharif* season transplanted rice. The crop was sown one week after rice harvest after manual field preparation, without disturbing the original experimental layout. Sowing was carried out at a seed rate of 25 kg/ha. The residual effects of herbicide treatments on cowpea were assessed based on cowpea seedlings emergence percentage, plant stand, plant height, and seed yield. The data were analysed statistically by following the analysis of variance (ANOVA) as suggested by Gomez and Gomez (1984), and means were separated at $p < 0.05$ and adjusted with Fisher's protected least significant difference (LSD) test.

RESULTS AND DISCUSSION

Effect on weeds

The major weed species in the experimental plots were: *Echinochloa colona*, *Fimbristylis miliacea*, *Monochoria vaginalis*, *Eclipta alba*, and *Ludwigia parviflora*. Significant variation in weed management efficacy was recorded among treatments and growth stages (Table 1, 2 and 3). The hand-weeding caused complete elimination of all species (100%), while the untreated control recorded the highest weed density and biomass at all the crop growth stages. Among the herbicidal treatments, bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha (pre-mix) with a silicon-based non-ionic surfactant recorded the highest reductions of weed density (67.7% at 30 days after application (DAA), 68.8% at 45 DAA, and peaking at 83.3% at 60 DAA over the unweeded control) and weed biomass (average reductions of 77.8%, 78.5%, and 83.0% at 30, 45 and 60 DAA, respectively). The variation in weed density reduction at different rice growth stages indicates the herbicide formulation's prolonged residual efficacy and broad-spectrum activity under puddled transplanted conditions. This treatment resulted in higher control of *Fimbristylis miliacea* (67.6-83.8%) and *Eclipta alba* (75.5-88.2%) throughout the season, reflecting the combined strength of bispyribac-sodium on grasses and sedges such as *Echinochloa colona* and *Fimbristylis miliacea*, as reported earlier by Kaur *et al.* (2016) and Yadav *et al.* (2021), and pyrazosulfuron-ethyl's activity against broad-leaved aquatic weeds such as

Monochoria vaginalis and *Ludwigia parviflora*. A clear dose response was observed within the same premix. The intermediate dose of bispyribac-sodium 30 g/ha + pyrazosulfuron-ethyl 22.5 g/ha caused moderate reduction in weed density (averaging 56-58% across stages) and weed biomass (51.7%, 61.2%, and 65.3% at 30, 45 and 60 DAA, respectively), while the lowest rate of bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 18.75 g/ha was markedly less effective, with weed density

reduction (of 21.4% at 30 DAA and 43.2% at 60 DAA) and weed biomass reduction of 27.7% at 30 DAA and 43.3% at 60 DAA. This highlights the importance of applying the recommended rate to ensure season-long control of the diverse transplanted rice weed flora that emerges at multiple flushes (Singh *et al.* 2017; Khippal *et al.* 2019). The superior performance of bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha across grasses, sedges, and broad-leaved weeds underscores the

Table 1. Effect of different weed management treatments on weed density(no./m²) and weed biomass(g/m²) at 30 DAA (pooled data)

Treatment	<i>Echinochloa crus-galli</i>		<i>Cyperus iria</i>		<i>Ludwigia parviflora</i>		<i>Fimbristylis miliacea</i>		<i>Monochoria vaginalis</i>	
	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	1.5(6.2)	3.5(12.2)	0.9(3.1)	3.1(9.5)	0.6(1.9)	3.8(13.4)	0.8(2.6)	3.2(10.3)	0.8(2.9)	3.5(12.2)
Bispyribac-sodium 30 g/ha+ pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	1.0(3.9)	2.8(7.9)	0.6(1.8)	2.5(6.3)	0.4(1.1)	3.1(9.5)	0.6(2.0)	2.6(6.9)	0.3(0.9)	2.8(7.9)
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	0.6(1.8)	1.9(3.7)	0.4(1.1)	1.7(2.9)	0.3(0.8)	2.1(4.2)	0.4(1.2)	1.8(3.2)	0.5(1.6)	1.9(3.7)
Bispyribac-sodium 25 g/ha	0.8(2.6)	2.9(8.5)	0.5(1.5)	2.6(6.9)	0.4(1.2)	3.3(10.9)	0.7(2.4)	2.7(7.5)	0.5(1.7)	2.9(8.5)
Pyrazosulfuron-ethyl 15 g/ha	0.7(2.3)	2.5(6.3)	0.5(1.5)	2.2(4.9)	0.4(1.2)	2.8(7.9)	0.6(2.1)	2.3(5.6)	0.5(1.7)	2.5(6.3)
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	1.2(4.9)	3.8(13.4)	0.7(2.3)	3.4(11.4)	0.6(2.0)	4.2(16.1)	0.9(3.4)	3.5(12.2)	0.5(1.7)	3.8(13.4)
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	0.9(3.3)	3.2(10.3)	0.6(2.0)	2.9(8.5)	0.5(1.7)	3.6(12.8)	0.8(2.9)	3.0(9.2)	0.3(0.9)	3.2(10.3)
Untreated control	1.6(7.1)	4.5(16.1)	0.9(3.4)	4.1(14.1)	0.7(2.5)	4.9(17.6)	1.1(4.9)	4.2(15.5)	0.9(3.4)	4.5(16.1)
Hand weeding twice	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)
LSD(p=0.05)	0.09	0.81	0.07	0.73	0.05	0.92	0.09	0.75	0.07	0.81

The values mentioned in parentheses are original; DAA = days after herbicide application

Table 2. Effect of different weed management treatments on density(no./m²) and weed biomass(g/m²) at 45 DAA (pooled data)

Treatment	<i>Echinochloa crus-galli</i>		<i>Cyperus iria</i>		<i>Ludwigia parviflora</i>		<i>Fimbristylis miliacea</i>		<i>Monochoria vaginalis</i>	
	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	2.3(13.9)	4.2(12.8)	1.6(6.9)	3.8(10.3)	1.1(3.9)	4.8(15.1)	1.7(8.1)	4.0(11.9)	1.1(3.9)	4.2(12.8)
Bispyribac-sodium 30 g/ha+ pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	1.8(9.1)	3.3(8.5)	1.2(4.5)	3.0(7.1)	0.9(3.2)	3.7(10.9)	1.4(6.1)	3.2(8.1)	0.9(3.2)	3.3(8.5)
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	1.0(3.5)	2.2(4.9)	0.8(2.5)	2.0(3.7)	0.6(2.0)	2.5(6.3)	0.9(3.2)	2.1(4.2)	0.7(2.3)	2.2(4.9)
Bispyribac-sodium 25 g/ha	1.5(6.9)	3.6(10.3)	1.1(4.1)	3.3(9.2)	0.8(2.9)	4.1(12.8)	1.3(5.9)	3.5(10.3)	0.9(3.5)	3.6(10.3)
Pyrazosulfuron 15 g/ha	1.3(5.9)	3.1(8.1)	1.0(3.5)	2.8(7.1)	0.7(2.5)	3.5(9.5)	1.2(4.9)	3.0(7.9)	0.8(2.9)	3.1(8.1)
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	2.1(12.1)	4.9(16.1)	1.5(6.5)	4.5(14.1)	1.0(3.9)	5.4(20.1)	1.8(9.1)	4.7(15.5)	1.0(3.9)	4.9(16.1)
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	1.9(10.1)	3.9(11.9)	1.3(5.1)	3.6(10.9)	0.9(3.5)	4.3(14.5)	1.6(7.9)	3.8(11.9)	0.9(3.5)	3.9(11.9)
Untreated control	2.6(17.9)	5.6(22.1)	1.8(9.1)	5.2(19.1)	1.2(4.9)	6.2(25.9)	2.3(15.1)	5.4(21.5)	1.2(4.9)	5.6(22.1)
Hand weeding twice	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)
LSD (p=0.05)	0.14	0.98	0.11	0.89	0.08	1.09	0.14	0.95	0.11	0.98

The values mentioned in parentheses are original; DAA = days after herbicide application

advantage of using a premix with complementary modes of action to ensure comprehensive control under transplanted rice ecosystems.

The combination of triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha was least effective option, with poor efficacy on *Ludwigia parviflora* and *Monochoria vaginalis*, indicating limited residual control under the tested conditions. Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha recorded intermediate performance, with average reduction in weed density of 48-55% and weed biomass of 35.9% and 49.8%, showing early-season activity on grasses

and sedges but limited residual control of broad-leaved weeds in later stages. The variation in the efficacy of individually applied herbicides on specific weeds highlights the need for herbicide selection based on predominant weed species in transplanted rice fields.

Weed indices

Weed control index (WCI) (Table 4) and weed control efficiency (WCE) (Table 5) varied significantly across treatments and crop growth stages, reflecting the differential efficacy of

Table 3. Effect of different weed management treatments on density (no./m²) and weed biomass (g/m²) at 60 DAA (pooled data)

Treatment	<i>Echinochloa crus-galli</i>		<i>Cyperus iria</i>		<i>Ludwigia parviflora</i>		<i>Fimbristylis miliacea</i>		<i>Monochoria vaginalis</i>	
	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass	Weed density	Weed biomass
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	5.29(27.5)	6.3(24.5)	3.10(9.6)	5.7(20.1)	2.16(4.7)	7.4(31.9)	3.37(11.3)	6.1(22.9)	2.58(6.6)	6.3(24.5)
Bispyribac-sodium 30 g/ha + pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	4.47(19.9)	4.9(14.9)	2.65(7.0)	4.4(12.8)	1.93(3.7)	5.6(19.1)	2.95(8.6)	4.7(13.9)	2.22(4.9)	4.9(14.9)
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	2.58(6.6)	3.4(7.1)	1.62(2.6)	3.1(6.3)	1.22(1.5)	3.9(9.5)	1.95(3.8)	3.3(7.1)	1.44(2.1)	3.4(7.1)
Bispyribac-sodium 25 g/ha	3.83(14.7)	5.4(18.3)	2.32(5.4)	4.9(15.1)	1.73(3.0)	6.3(24.5)	2.83(8.0)	5.2(17.3)	1.93(3.7)	5.4(18.3)
Pyrazosulfuron 15 g/ha	3.54(12.5)	4.6(13.4)	2.17(4.7)	4.2(11.9)	1.58(2.5)	5.2(17.3)	2.65(7.0)	4.4(12.8)	1.79(3.2)	4.6(13.4)
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	5.10(26.0)	7.4(33.5)	3.00(9.0)	6.7(28.1)	2.32(5.4)	8.5(43.1)	4.00(16.0)	7.2(32.5)	2.50(6.3)	7.4(33.5)
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	4.22(17.7)	5.8(21.5)	2.76(7.6)	5.3(18.3)	2.00(4.0)	6.7(28.1)	3.32(11.0)	5.6(20.1)	2.32(5.4)	5.8(21.5)
Untreated control	6.71(44.9)	8.3(42.5)	4.00(16.0)	7.6(36.5)	2.95(8.7)	9.6(56.3)	5.66(32.1)	8.1(40.5)	3.00(9.0)	8.3(42.5)
Hand weeding twice	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)
LSD(p=0.05)	0.13	1.37	0.09	1.26	0.07	1.48	0.13	1.35	0.09	1.37

The values mentioned in parentheses are original; DAA = days after herbicide application

Table 4. Effect of different weed management treatments on weed control index (%) in transplanted rice (pooled data)

Treatment	<i>Echinochloa crus-galli</i>			<i>Cyperus iria</i>			<i>Ludwigia parviflora</i>			<i>Fimbristylis miliacea</i>			<i>Monochoria vaginalis</i>		
	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA	30 DAA	45 DAA	60 DAA
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	24.2	42.1	42.4	32.6	46.1	44.9	23.9	41.7	25.8	33.5	44.7	43.2	24.2	42.1	42.4
Bispyribac-sodium 30 g/ha + pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	51.0	61.5	64.9	55.3	62.8	64.9	46.0	58.1	55.7	55.5	62.3	65.7	51.0	61.5	64.9
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	77.0	77.8	83.3	79.4	80.6	82.7	76.1	75.7	77.9	79.4	80.5	82.5	77.0	77.8	83.3
Bispyribac-sodium 25 g/ha	47.2	53.4	56.9	51.1	51.8	58.6	38.1	50.6	43.2	51.6	52.1	57.3	47.2	53.4	56.9
Pyrazosulfuron 15 g/ha	60.9	63.4	68.5	65.2	62.8	67.4	55.1	63.3	59.8	63.9	63.3	68.4	60.9	63.4	68.5
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	16.7	27.2	21.2	19.1	26.2	23.0	8.5	22.4	0.0	21.3	27.9	20.0	16.7	27.2	21.2
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	36.0	46.2	49.4	39.7	42.9	49.9	27.3	44.0	34.8	40.6	44.7	50.4	36.0	46.2	49.4
Untreated control	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hand weeding twice	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The values mentioned in parentheses are original; DAA = days after herbicide application

herbicides on transplanted rice weed flora. Among herbicidal treatments, the bispyribac sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha with a silicon-based surfactant was most effective, recording WCI of 77.8%, 78.5%, and 81.9%, and WCE of 79.1%, 68.6%, and 85.3% at 30, 45, and 60 DAA, respectively. Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha provided broad-spectrum control, controlling grasses: *Echinochloa colona* and *Fimbristylis miliacea* (>82% WCI; >85% WCE); and broad-leaved weeds: *Eclipta alba*, *Monochoria vaginalis*, and *Ludwigia parviflora* (WCE of 77-80%). Overall, bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha was effective on all weed groups and at different stages, demonstrating its suitability for integrated weed management in transplanted rice under mixed weed flora and labour-constrained conditions.

Effect on rice

Yield and yield attributing characters of rice (Table 6) exhibited marked variation in response to different weed management treatments. The untreated control consistently recorded the lowest values across all growth parameters. Due to uncontrolled weed competition during the crop’s critical growth stages, which restricted nutrient uptake, reduced tiller formation, and impaired assimilate translocation to the developing panicles. In the absence of weed control measures, intense competition between weeds and rice for essential resources such as light, nutrients, and water led to a significant reduction in rice biomass, plant height, number of tillers, and panicle size, owing to

decreased photosynthate assimilation (Mir *et al.* 2023). In contrast, hand weeding twice resulted in the highest values for most of the rice growth parameters, rice grain and straw yield. Due to vigorous rice vegetative growth in the absence of crop-weed competition. Among the herbicidal treatments, the bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha EPoE recorded higher plant height, panicles/hill, grains/panicle, and grain yield, which was statistically at par with hand weeding twice. The lower number of chaffy grains and higher panicle weight under this treatment reflected the positive effect of sustained weed suppression on grain setting and assimilate allocation towards reproductive organs. The high 1000-seed weight (29.91 g) further indicated improved nutrient availability and better photosynthate partitioning under reduced weed pressure.

Residual effect on succeeding cowpea

The data on the residual influence of herbicides applied in transplanted *Kharif* rice on the emergence, growth, and yield of the succeeding cowpea crop revealed (Table 6) that none of the recorded growth parameters of cowpea were significantly affected by herbicide treatments in rice. Emergence percentage in cowpea ranged from 78.2% under bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 18.75 g/ha) to 84.2% in hand weeding twice, while plant stand varied between 18.2 and 22.2 plants/m². However, the differences were statistically non-significant, indicating that the herbicides used in transplanted rice did not leave any residues affecting seedling emergence or early crop establishment of cowpea.

Table 5. Effect of different weed management treatments on weed control efficiency (%) in transplanted rice (pooled data)

Treatment	<i>Echinochloa crus-galli</i>			<i>Cyperus iria</i>			<i>Ludwigia parviflora</i>			<i>Fimbristylis miliacea</i>			<i>Monochoria vaginalis</i>		
	30	45	60	30	45	60	30	45	60	30	45	60	30	45	60
	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA	DAA
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	12.7	22.3	38.7	73.5	24.2	68.2	76.0	20.4	55.3	18.4	46.4	64.7	17.7	20.4	73.3
Bispyribac-sodium 30 g/ha + pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	85.9	49.2	55.3	82.4	50.6	56.3	82.9	34.7	57.6	59.2	59.6	73.3	73.5	34.7	75.6
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	91.6	80.5	85.3	88.2	72.5	83.8	87.1	58.2	82.8	75.5	78.8	88.2	52.9	53.1	86.7
Bispyribac-sodium 25 g/ha	63.4	61.3	67.3	78.4	54.4	66.3	80.0	40.8	65.5	39.8	60.4	75.1	50.0	28.6	58.9
Pyrazosulfuron 15 g/ha	70.4	67.0	72.3	78.4	61.5	70.3	80.0	49.0	71.4	49.0	67.2	78.1	50.0	40.8	64.4
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	46.5	32.4	42.3	69.1	28.6	43.8	68.6	20.4	38.5	26.5	39.7	50.0	50.0	20.4	30.0
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	55.6	43.6	60.7	73.5	43.9	52.5	72.0	28.6	54.0	38.8	47.6	65.7	73.5	28.6	40.0
Untreated control	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hand weeding twice	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

The values mentioned in parentheses are original; DAA = days after herbicide application

Table 6. Effect of different weed management treatments on growth and yield of transplanted rice and succeeding cowpea (pooled data)

Treatment	Growth and yield of rice									Growth and yield of cowpea			
	Plant height (cm)	No. of panicles/hill	No. of chaffy grains/panicle	No. of grains/panicle	Panicle length (cm)	Panicle weight (g)	1000 seed weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Emergence (%)	Plant stand (no./m ²)	Plant height (cm)	Yield (t/ha)
Bispyribac-sodium 25 g/ha + pyrazosulfuron 18.75 g/ha + surfactant 5 ml/l	63.3	7.9	16.7	108.7	21.2	3.4	24.9	4.51	5.94	78.2	18.2	80.5	1.04
Bispyribac-sodium 30 g/ha + pyrazosulfuron 22.5 g/ha + surfactant 5 ml/l	66.7	9.0	14.7	116.3	23.1	3.6	26.8	5.44	7.04	81.5	20.5	86.2	1.14
Bispyribac-sodium 35 g/ha + pyrazosulfuron 26.25 g/ha + surfactant 5 ml/l	70.9	9.9	12.0	130.7	25.4	4.0	29.9	6.34	8.14	80.8	19.8	88.5	1.20
Bispyribac-sodium 25 g/ha	67.3	8.9	13.7	115.3	23.3	3.7	26.4	5.30	6.84	79.2	18.8	83.8	1.10
Pyrazosulfuron 15 g/ha	68.8	8.7	12.7	116.7	23.8	3.7	26.2	5.54	7.14	82.2	20.8	87.2	1.18
Triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha	69.4	8.6	12.3	118.7	24.3	3.8	25.9	5.24	6.74	80.2	19.2	82.8	1.06
Penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha	68.5	8.9	11.7	117.3	23.5	3.7	26.0	5.40	6.94	78.8	18.5	81.2	1.02
Untreated control	46.4	4.6	28.3	70.3	13.4	2.3	23.3	2.94	3.75	82.8	20.2	83.2	1.08
Hand weeding twice	72.6	10.9	9.3	138.3	26.6	4.2	31.3	6.54	8.34	84.2	22.2	90.2	1.22
LSD(p=0.05)	6.1	0.9	5.5	11.7	2.5	0.5	2.2	5.84	0.76	NS	NS	NS	NS

The values mentioned in parentheses are original

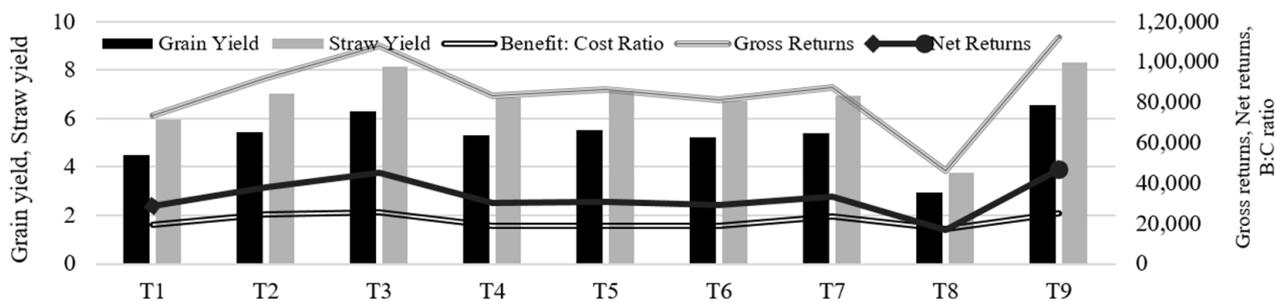


Figure 1. Effect of different weed management treatments on transplanted rice grain yield (t/ha), gross returns (₹/ha), net returns (₹/ha) and B:C ratio.

(T₁: bispyribac-sodium 25 g/ha + pyrazosulfuron-ethyl 18.75 g/ha + surfactant; T₂: bispyribac-sodium 30 g/ha + pyrazosulfuron-ethyl 22.5 g/ha + surfactant; T₃: bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha + surfactant; T₄: bispyribac-sodium 25 g/ha; T₅: pyrazosulfuron-ethyl 15 g/ha; T₆: triafamone 45 g/ha + ethoxysulfuron 22.5 g/ha; T₇: penoxsulam 22.95 g/ha + cyhalofop-butyl 114.75 g/ha; T₈: untreated control; T₉: hand weeding twice)

Plant height of cowpea and grain yield of cowpea followed a similar pattern with non-significant variation among treatments.

The differences were not statistically significant, suggesting that the herbicides used in rice either degraded rapidly under *Kharif* season soil moisture and temperature regimes or persisted at concentrations below phytotoxic thresholds for the succeeding cowpea. This aligns with earlier findings that most ALS-inhibiting herbicides, including bispyribac-sodium and pyrazosulfuron-ethyl, undergo rapid microbial and hydrolytic degradation in flooded rice soils, leaving negligible residues by the time of rabi or summer crop sowing. The overall results clearly demonstrate that the herbicide regimes evaluated for transplanted *Kharif* rice were safe to the succeeding crop cowpea, under the experimental soil and climatic conditions.

Economics

The analysis of weed management treatments in transplanted rice highlighted significant variations in cost-benefit (**Figure 1**). Hand weeding twice incurred the highest cultivation cost (₹ 65,390/ha) and yielded the highest gross returns (₹ 1,12,285/ha) and net returns (₹ 46,895/ha), with a B:C ratio of 2.07. The bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha (pre-mix) had a lower cultivation cost (₹ 63,190/ha) and achieved gross returns of ₹ 1,08,285/ha, net returns of ₹ 45,095/ha with highest B:C ratio of 2.11, demonstrating its profitability. The untreated control demonstrated the lowest economic performance. Thus, effective weed management using effective and economic treatment is essential for maximizing profitability.

It was concluded that bispyribac-sodium 35 g/ha + pyrazosulfuron-ethyl 26.25 g/ha with a silicon-based surfactant EPoE provided effective and economical broad-spectrum control of grasses, sedges, and broad-leaved weeds, with higher rice grain yield comparable to hand weeding twice and without adverse residual effects on the succeeding cowpea.

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