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Performance of Post-emergence Herbicides in Rice-Lentil Cropping Sequence under Coastal Saline Zone of West Bengal

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The transition from puddled transplanted rice to direct-seeded systems in saline-prone coastal areas of West Bengal necessitates strategic weed management measures to ensure crop viability. A field experiment was conducted during the *Kharif* seasons of 2021 and 2022 at Rangabelia, Gosaba Block of South 24 Parganas district, West Bengal (21.92° N latitude and 88.80° E longitude with an elevation 4 m. above mean sea level) to evaluate the efficacy of herbicides in controlling weed flora, enhancing rice yield, herbicidal phyto-toxicity and nutrient uptake pattern for achieving the optimization of dose of these chemicals for sustainable direct seeded rice production and assessing their residual impact on the succeeding lentil crop. The study was laid out in a randomized complete block design with seven treatments including three doses of pyribenzoxim 5% EC (25, 30 and 35 g a.i. ha^{-1}), fenoxaprop-p-ethyl 6.7% EC (56.06 g a.i. ha^{-1}), oxadiargyl 80% WP (100 g a.i. ha^{-1}), weed-free and weedy check plots. Pyribenzoxim 5% EC at 35 g a.i. ha^{-1} was found to be the most cost effective (B:C=1.76) significantly reducing the total weed density (61.81%) and its dry weight (60.71%) at 30 days after application, enabling the rice crop to mine maximum amount of plant nutrients and ultimately resulting in the highest rice yield (3.45 t ha^{-1}). Moreover, no adverse residual effects were observed on succeeding lentil crop, indicating its safety and suitability in a rice-lentil cropping system. Therefore, pyribenzoxim 5% EC at 35 g a.i. ha^{-1} can be recommended as an effective and sustainable herbicide for direct seeded rice (DSR) in the coastal saline ecosystem of West Bengal.

(***Key words:*** *Coastal saline zone (CSZ), Direct seeded rice (DSR), Post-emergence herbicides, Weed indices)*

Rice (*Oryza Sativa* L.), one of the most important poaceous cereal crops of the globe, serves around 70% of the mammoth population of India as a staple food crop. The slogan 'rice is life' is the most appropriate for India as this crop plays a pivotal role in achieving its national food security, sketching agricultural policy and formulating the means of livelihood for millions of rural households. In coastal saline zone (CSZ) of West Bengal, farmers are mostly habituated with rice based mono cropping which accounts for approximately 17% of the state's total rice cultivation area (Banerjee *et al.*, 2018). Especially direct-seeding eliminates the need of raising, maintaining and subsequent transplanting of seedlings. Besides, it is cost effective, can save water through earlier rice crop establishment and allows timely sowing of succeeding crop (Chaudhary *et al.*, 2023). Under such circumstances, cultivation of rice with direct seeding may provide alternatives in sustainable production. However, direct seeding faces more intense weed competition compared to transplanted rice. The high weed pressure in direct-seeded rice (DSR) primarily arises due to absence of water stagnation during crop emergence, which typically suppresses weeds (Rao and Chandrasena, 2024). According to Shekhawat *et al.* (2020), weeds can decrease the grain yield of DSR by as much as 50%. Further, in coastal saline zone weed competition as well as its management are significant constrains in rice production due to natural presence of salt-tolerant and problematic weed species over time. Thus, weed population dynamics and composition in saline ecology differs from that under traditional rice culture. Taking these facts consideration management of weeds to the optimum threshold level we usually go for manual, mechanical or chemical treatments. But now-a-

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days due to shortage of labour and high wages, people are being compelled to shift towards chemical treatment with new broad spectrum post emergence herbicide. But most of the herbicides are weed genera specific. Sometimes some herbicides show phytotoxicity in crops with little higher doses. Thus, introduction of such herbicides having broad-spectrum bio-efficacy, flexibility in time of application with less phytotoxicity on crops is the demand for the day.

Recently, numerous new generation herbicides have been formulated by various agro-chemical houses. Pyribenzoxim (benzophenone O-[2,6-bis[(4,6-dimethoxy-2-pyrimidinyl) oxybenzoyl] oxime) is a board spectrum post-emergence herbicide that tackles the problem of weeds by inhibiting plant amino acid known as ALS (acetolactate synthase) and AHAS (acetohydroxyacid synthase) (Chang *et al.*, 2011). However, its effectiveness still needs to be evaluated. Each herbicide has an optimal dose under specific environmental conditions for successful weed control. Under or overdose of herbicide is not desirable as under dose may be ineffective and may promote weed resistance, while overdose may cause phytotoxicity (Pawar *et al.*, 2017). Keeping these issues under consideration, a field experiment was conducted in coastal saline zone of West Bengal with the objectives of determining the effect of Pyribenzoxim against weed flora in direct seeded rice and its residual effect in succeeding lentil crop.

MATERIALS AND METHODS

The field experimental study was carried out in the farmer's field of Rangabelia, Gosaba Block of West Bengal (21.92° N latitude and 88.80° E longitude with an elevation 4 m above mean sea level) under the CSZ of West Bengal, during *Kharif* season of 2021 and 2022 to study the bio-efficacy of Pyribenzoxim as a post emergence herbicide in direct seeded rice followed by lentil. The topography of the land is of medium low type. The soil having sandy clay in texture was acidic in reaction (pH 5.58), medium in organic carbon (0.51%) and available NPK (470.15, 15.9 and 128.46 kg ha^{-1}, respectively). The experimental plots were laid out in a randomized block design (RBD) with seven treatments consisting of pyribenzoxim 5% EC at 25 g a.i.ha^{-1}; pyribenzoxim 5% EC at 30 g a.i. ha^{-1}; pyribenzoxim 5% EC at 35 g a.i. ha^{-1}; fenoxaprop-p-ethyl 6.7% EC at 56.06 g a.i. ha^{-1}, oxadiagryl 80% WP at 100 g a.i. ha^{-1}, two hand weeding at 15 and 35 DAS and control or weedy check, replicated thrice. The individual plot size was 5 × 5 m. All the herbicides except oxadiagryl 80 % WP (5DAS) were applied at 15 DAS, when both the target weed species were at 2-3 leaf stage. The herbicides were sprayed with knapsack sprayer fitted with flat fan nozzle by dissolving in 300 l water ha^{-1}. Before execution of the present investigation, rice was continuously grown in the previous five years during *Kharif* and in the winter seasons the land was kept fallow. Healthy paddy seeds (cv. IET 4786) soaked for 24 hours in clean water, were treated with *Trichoderma viride* at 4 g kg^{-1} and were dried in shade for 6 hours prior to sowing. In both the years of experiment, seeds were sown on July 26 at 60 kg ha^{-1} at the distance of 20 × 20 cm. The recommended fertilizer dose of 60:30:30 kg ha^{-1} (N: P: K) were applied in three splits-full doses of P, K and 1/3rd N as basal (at sowing time), 1/3rd N at maximum tillering stage and remaining 1/3rd N at panicle initiation stage. The test crop took 115 days for maturity and was harvested on 18 November in both the years of study. After harvesting of rice, lentil (cv. 'Moitree') was sown on November 25 and November 30 and harvested on March 27 and April 5 in 1st and 2nd years of study, respectively. Standard agronomic management practices suitable for CSZ was provided to the succeeding crop. In each plot four permanent quadrates (0.5 m × 0.5 m) were earmarked for recording weed density and biomass. Weed density was measured as the number of weeds per unit area at pre-spray, 15, 30 and 45 days after herbicide application. After counting, the destructed samples were first washed in fresh tap water, then sun-dried and kept in a hot air oven for 48 h at 70°C and weighed. Different weed indices were worked out by using following equations (Banerjee *et al.* 2019; Kundu *et al.*, 2020) respectively

$$WCE = \frac{WDM_c - WDM_T}{WDM_c} \times 100 \quad \text{.... (1)}$$

where, WCE is weed control efficiency; WDM_C is the weed dry matter weight (g m^{-2}) in control plot; WDM_T is the weed dry matter weight (g m^{-2}) in treated plot.

$$\text{Weed Infestation} = \frac{\text{Total number of weeds in unit area}}{\text{Total number of weeds and crop plants in the same area}} \times 100 \quad \text{.... (2)}$$

$$TEI = \frac{Y_T - Y_c}{Y_T} \times \frac{WDM_c}{WDM_T} \quad \text{.... (3)}$$

where TEI is treatment efficiency index; Y_T is crop yield from the treated plot; Y_C is crop yield from the control plot.

$$Wl = \frac{Y_f - Y_T}{Y_f} \times 100 \quad \text{.... (4)}$$

where WI is weed index; Y_f is yield from weed free plot; Y_T is yield from treated plot.

$$Hl = \frac{Economic\ yield}{Biological\ yield} \quad \text{.... (5)}$$

where HI is harvest index

Benefit: cost (B: C) was calculated as follows

$$B{:}C = \frac{Gross\ return}{Total\ cost\ of\ cultivation} \quad \text{.... (6)}$$

Soil samples were collected from different field locations, air-dried, homogenized and sieved (2 mm). Texture was determined using the textural triangle method and mechanical composition (sand, silt and clay) was analyzed by the hydrometer method (Bouyoucos, 1962). Soil pH and EC (1:2.5 soil: water) were measured using a microprocessor based pH-EC-Ion meter (Jackson, 1967). Available N was estimated using the hot alkaline permanganate method (Subbiah and Asija, 1956); available P using 0.5 M $NaHCO_3$ and a UV-VIS spectrophotometer (Olsen *et al.*, 1954); and available K using neutral normal ammonium acetate and flame photometry (Brown and Warncke, 1988). Above-ground biomass (crop and weed) was oven-dried at 60 ± 5°C, ground, and sieved (0.5 mm). Total N, P, and K were determined post-acid digestion (Jackson, 1973) and nutrient uptake was computed on a per-hectare basis (Sunil *et al.*, 2011).

All the collected data was subjected to analysis of variance (ANOVA) according to the techniques defined for simple randomized block design (RBD). The differences between treatment means were tested at the significance level of 5%.

RESULTS AND DISCUSSION

Predominance of weed in DSR

Thirteen weed species were observed in experimental plots during the experimental seasons of 2021 and 2022, amongst them five were grasses, two were sedges and rest belonged to board leaf category. The dominant grassy weeds included *Echinochloa crusgalli* (barnyard grass), *Echinochloa colona* (jungle rice), and *Eleusine indica* (goose grass); the sedges included *Cyperus rotundus* (purple nutsedge) and *Cyperus iria* (flat sedge); and the broadleaf weeds (BLW) were *Ammannia baccifera* (blistering ammannia), *Parthenium hysterophorus* (carrot grass), *Ludwigia octovalvis* (primrose willow) and *Sphenoclea zeylanica* (goose weed). Among these, *Cyperus iria* was the most dominant at 45 days after application (DAA) in the first year, while *Echinochloa colona* was more prevalent in the following year. Banerjee *et al.* (2021) reported that *E. colona* and *C. iria* are the predominant weed species in DSR in CSZ of West Bengal.

Weed density and dry weight

The weed density and dry weight of the total weed population (grasses, broadleaf weeds and sedges) were measured before spraying and at 15, 30 and 45 DAA. Prior to herbicide application, no significant differences in weed density and dry weight were observed across various weed management practices. At 15, 30 and 45 DAA, the weedy check plots exhibited the highest weed density; while the manually weeded plots (hand weeding at 15 and 35 DAS) recorded the lowest weed density and it was closely followed by the plots treated with pyribenzoxim 5% EC at 35 g a.i. ha^{-1}. However, among all herbicidal treatments assessed, the application of pyribenzoxim 5% EC at 35 g a.i. ha^{-1} was found to be the most effective in reducing weed populations compared to the untreated plot, with a decline of 60.68, 57.06 and 56.85% for grasses; 68.59, 64.98 and 66.46% for BLW and 63.36, 63.25, and 64.30% for sedges at 15, 30 and 45 DAA respectively (Table 1). The findings indicate that the application of post-emergence herbicide pyribenzoxim 5% EC at 35 g a.i. ha^{-1} significantly reduces the density of both broadleaved as well as narrow leaved weeds as compared to other post-emergence herbicides evaluated in

Table 1. *Effect of treatments on weed density (count m^{-2}) at pre-spray, 15 DAA, 30 DAA and 45 DAA in direct seeded paddy (mean value of two years)*

Treatments	Pre-Spray			15 DAA			30 DAA			45 DAA		
	Grasses (count m^{-2})	Broad leaf weeds (count m^{-2})	Sedges (count m^{-2})	Grasses (count m^{-2})	Broad leaf weeds (count m^{-2})	Sedges (count m^{-2})	Grasses (count m^{-2})	Broad leaf weeds (count m^{-2})	Sedges (count m^{-2})	Grasses (count m^{-2})	Broad leaf weeds (count m^{-2})	Sedges (count m^{-2})
Pyribenzoxim 5% EC at 25 g a.i. ha^{-1}	5.50* (2.55) #	20.33 (4.61)	8.33 (3.05)	2.67 (1.91)	9.33 (3.21)	7.67 (2.94)	3.83 (2.19)	12.83 (3.71)	11.17 (3.47)	4.83 (2.41)	16.33 (4.15)	13.17 (3.75)
Pyribenzoxim 5% EC at 30 g a.i. ha^{-1}	5.52 (2.56)	19.98 (4.58)	8.83 (3.13)	0.83 (1.35)	2.99 (1.97)	4.00 (2.23)	1.50 (1.58)	5.17 (2.48)	6.50 (2.73)	2.00 (1.73)	6.17 (2.67)	7.50 (2.91)
Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}	5.56 (2.56)	20.81 (4.68)	9.03 (3.16)	0.67 (1.27)	1.67 (1.63)	2.83 (1.96)	1.33 (1.52)	3.67 (2.15)	3.50 (2.12)	1.67 (1.63)	4.00 (2.22)	4.00 (2.22)
Fenoxaprop -p -ethyl 6.7% EC @ 56.06 g a.i. ha^{-1}	5.33 (2.51)	20.60 (4.64)	8.67 (3.10)	1.00 (1.41)	25.83 (5.18)	22.17 (4.81)	2.00 (1.73)	34.17 (5.93)	32.00 (5.73)	2.50 (1.87)	39.83 (6.39)	37.17 (6.16)
Oxadiargyl 80%WP @ 100 g a.i. ha^{-1}	5.33 (2.51)	20.64 (4.65)	9.01 (3.16)	2.67 (1.91)	6.83 (2.79)	6.83 (2.79)	4.83 (2.41)	13.17 (3.76)	11.17 (3.48)	5.83 (2.61)	15.17 (4.02)	12.83 (3.71)
Hand Weeding at 15 and 35 DAS	5.33 (2.51)	20.51 (4.64)	8.45 (3.07)	0.33 (1.15)	1.00 (1.41)	2.00 (1.73)	0.83 (1.35)	1.83 (1.67)	2.83 (1.95)	1.33 (1.53)	2.83 (1.95)	3.00 (2.00)
Weedy check (Untreated)	5.50 (2.55)	20.91 (4.68)	9.17 (3.19)	9.50 (3.23)	26.00 (5.19)	27.67 (5.35)	11.67 (3.54)	36.67 (6.14)	32.50 (5.77)	14.00 (3.87)	42.83 (6.62)	37.83 (6.22)
LSD ($p \leq 0.05$)	NS	NS	NS	0.06	0.09	0.10	0.07	0.11	0.11	0.08	0.13	0.12

*DAA: Days after application, *Mean of 3 replications; #Figures in the parenthesis are square root transformed values (sq. root of x+1)*

Table 2. *Effect of treatments on weed dry weight (g m^{-2}) at pre-spray, 15 DAA, 30 DAA and 45 DAA in direct seeded paddy (mean value of two years)*

Treatments	Pre-Spray			15 DAA			30 DAA			45 DAA		
	Grasses (g m^{-2})	Broad leaf weeds (g m^{-2})	Sedges (g m^{-2})	Grasses (g m^{-2})	Broad leaf weeds (g m^{-2})	Sedges (g m^{-2})	Grasses (g m^{-2})	Broad leaf weeds (g m^{-2})	Sedges (g m^{-2})	Grasses (g m^{-2})	Broad leaf weeds (g m^{-2})	Sedges (g m^{-2})
Pyribenzoxim 5% EC at 25 g a.i. ha^{-1}	1.49* (1.57) #	6.41 (2.72)	1.23 (1.49)	1.51 (1.58)	5.79 (2.60)	2.84 (1.95)	3.95 (2.22)	11.22 (3.48)	7.71 (2.94)	9.89 (3.30)	34.12 (5.90)	13.43 (3.78)
Pyribenzoxim 5% EC at 30 g a.i. ha^{-1}	1.61 (1.61)	6.59 (2.74)	1.26 (1.50)	0.51 (1.23)	1.86 (1.67)	1.48 (1.57)	1.80 (1.67)	4.67 (2.35)	4.49 (2.31)	5.16 (2.46)	18.65 (4.43)	7.65 (2.88)
Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}	1.64 (1.62)	6.40 (2.71)	1.26 (1.50)	0.28 (1.13)	1.03 (1.41)	1.05 (1.43)	1.48 (1.56)	3.19 (2.04)	2.42 (1.85)	4.06 (2.22)	14.85 (3.96)	4.08 (2.25)
Fenoxaprop -p-ethyl 6.7%EC @ 56.06 g a.i. ha^{-1}	1.53 (1.59)	6.16 (2.68)	1.15 (1.46)	0.58 (1.26)	16.02 (4.12)	8.20 (3.01)	1.98 (1.72)	29.73 (5.54)	22.08 (4.79)	7.60 (2.91)	89.09 (9.50)	29.24 (5.50)
Oxadiargyl 80%WP @ 100 g a.i. ha^{-1}	1.44 (1.56)	6.50 (2.73)	1.19 (1.48)	1.27 (1.50)	4.24 (2.28)	2.53 (1.87)	4.78 (2.39)	11.15 (3.48)	7.71 (2.95)	11.26 (3.49)	28.42 (5.40)	13.09 (3.75)
Hand Weeding at 15 and 35 DAS	1.42 (1.55)	6.63 (2.75)	1.27 (1.51)	0.13 (1.06)	0.62 (1.27)	0.74 (1.32)	0.81 (1.34)	1.59 (1.58)	1.96 (1.69)	2.57 (1.89)	10.25 (3.30)	3.06 (1.97)
Weedy check (Untreated)	1.66 (1.62)	6.74 (2.78)	1.33 (1.52)	5.35 (2.51)	16.12 (4.14)	10.24 (3.35)	11.72 (3.55)	31.90 (5.73)	22.43 (4.83)	27.02 (5.26)	89.48 (9.51)	30.09 (5.57)
LSD ($p \leq 0.05$)	NS	NS	NS	0.05	0.08	0.06	0.07	0.11	0.10	0.11	0.19	0.11

*DAA: Days after application, *Mean of 3 replications; #Figures in the parenthesis are square root transformed values (sq. root of x+1)*

the study. This outcome corroborates the findings of Soni *et al.* (2020). A similar trend was observed with weed dry weight, where hand weeding at 15 and 30 DAS resulted in the greatest reduction across all weed categories and this treatment was followed by the application of pyribenzoxim 5% EC at 35 g a.i. ha^{-1}. Throughout the investigation, the weedy check plot consistently recorded the highest biomass across all categories of weed flora in comparison to the other treatments. However, among the herbicidal treatments, the plot treated with pyribenzoxim 5% EC at 35 g a.i. ha^{-1} exhibited a pronounced suppressive effect on weed dry weight as compared to the untreated plot, achieving reductions of 54.98, 56.05, and 57.79% for grasses; 65.94, 64.39 and 58.65% for broadleaf weeds and 57.31, 61.69, and 59.60% for sedges at 15, 30 and 45 DAA, respectively (Table 2). Jain (2017) also reported a significantly lower total weed dry weight in plots treated with pyribenzoxim compared to the untreated control plots. The data indicate that broadleaf weeds accumulated the highest dry weight followed by sedges and grasses at 15, 30 and 45 DAA (Table 2). The plot treated with another post emergence herbicide fenoxaprop-p-ethyl 6.7% EC at 56.06 g a.i. ha^{-1} also exhibited better control of grassy weed in DSR by reducing their population and biomass production at 15, 30 and 45 DAA but it was not effective against board leaf weeds (Soni *et al.*, 2020).

Weed control efficiency (WCE)

Data in Table 3 revealed that hand weeding (twice at 15 and 35 DAS) was the most efficient technique regardless of weed species and growth stages in direct seeded rice, whereas, the lowest efficiency was observed in the weedy check as no weed control measures were implemented. WCEs were recorded at 15, 30 and 45 DAS and it was found that among the herbicides, pyribenzoxim 5% EC at 35 g a.i. ha^{-1} performed the best WCE (%) against grasses, sedges and board leaf weeds (Table 3). Former researchers also established that application of post emergence herbicide pyribenzoxim recorded the highest weed control efficiency (Ma *et al.*, 2014; Soni *et al.*, 2020). Fenoxaprop-p-ethyl 6.7% EC at 56.06 g a.i. ha^{-1} was effective in controlling grassy weeds than pyribenzoxim 5% EC at 25 g a.i. ha^{-1} during the entire crop growth period. The leaves and stems of grassy weeds rapidly absorb the active ingredient of fenoxaprop-p-ethyl. Biochemically, it primarily inhibits fatty acid synthesis in the meristematic tissues of grassy weeds (Bakkali *et al.*, 2007).

Weed Indices

The weed infestation index refers to the percentage of weeds within the composite population of both weed and crop plants. Data presented in table 3 indicates that among the plots receiving herbicidal treatments, the plot treated with pyribenzoxim 5% EC at 35 g a.i. ha^{-1} recorded the lowest weed infestation index (12.87%) which further confirming the superior efficacy of this treatment against the weed flora. The higher infestation index in the weedy check plot was due to the omission of weed control measures. The Treatment Efficiency Index (TEI) is a comprehensive parameter that reflects both the weed-suppressive potential of a given treatment and its associated phytotoxic effects on the crop. As shown in Table 3, the highest Treatment Efficiency Index (TEI = 2.67) among the herbicidal treatments was recorded with the highest dose of Pyribenzoxim. In contrast, apart from the weedy check plot, the lowest Treatment Efficiency Index (TEI = 0.21) was observed in the plot treated with Fenoxaprop-p-ethyl 6.7% EC at 56.06 g a.i. ha^{-1}. From the crop productivity perspective, Pyribenzoxim 5% EC at 35 g a.i. ha^{-1} resulted in the lowest weed index (3.08), signifying the most substantial yield escalating over the untreated control. Previously, Soni *et al.* (2020) also reported that the application of pyribenzoxim demonstrated superior performance compared to other herbicides in rice ecosystems with respect to weed indices.

Yield attributes and yield of direct seeded rice and cost effectiveness of herbicides

The yield components of direct seeded rice varied significantly with different weed management practices (Table 4). During maturity, the highest number of grains per panicle (150.3) was achieved under hand-weeding treatment, followed by the maximum dose of pyribenzoxim 5% EC (138.6). The application of herbicides as compared to manual hand weeding did not have a significant effect on the test weight of paddy and the results were statistically insignificant, as reflected in Table 4. As a genetic trait, test weight was not notably

Table 3. *Effect of treatments on Weed Control Efficiency (WCE), Weed Infestation Index (WII), Weed Index (WI) and Treatment Efficiency Index (TEI) in direct seeded paddy (mean value of two years)*

Treatments	WCE (%)									WII (%)			WI (%)	TEI (%)
	15 DAA			30 DAA			45 DAA							
	Grasses	Sedges	Broad leaf weeds	Grasses	Sedges	Broad leaf weeds	Grasses	Sedges	Broad leaf weeds	15 DAA	30 DAA	45 DAA		
Pyribenzoxim 5% EC at 25 g a.i. ha^{-1}	71.8	72.3	64.8	66.3	65.6	64.1	63.4	55.4	61.9	36.64	43.54	63.33	30.05	0.51
Pyribenzoxim 5% EC at 30 g a.i. ha^{-1}	90.5	85.5	85.4	84.6	80.0	88.5	80.9	74.6	79.2	18.27	28.26	46.96	10.39	1.77
Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}	94.8	89.8	90.0	87.3	89.2	93.6	85.0	86.4	83.4	12.87	19.04	40.0	3.08	2.67
Fenoxaprop–p–ethyl 6.7% EC @ 56.06 g a.i. ha^{-1}	89.2	19.9	6.8	83.1	1.5	0.6	71.9	2.8	0.4	58.33	67.32	78.12	31.74	0.21
Oxadiargyl 80%WP @ 100 g a.i. ha^{-1}	76.2	75.3	65.0	59.2	65.6	73.7	58.3	56.5	68.2	32.44	46.77	60.46	28.37	0.61
Hand Weeding at 15 and 35 DAS	97.6	92.8	95.0	93.1	91.3	96.2	90.5	89.8	88.5	9.86	12.82	31.25	0	4.06
Weedy check (Untreated)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.0	69.56	80.66	44.66	0

DAA: Days after application; WCE: Weed control efficiency; WII: Weed infestation index; WI: Weed index; TEI: Treatment efficiency index

Table 4. *Yield attributes, yield and benefit-cost ratio of DSR as influenced by different weed control practices (mean value of two years)*

Treatments	No. of grains per panicle	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest Index	B:C ratio
Pyribenzoxim 5% EC at 25 g a.i. ha^{-1}	111.60	19.13	2.49	3.93	38.78	1.29
Pyribenzoxim 5% EC at 30 g a.i. ha^{-1}	135.30	19.45	3.19	4.43	41.86	1.63
Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}	138.60	19.55	3.45	4.59	42.91	1.76
Fenoxaprop−p−ethyl 6.7% EC @ 56.06 g a.i. ha^{-1}	110.30	19.06	2.43	3.84	38.75	1.31
Oxadiargyl 80%WP @ 100 g a.i. ha^{-1}	128.40	19.46	2.55	4.04	38.69	1.24
Hand Weeding at 15 and 35 DAS	150.30	19.58	3.56	4.84	42.30	1.41
Weedy check (Untreated)	109.20	19.00	1.97	3.50	36.01	1.03
LSD ($p \leq 0.05$)	4.76	NS	0.11	0.16	1.47	0.05

Table 5. *Effect of herbicides on succeeding crop lentil after direct seeded rice (mean value of two years)*

Treatments	Yield and yield components					
	Plant m^{-2}	Branches $plant^{-1}$	Pods $branch^{-1}$	Seeds pod^{-1}	Test weight (g)	Seed yield (kg ha^{-1})
Pyribenzoxim 5% EC at 25 g a.i. ha^{-1}	39.45	17.30	19.00	2.60	32.13	729.20
Pyribenzoxim 5% EC at 30 g a.i. ha^{-1}	40.55	17.35	19.10	2.59	32.07	726.60
Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}	40.85	17.65	19.25	2.60	31.83	733.30
Fenoxaprop – p –ethyl 6.7% EC @ 56.06 g a.i. ha^{-1}	39.60	17.30	18.95	2.61	31.23	730.40
Oxadiargyl 80%WP @ 100 g a.i. ha^{-1}	39.20	17.60	18.80	2.59	32.30	725.30
Hand Weeding at 15 and 35 DAS	40.00	17.90	20.25	2.65	31.40	735.00
Weedy check (Untreated)	38.60	16.85	18.91	2.55	31.03	725.10
LSD ($p \leq 0.05$)	NS	NS	NS	NS	NS	NS

influenced by herbicidal treatments. Expect weed-free check, all herbicide-treated plots yielded significantly more ($p \leq 0.05$) than the non-treated control. Varied weed management practices led to significant variations in grain yield of rice var. Shatabdi, ranging from 1.97 to 3.56 t ha^{-1}; with yield increases of 23.35 to 80.71% compared to the control (Table 4). Among the herbicidal treatments, the higher dose of pyribenzoxim 5% EC at 35 g a.i. ha^{-1} resulted in a significant higher grain yield (3.45 t ha^{-1}) and this dose was followed by pyribenzoxim 5% EC 30 g a.i. ha^{-1} dose. Although these two treatments were statistically different from each other. However, the grain yield (3.56 t ha^{-1}) recorded in the weed-free plot (hand weeded at 15 and 35 DAS) did not differ significantly from that obtained with the highest pyribenzoxim dose. In contrast, the minimum grain yield (1.97 t ha^{-1}) was observed in the weedy check plot. A similar trend was observed in the straw yield and harvest index of direct-seeded rice. Regarding cost-effectiveness of herbicides, it may be opined that Pyribenzoxim 5% EC exhibited the highest benefit-cost (B:C) ratio of 1.76 which reflecting its superior economic efficiency among the evaluated treatments. A negative correlation ($r^2 = 0.912$) was found between weed dry matter at 45 DAA and rice grain yield (Fig. 1). These findings highlight poor competitiveness of rice against weeds and underscore the need for effective weed control during the early growth stages. The promising results of the present study indicate that herbicide application is highly effective, less labour-intensive and strategically superior to manual weeding. By ensuring timely and effective suppression of weed biomass during the critical crop-weed competition period, herbicide treatment contributed to enhanced yield performance. This improvement can be attributed to reduced weed density and improved soil physical conditions resulting from minimal soil disturbance. In addition, herbicide use significantly lowered labour requirements, offering a clear economic advantage over manual weeding, particularly in the context of rising labour costs and limited rural workforce availability. Overall, herbicide-based weed management supports the goals of sustainable intensification by enhancing productivity, reducing input demands and improving

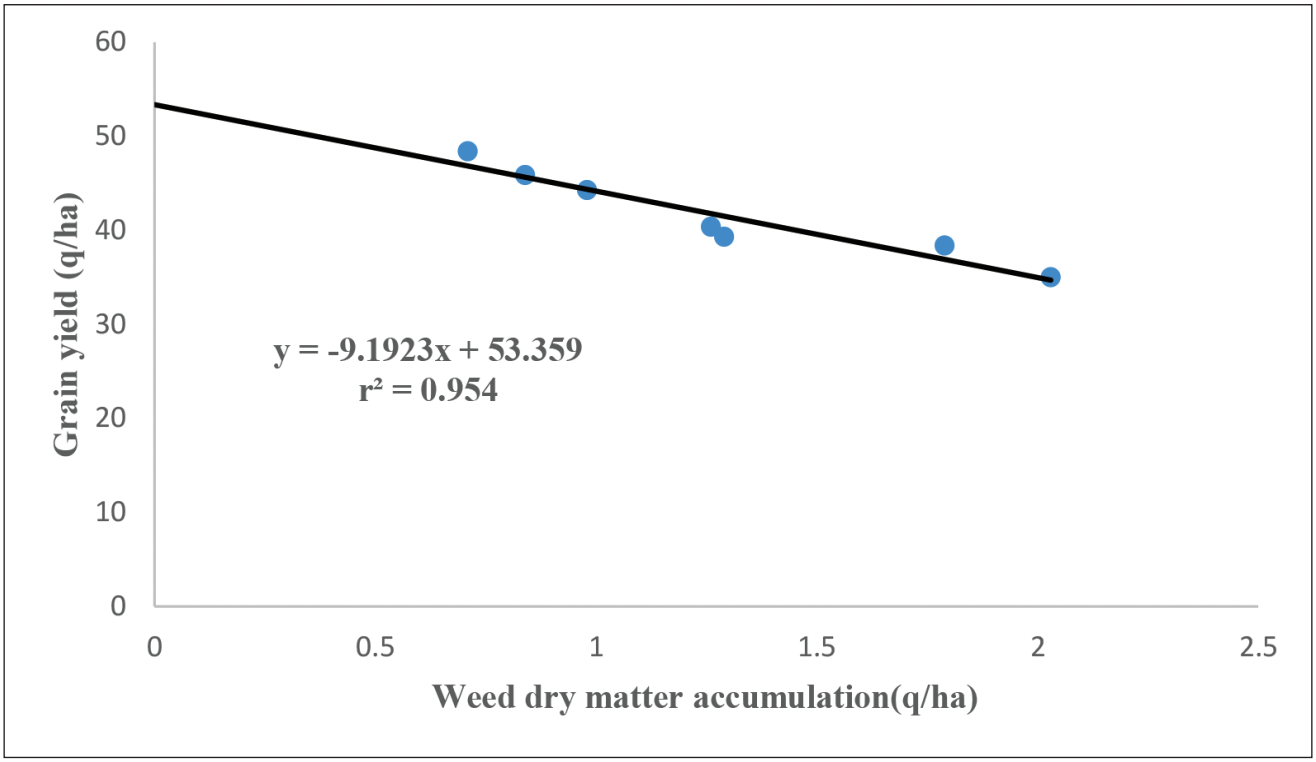


Fig.1. *Relationship between weed dry matter accumulation and grain yield*

the resilience of rice production systems under variable climatic conditions.

Nutrient uptake by rice

Plant nutrient uptake by direct-seeded rice exhibited an inverse relationship with nutrient uptake by weeds. All weed control treatments were significantly more effective than the weedy check in enhancing NPK uptake by rice at 45 days after application (DAA) of herbicides (Fig. 2). Among the primary nutrients, the highest total uptake was recorded under the treatment T_7 (two hand weeding at 20 and 40 days after sowing) 78.91 kg ha^{-1} N, 17.81 kg ha^{-1} P and 101.38 kg ha^{-1} K. This was followed by the treatment with Pyribenzoxim 5% EC at 35 g a.i. ha^{-1}, demonstrating considerable nutrient uptake, showing resemblance in trend of escalation in rice grain and straw yield. The crop treated with a higher dose of Pyribenzoxim resulted in NPK uptake of 68.75, 14.80 and 96.75 kg ha^{-1}, respectively out performing other herbicidal treatments. This improvement can be attributed to enhanced weed suppression achieved through a combination of chemical and manual methods, which effectively reduced crop-weed competition and improved nutrient availability and absorption by the rice plants. Moreover, nutrient uptake was influenced by both nutrient concentrations in the plant dry matter and the total dry matter accumulation.

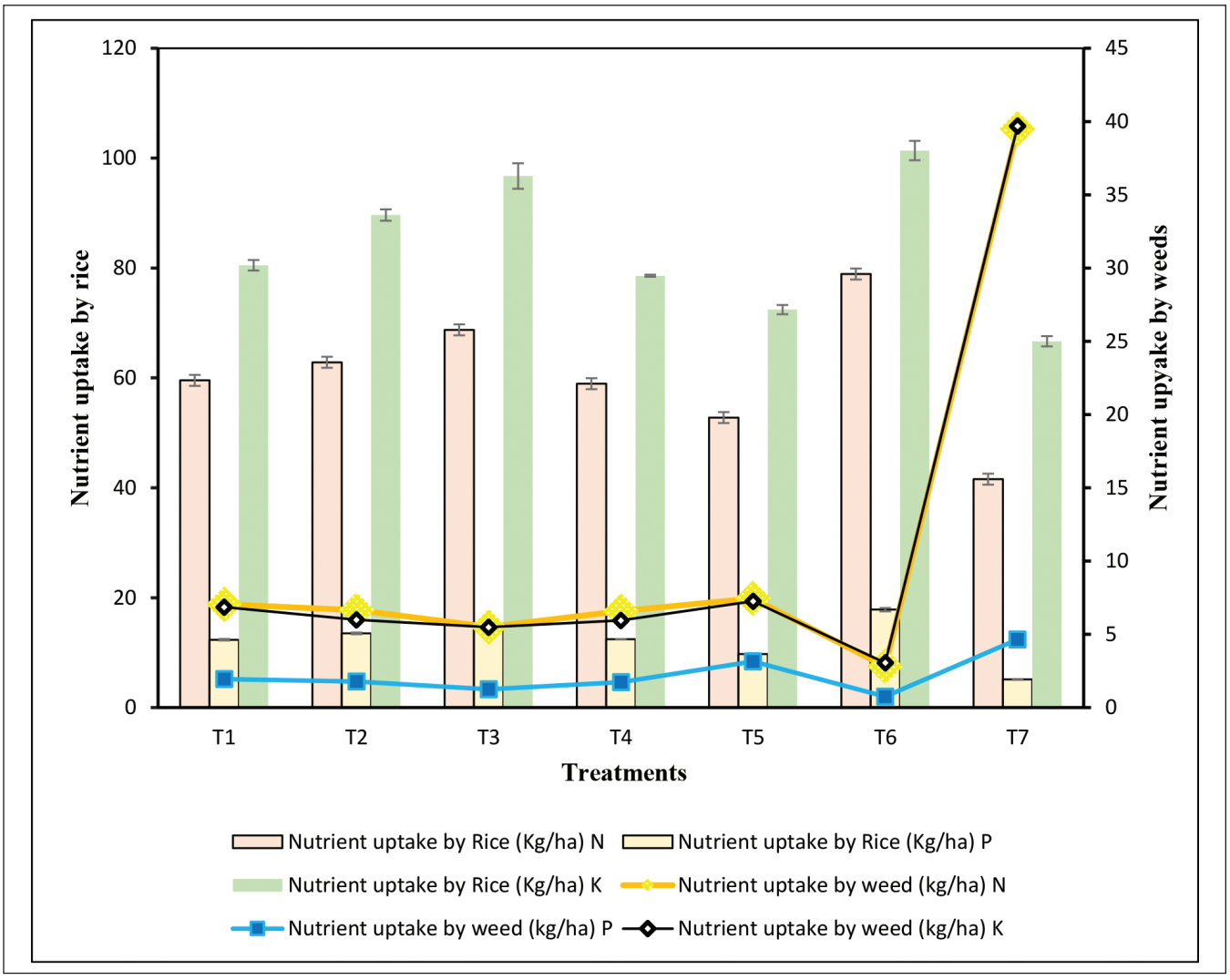


Fig.2. *Nutrient uptake (kg ha^{-1}) by rice (column) and weed (line) as affected by weed control treatments at the time of rice harvesting (mean value of two years)*

The lowest NPK uptake was observed in the weedy check, likely due to severe competition between the crop and weeds for available nutrients. These findings are consistent with those reported by Chakraborti *et al.* (2017).

Nutrient removal by weeds

The uptake of nitrogen, phosphorus, and potassium by weeds followed a pattern similar to that of weed biomass accumulation. Consequently, minimal nutrient removal was observed in the hand-weeded plot (T_6 treatment), whereas, the highest uptake of major nutrients occurred in the weedy check (Fig. 2). Owing to its effective weed control, the application of Pyribenzoxim 5% EC at 35 g a.i. ha^{-1} resulted in the lowest removal of N (5.50 kg ha^{-1}), phosphorus (1.25 kg ha^{-1}), and potassium (5.48 kg ha^{-1}). As an efficient herbicide, pyribenzoxim substantially reduced nutrient removal by weeds in this study. These findings are in agreement with those reported by Jaiswal *et al.* (2023).

Effect of herbicides on phytotoxicity

No phytotoxic symptoms such as epinasty/ hyponasty, leaf yellowing, necrosis, stunting growth, wilting, etc., were observed in rice as well as succeeding lentil crop during both the year of experiment.

Effect on succeeding crop

The residual effect of pyribenzoxim applied in the previous rice crop was assessed on the succeeding lentil crop by evaluating various growth and yield parameters, including population density, number of branches per plant, pods per branch, seeds per pod, test weight and final yield (Table 5). The recorded data revealed no significant variation among the treatments applied to the preceding rice crop. So, it clearly indicates that pyribenzoxim residues had no adverse effect on the growth and productivity of lentil crop.

CONCLUSION

So, from the above study, it may be concluded that Pyribenzoxim 5% EC at 35 g a.i. ha^{-1} can profitably and safely be used to replace the tedious, time consuming and expensive hand weeding practice for weed control in direct seeded rice under coastal saline zone of West Bengal. The results reinforce the importance of judicious post-emergence herbicide selection as an integral component of integrated weed management (IWM) strategies, particularly in stress-prone environments like coastal saline ecosystems, where timely and effective weed control is vital for stabilizing yields and minimizing production costs.

CONFLICTS OF INTEREST

Authors did not have any conflicts of interest for the publication of this research output.

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