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RESEARCH ARTICLE

Efficacy of pre- and post-emergence herbicides in managing weeds and improving productivity of rice under new alluvial zone

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ABSTRACT

An experiment was conducted during two consecutive *Kharif* seasons of 2020 and 2021 at Kalyani D- Block Research Farm, BCKV, Mohanpur, West Bengal, India. The objective was to study the efficacy of pre- and post-emergence herbicides in managing weeds and improve grain yield of transplanted rice. The dominant grassy weeds in fields were: *Echinochloa colona*, *Cynodon dactylon, Panicum repens;* broad-leaved weeds were: *Ludwigia parviflora*, *Malva neglecta, Eclipta alba* and *Alternanthera philoxeroides* and sedges were: *Cyrus iria and Fimbristylis miliacea*. Pre-emergence application (PE) of pretilachlor 50 % EC (pretilachlor) 0.70 kg/ha followed by (*fb*) passing of conoweeder and sequential application of pretilachlor 0.70 kg/ha PE *fb* post-emergence application (PoE) of bispyribac-Na 10% SC (bispyribac-Na) 25 g/ha were highly effective in providing effective weed control with greater productivity and profitability. The sequential application of pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE provided broad-spectrum weed management, higher crop productivity, and profitability in transplanted rice without any tracible residues in the rice grain and in the soil after harvest.

Keywords: Bispyribac-Na; Conoweeder, Pretilachlor, Productivity, Transplanted rice, Weed management

INTRODUCTION

Rice, a staple food for more than half of the world's population, is grown in more than100 countries with 90% of the total global production from Asia. In India, 44 million hectares (M ha) area is under rice cultivation, with 124 million tonne (MT) production, which shares 21.5% of world rice production (DES 2024). India is largely self-sufficient in rice production, but to sustain self-sufficiency by 2050 and feed a projected population of 1.64 billion people, 197.4 MT of rice will be needed. An additional challenge is that the extra rice will be produced with a lower environmental footprint with limited resources (*i.e.,* land, labour, water, agrochemicals, *etc*.) (Ahmad *et al.* 2021). Biotic and abiotic stresses are a major concern in the modern-day input-intensive agricultural production system as they cause serious economic losses. Among biotic stresses, weeds are major biological constraints and cause a 37% yield loss (Mishra *et al.* 2021). If weeds are not properly controlled, they capture distinctive amount of nutrients, which result in significant loss of yield and economic returns. Weeds were reported to remove approximately 367.8, 220.0 and 291.0% of N, P and K from rice field (Raj and Syriac 2017). Because of weed competition with rice for moisture, nutrients, light and space, about 50.4–80.0% reduction in grain yield was reported (Mahajan and Chauhan 2015, Parthipan and Ravi 2016) with reduced benefit cost ratio by 60.7% (Riaz *et al.* 2018). Puddle-transplanted rice has several advantages, including the retention of a thin layer of water, prevention of percolation losses, the suppression of weeds, and supply of nutrients (Choudhary *et al.* 2021). Rice crop is heavily infested with annual grasses, broad-leaved weeds, and sedges, posing a challenge to weed management (Choudhary and Dixit 2018). Manual weeding is suggested as the best weed management method, but frequent rains, labour shortages, and high labour wages make it challenging, time-consuming, and uneconomical, especially during the critical period of weed competition (Choudhary and Dixit 2018).

Herbicides are an effective alternative weed management strategy at this situation as they require less labour and have the potential to provide useful weed control while reducing labour and production costs (Rao *et al.* 2017). Non-selective herbicides

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have been used prior to crop establishment to control annual and biennial weeds; however, they are less effective for complete weed removal for entire life cycle (Carretta *et al.* 2021). Pre-emergence (PE) herbicides can effectively control weeds during the initial stages of crop growth, while post-emergence (PoE) herbicides are best used for killing the later emerging weeds. Maintaining desired water levels after herbicide application can enhance their efficacy (Kaur *et al.* 2016). Control of complex weed flora through a single pre- or post-emergence herbicide application is a very challenging task, and it is likely that the use of the same herbicides over a prolonged period may contribute to herbicide resistance in weeds (Kim 1996). Applying several herbicides which have different active ingredients is to be encouraged for broad-spectrum weed control. The sequential application of pre-followed by post-emergence herbicides in rice has proved to be effective in controlling weed flora well without yield penalty (Ramesha *et al.* 2017, Zahan *et al.* 2018). At the same time, applying different herbicides in combination may reduce herbicide resistance (Mahajan and Chauhan 2015). Transplanting is facilitated by the application of herbicides, including pre-emergence herbicides options like pendimethalin, oxadiazon, oxadiargyl, pretilachlor, and post-emergence herbicides such as cyhalofop–butyl, bispyribac-sodium, penoxsulam, fenoxaprop, azimsulfuron, 2,4-D, metsulfuron-methyl, triafamone + ethoxysulfuron (Mishra *et al.* 2016, Arthanari 2023). However, the optimal time window for herbicide application, tailored to specific crop environments, remains crucial for effective weed suppression. Against this backdrop, a field experiment was conducted at the research farm of BCKV, Kalyani, to evaluate the response of rice and associated weed flora to new herbicides under transplanted conditions in a subtropical ecological setting. The objective of the experiment was to study the efficacy of pre- and post-emergence herbicides in managing weeds and improving productivity of rice under new alluvial zone. This study aims to contribute valuable insights into the sustainable management of weeds in transplanted rice, offering practical solutions for enhancing productivity in rice cultivation systems.

MATERIALS AND METHODS

A field study was carried out during *Kharif*, 2020 and 2021 at the research farm of BCKV, Kalyani (18.1243° N latitude, 84.5447° E longitude with an average altitude of 257 meters above mean sea level), India. The study site experienced an average annual rainfall of 1150 mm, with 85% received during the south-west monsoon. The region has a subtropical climate with hot summers and a mean minimum temperature of 22.7°C in January, while May is the hottest month with a mean maximum temperature of 43°C. The soil was of Arang Series with a clay loam texture containing 32.8% clay, 21.7% silt and 45.5% sand. The soil had a neutral pH of 6.8-7.2 and medium soil organic carbon content of 0.46%. The study was conducted with rice variety '*IET 4786*', (Shatabdi) at a spacing of 20 × 10 cm. The tested treatments were: oxadiargyl 80% WP (oxadiargyl) 0.1 kg/ha followed by (*fb*) post-emergence application (PoE) of 2,4-D 0.5 kg/ha 25 days after transplanting (DAT); pretilachlor 0.70 kg/ha PE; pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 10% SC (bispyribac-Na) 25 g/ha PoE at 25 DAT; pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 5.1% + penoxsulam 1.02% OD ready mix (RM) (cyhalofop-butyl + penoxsulam) 112.5 + 22.5 g/ha PoE at 25 DAT ; oxadiargyl 0.1 kg/ha *fb* passing of conoweeder; pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder; pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0 + 22.5 g/ha PoE at 25 DAT; hand weeding twice at 20 and 40 DAT and weedy check. A randomized complete block design with four replications was used. The gross plot size was 5 m × 4 m. Herbicide application was done using a knapsack sprayer equipped with a flat fan nozzle using a spray volume of 500 L/ha. The crop was fertilized with 80: 40: 40 kg N, P and K/ha through urea (N) and muriate of potash (K), where the full dose of P and K fertilizers were applied at the time of transplanting. Nitrogen was applied in three splits at before transplanting, 30 and 60 DAT. Weed parameters (weed density and biomass) were recorded using quadrats, measuring 0.25 m^2 (0.5 m × 0.5 m dimension), placed at three random places in each of the plot at 60 DAT. Weeds of different groups were identified, counted and cut at collar portion of the plants and placed them separately in brown bags for sun drying for 3–5 days. After drying off the excess moisture, these paper bags were placed in an oven at 70±2°C for 72 hours until the weed samples attained a constant weight, which was considered the biomass of the respective weed species. The mean of both quadrats was converted into numbers/m^2 (weed density) and g/m^2(weed biomass), for analysis and interpretation. The weed control efficiency was calculated from total weed biomass. To homogenize the variance, a square root ($\sqrt{x+0.5}$) transformation was performed to the weed data (weed density and biomass). Yield attributes, including the number of panicles/m^2, the number of grains/ panicles, and the 1,000-grain weight (g) at harvest, were recorded from ten randomly chosen hills within each treatment. Data pertaining to grain yield and straw yield were recorded on per plot basis in kilograms. The entire plot was systematically harvested, dried, and weighed, with the recorded figures subsequently converted into metric tons per hectare (t/ha) to facilitate the comparative analyses. The influence of herbicides on yield was evaluated utilizing the following formulae.

$$\text{YOC}(\%) = \frac{\text{Yield from treated plot} - \text{yield from weedy check plot}}{\text{yield from weedy check plot}} \times 100$$

$$\text{RYL}(\%) = \frac{\text{Yield from weed free plot} - \text{yield from treatment plot}}{\text{yield from weed free plot}} \times 100$$

Where,

YOC = Yield over check

RYL = Relative yield loss

Statistical analysis of all field data was conducted using SAS statistical software (version 9.3). The Tukey's Honest Significant Difference test was selected, and analysis of variance (ANOVA) was performed to determine the level of significance (p=0.05) between treatment means. As the effect of year was not that significant in most of the cases, results were presented as pooled data of two years.

RESULTS AND DISCUSSION

Weed flora

Ten distinct weed species, categorized into grasses, broad-leaved weeds (BLW), and sedges, were identified. *Cynodon dactylon* weed exhibited varying occurrences across different herbicide treatments, with noteworthy contributions to the total weed population (**Table 1**). *Cynodon dactylon* was recorded in plots treated with oxadiargyl 0.1 kg/ha PE *fb* passing of conoweeder, pretilachlor 0.70 kg/ha PE, and pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl + penoxsulam (RM) 112.5 + 22.5 g/ha PoE, with respective contributions of 27.30%, 23.9% and 19.93% of the total weed density. The presence of *Panicum repens* was significantly affected by herbicide applications. The combination of pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder resulted in the lower density of *Panicum repens*. The distribution of *P. repens* in the order of decreasing density in response to post-emergence herbicide application was: pretilachlor PE *fb* triafamone + ethoxysulfuron PoE > pretilachlor PE *fb* cyhalofop-butyl + penoxsulam PE > pretilachlor PE *fb* bispyribac-Na PoE > hand weeding twice at 20 and 40 DAT, with percentage shares of 31.25%, 28.69%, 36.19%, and 30.33%, respectively. *Ludwigia parviflora* was observed only with oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE (1.97 no./m^2) and weedy check (6.74 no./m^2). *Eclipta alba* dominated the overall weed flora, with the highest density in non-treated weedy check plots, followed by oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE, pretilachlor 0.70 kg/ha, and hand weeding twice at 20 and 40 DAT. The treatments with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder and pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0 + 22.5 g/ha PoE recorded the lowest density of *Eclipta alba.* Rishi *et al.* (2016) observed that the sequential application of pendimethalin PE *fb* bispyribac-sodium PoE significantly reduced the *Eclipta alba*, *Echinochloa colona* density as compared to single application of pendimethalin PE, butachlor PE and oxydiargyl PE, ethoxysulfuron PoE and bispyribac-sodium PoE and weedy check at 30 and 90 DAT stage of rice respectively. Similar results were reported by Singh *et al.* (2016).

The density of *Cyprus iria* was highest in weedy check, followed by pretilachlor 0.70 kg/ha PE, hand weeding twice at 20 and 40 DAT, and pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl + penoxsulam 112.5 + 22.5 g/ha PoE. Maximum biomass of *Echinochloa colona* was in the weedy check, followed by pretilachlor 0.70 kg/ha PE. However, pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder resulted in best control of *Echinochloa colona*. *Malva neglecta* density was least with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder, while highest with oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE. *Fimbristylis miliacea* was observed only with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder and its highest density was found in weedy check, among all other treatments. Reductions in the density of grasses like *Echinochloa* spp. was previously observed with pretilachlor widely across South Asia (Hossain *et al.* 2020, Chatterjee *et al.* 2021, Rao *et al.* 2007, Singh *et al.* 2015). Most of the pre-emergence herbicides lack efficacy against sedge weeds, particularly on those which multiply through rhizomes and stolon rather than by cell division; thus, the pre-emergence herbicides tested here were less effective against sedges (Rao *et al.* 2007, Singh *et al.* 2015, Hossain *et al.* 2020, Chatterjee *et al.* 2021)

Pre-emergence herbicides alone were not effective at preventing the establishment of weeds at later dates due to their relatively short-lived persistence under hot and moist conditions (Saha et al. 2021). Post-emergence herbicides, the bispyribac alone or bispyribac + pyrazosulfuron not only controlled both grassy and broad-leaved weed well but also effectively controlled sedges, particularly *Cyrus iria* which is a major sedge weed in the region (Jat *et al.* 2021, Saha *et al.* 2021). Similarly, Mitra *et al.* (2022) also reported the maximum biomass reduction of all weeds at both 35 and 55 DAT with the sequential application of pendimethalin PE fb bispyribac + pyrazosulfuron PoE.

Weed control

In the experimental fields, a diverse weed flora was observed across various treatments, and the total weed population dynamics were influenced by different weed management strategies (**Table 2**). In comparison to the weedy check, the treatments tested exhibited lower densities of grasses, BLW, and sedges. Notably, treatments with pretilachlor were predominantly infested by grassy weeds, while BLW weeds dominated the weed flora in other treatments. Plots treated with pendimethalin followed by 2,4-D were primarily infested with sedges. Strikingly, the application of pretilachlor followed by bispyribac sodium resulted in the lowest density of grasses and sedges, while a few grasses at 60 DAT were observed with triafamone+ ethoxysulfuron, but complete control was achieved as the days from sowing progressed. Notably, the herbicide treatments involving triafamone+ ethoxysulfuron PoE and pretilachlor followed by bispyribac-sodium demonstrated superior efficacy in controlling a majority of weed species. Triafamone+ ethoxysulfuron herbicide is acetolactate synthase (ALS) inhibitors working on the principle of halting the flow of assimilate supply to sink thereby inhibiting weed growth (Aranthari *et al.* 2023). Furthermore, the advantages associated with triamafone + ethoxysulfuron can be accounted for its greater availability encompassing both foliar and root pathways. *Ammania* spp. and *Eclipta* spp., although in limited numbers, were the only weed species observed with triafamone+ethoxysulfuron. This observation can be potentially attributed to its greater phenotypic plasticity and persistent seed bank encouraging multiple-year germination (Caton *et al.* 1997). Pretilachlor *fb* bispyribac-sodium demonstrated efficacy due to the mode of action of pretilachlor involves inhibiting the biosynthesis of fatty acids in the target weeds. Pretilachlor works by preventing the target plants from synthesizing very long chain fatty acids. Grassy weeds in rice crops are the main target of pretilachlor, a herbicide belonging to the chloroacetamide group. Pretilachlor is absorbed by the roots or absorbed via the leaves of plants when it is applied to their soil or foliage, and it is subsequently transferred throughout the plant. Once within the plant, pretilachlor prevents the Acetyl-CoA carboxylase enzyme, which is responsible for fatty acid production. Pretilachlor interferes with the synthesis of vital fatty acids required for the target plants' growth and development by blocking ACCase. Plants cannot build

Table 1. Effect of herbicide on the density of different weeds in transplanted rice at 60 DAT (two years pooled data)

Treatment	Weed density (no./ m^2)									
	Grasses			Broad-leaved weeds					Sedges	
	Cynodon dactylon	*Echinochloa colona*	*Panicum repens*	*Ludwigia parviflora*	*Alternanthera philoxeroides*	*Malva neglecta*	*Eclipta alba*	Other BLW	*Cyrus iria*	*Fimbristylis miliacea*
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	1.99 (3.48)	2.71 (6.82)	2.46 (5.55)	1.57 (1.97)	1.78 (2.66)	2.32 (4.86)	2.50 (5.77)	2.27 (4.65)	1.83 (2.84)	1.57 (1.96)
Pretilachlor 0.70 kg/ha PE	2.14 (4.07)	3.03 (8.70)	3.85 (7.65)	1.53 (1.85)	1.81 (2.78)	2.25 (4.55)	2.48 (5.63)	2.34 (4.99)	1.96 (3.36)	1.65 (2.23)
Pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE	1.74 (2.54)	2.22 (4.41)	2.11 (3.96)	1.14 (0.79)	1.23 (1.00)	1.77 (2.64)	2.27 (4.65)	2.09 (3.88)	1.57 (1.95)	1.32 (1.23)
Pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 112.5 + 22.5 g/ha (RM) PoE	2.01 (3.53)	2.49 (5.68)	2.05 (3.71)	1.44 (1.56)	1.48 (1.7)	2.16 (4.17)	2.41 (5.31)	2.24 (4.5)	1.77 (2.63)	1.49 (1.72)
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	2.16 (4.18)	2.75 (7.04)	2.59 (6.20)	1.54 (1.86)	1.91 (3.15)	2.18 (4.23)	2.46 (5.55)	2.34 (4.99)	1.87 (2.99)	1.61 (2.10)
Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder	1.58 (1.98)	2.04 (3.67)	1.89 (3.06)	1.14 (0.81)	1.14 (0.80)	1.40 (1.45)	2.07 (3.80)	1.73 (2.48)	1.51 (1.78)	1.26 (1.09)
Pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5 g/ha) PoE	1.81 (2.78)	2.38 (5.15)	2.03 (3.61)	1.32 (1.23)	1.34 (1.30)	2.03 (3.61)	2.24 (4.51)	2.16 (4.14)	1.63 (2.16)	1.36 (1.34)
Hand weeding twice at 20 and 40 DAS	2.02 (3.57)	2.66 (6.55)	2.20 (4.32)	1.56 (1.92)	1.72 (2.47)	2.22 (4.45)	2.48 (5.63)	2.22 (4.42)	1.78 (2.67)	1.54 (1.86)
Weedy check (control)	3.19 (9.67)	4.89 (23.45)	4.58 (20.47)	2.69 (6.74)	2.97 (8.32)	3.21 (9.82)	3.96 (15.18)	4.25 (17.54)	2.69 (6.76)	2.23 (4.45)
LSD (p=0.05)	0.30	0.77	0.69	0.14	0.21	0.31	0.5	0.41	0.28	0.19

PE = pre-emergence application; PoE = post emergence application; DAT = days ater transplanting vital cell membranes and other lipid-containing structures if they do not have a sufficient supply of fatty acids, which inhibits growth and ultimately results in death (Shilpakar *et al.* 2020). After that bispyribac-sodium consists in the inhibition of the branched amino acid biosynthesis. This substance exhibits a favourable eco-toxicological profile, effectively disrupting the growth of various weed species across multiple cycles. Our findings regarding pretilachlor *fb* bispyribac-sodium align with Chaudhury and Dixit (2024), indicating its greater effectiveness against *Echinochloa crusgalli* when applied at 25 DAT. However, triafamone+ ethoxysulfuron and pretilachlor treatments exhibited good result in the control of grasses and sedges as observed earlier by Yadav *et al.* (2019). Additionally, the sequential application of pretilachlor *fb* 2,4-D demonstrated effective control of BLW. Jehangir *et al.* (2022) also highlighted the effectiveness of penoxsulam against both grasses and sedges up to 60 DAT.

Among the herbicide-based treatments, pretilachlor 0.70 kg/ha *fb* passing of conoweeder reduced grasses by 90.34%, broad-leaved weeds by 92.87%, sedges by 81.54% and total weed by 88.68%. Next effective treatments were pretilachlor PE *fb* bispyribac-sodium PoE (89.34, 87.23, 80.61 and 86.28%, respectively) and pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0+22.5/ha PoE over the weedy check. Suppression of weeds reduced the total weed biomass, resulting in a higher WCE in the sequential application of PE *fb* PoE herbicides. The sole application of pretilachlor was also weak as it controlled only 21-34%, 15-19% and 7-13% of grasses, BLW and sedges, respectively. Thus, using only pre- or post-emergence herbicides is not efficient enough to provide broad-spectrum weed control. Sequential use of pre-emergence herbicides such as pretilachlor followed by post-emergence herbicide (bispyribac-sodium) broadly controls mixtures of weed flora in transplanted rice. This is because broad-leaved weeds, sedges and some grasses were effectively controlled by bispyribac-sodium, whereas pretilachlor takes care of grasses and some broad-leaved weeds. Subsequent applications of bispyribac-sodium control the large group of weeds left after PE herbicide or late emerged weeds. Applications of PE herbicides significantly suppress initial weed establishment, and subsequently, bispyribac-sodium 25 g/ha takes care of the weeds at a later crop stage. Similarly, application of PE and PoE herbicides in sequence or compatible tank mix or premix herbicides with different mode of action is superior to weedy check in controlling weeds (**Tables 1** and **2**).

Weed Indices

The weed biomass was significantly influenced by weed control treatments (**Table 2**). The highest weed biomass was recorded in weedy plots, whereas hand weeding twice at 20 and 40 DAT recorded the minimum. Among the herbicides, pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder followed by pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE and triafamone+ ethoxysulfuron PoE treatments recorded significantly lower weed biomass at 60 DAT. The performance of pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE was also better than the herbicides applied alone. Pretilachlor and oxadiargyl alone were less effective than the other herbicides, but all the herbicides were better than weedy check during both the years.

Table 2. Effect of herbicides on the weed density and biomass and rice growth parameters in transplanted rice at 60 DAT (two years pooled data)

Treatment	Weed density (no./ m^2)	Weed biomass (g/ m^2)	WCE (%)	WI (%)	Rice plant Height (cm)	Rice plant dry matter accumulation (g/m^2)
Oxadiargyl 0.1 kg/ha PE *fb* 2,4-D 0.5 kg/ha PoE	4.04(15.86)	3.68(13.07)	76.3	22.42	100.57	621.50
Pretilachlor 0.70 kg/ha as PE	4.57(20.42)	4.15(16.71)	68.81	27.66	98.655	595.90
Pretilachlor 0.70 kg/ha as PE *fb* bispyribac-Na 25 g/ha as PoE	3.38(10.94)	2.82(7.47)	86.74	4.45	108.48	676.05
Pretilachlor 0.70 kg/ha as PE *fb* cyhalofop-butyl 112.5 + 22.5 g/ha (RM) as PoE	3.66(12.93)	3.36(10.80)	80.31	15.58	103.20	706.68
Oxadiargyl 0.1 kg/ha as PE *fb* passing of conoweeder	4.23(17.42)	3.93(14.94)	72.67	25.44	99.05	618.56
Pretilachlor 0.70 kg/ha as PE *fb* passing of conoweeder	3.04(8.72)	2.64(6.47)	88.68	0.00	112.11	683.92
Pretilachlor 0.70 kg/ha as PE *fb* triafamone + ethoxysulfuron 44.0 + 22.5 g/ha PoE	3.47(11.55)	3.16(9.50)	82.86	10.33	104.98	667.34
Hand weeding twice at 20 and 40 DAS	3.87(14.44)	3.55(12.12)	78.13	18.76	102.19	686.87
Weedy check (control)	7.36(53.6)	7.48(55.45)	0	54.21	86.91	525.34
LSD (p=0.05)	1.88	2.03	-	-	6.47	47.89

PE = pre-emergence application; PoE = post emergence application; DAT = days ater transplanting

The weed control efficiency was largely depended on weed biomass but influenced largely by weed control treatments (**Table 2**). The highest weed control efficiency was obtained with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder (88.68%) and it was closely followed by pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron 44.0+22.5 g/ha PoE (82.86%) and pretilachlor 0.70 kg/ha *fb* bispyribac-Na 25 g/ha (86.74%). These treatments were comparable to each other. This is contrary to the results of Meera and Menon (2019) who noticed the highest weed control efficiency with triafamone + ethoxysulfuron. Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder recorded the lowest WCE at 60 DAT (68.81%). Moreover, the observed increase in WCE at later stages of the crop may be attributed to the canopy closure, resulting in a smothering effect on weed growth. The better weed control was recorded due to timely sowing of crop and herbicide application, which are prerequisite to obtain the better efficacy. Herbicide combinations widen the spectrum of weed control (Singh and Singh 2012). Pre-mix of triafamone + ethoxysulfuron increased broad spectrum weed control (grasses, BLW and sedges). Notably, WCE tended to increase as the crop approached maturity. Among herbicides, pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder recorded the least WI value of (4.27) and a higher rice plant height and rice plant dry matter accumulation (**Table 2**).

The observed weed density and biomass indicated that pretilachlor effectively controlled grasses and to some extent BLW, but its efficacy was poor on sedges. Bispyribac-Na 25 g/ha PoE resulted in lesser BLW and sedges than the grasses. The pre-mix of triafamone + ethoxysulfuron had additive effect on controlling wide range of weeds and effective against grasses, broad-leaved weeds and sedges confirming earlier findings (Mahajan and Chauhan 2013). The broad-spectrum nature of triafamone, coupled with its diverse mechanisms of availability through foliage and soil residue activity might have contributed to its effective weed management (Rosinger *et al.* 2012). Arthanari (2023) also observed the higher WCE with triafamone + ethoxysulfuron PoE. The lower values of WI value associated with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder, indicate its broad-spectrum weed control efficacy confirming observations of Sen *et al.* (2020) and Meena *et al.* (2019).

Rice yield and yield attributes

Weed control treatments exerted a significant impact on rice yield attributes and grain yield. In comparison to the weedy check, all other treatments demonstrated higher rice yield attributes and grain yield. Specifically, pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder produced the highest panicle length (2.92 cm), grains/panicle (138.14), and 1,000-grain weight (22.08 g), closely followed by pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE (**Table 3**).

Weed-free yielded the highest rice grain yield, but was not significantly different from grain yield with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder. These treatments were statistically at par with rice grain yield recorded with pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE 25 DAT and pretilachlor 0.70 kg/ha PE *fb* triafamone + ethoxysulfuron (44.0 + 22.5 g/ha) PoE. This notable increase in grain yield can be attributed to the effective mitigation of weed competition by pre-emergence herbicides during the early stages. This early intervention curtailed weed growth during the initial growth phase of the crop. Furthermore, the subsequent application of post-emergent (PoE) measures further controlled subsequent flushes of weed emergence, thereby ensuring comprehensive weed management throughout the entire crop cycle. This combined PE and PoE approach collectively contributed to the improved crop growth conditions, ultimately leading to enhanced grain yield. The rice grain yield increase ranged from 61.20% to 123.64% with pretilachlor

Table 3. Effect of herbicides on rice growth parameters and rice yield in transplanted rice (two years pooled data)

Treatment	Rice grain yield (t/ha)	YOC (%)	RYL (%)	Panicle length (cm)	No. of grains/ panicle	1000 seed weight (g)
Oxadiargyl 0.1 kg/ha *fb* 2,4-D 0.5 kg/ha PoE	4.84	72.24	23.08	24.47	126.64	19.39
Pretilachlor 0.70 kg/ha PE	4.53	61.20	28.14	22.32	116.43	18.14
Pretilachlor 0.70 kg/ha as PE *fb* bispyribac-Na 25 g/ha as PoE	6.02	114.23	4.29	28.09	135.42	21.31
Pretilachlor 0.70 kg/ha PE *fb* cyhalofop-butyl 112.5 + 22.5 g/ha (RM) PoE	5.32	89.32	15.57	25.27	133.02	19.90
Oxadiargyl 0.1 kg/ha PE *fb* passing of conoweeder	4.61	64.05	26.91	23.81	122.28	19.10
Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder	6.29	123.84	0	28.92	138.14	22.08
Pretilachlor 0.70 kg/ha PE *fb* triafamone+ ethoxysulfuron (44.0+22.5) PoE	5.62	100	10.72	26.49	134.52	21.02
Hand weeding twice at 20 and 40 DAS	5.11	81.85	18.71	25.02	130.08	19.95
Weedy check (control)	2.81	0	55.47	21.20	103.26	16.49
LSD (p=0.05)	0.16	-	-	0.73	9.71	0.79

PE = pre-emergence; PoE = post-emergence; DAT = days ater transplanting; YOC = yield over check; RYL = relative yield loss

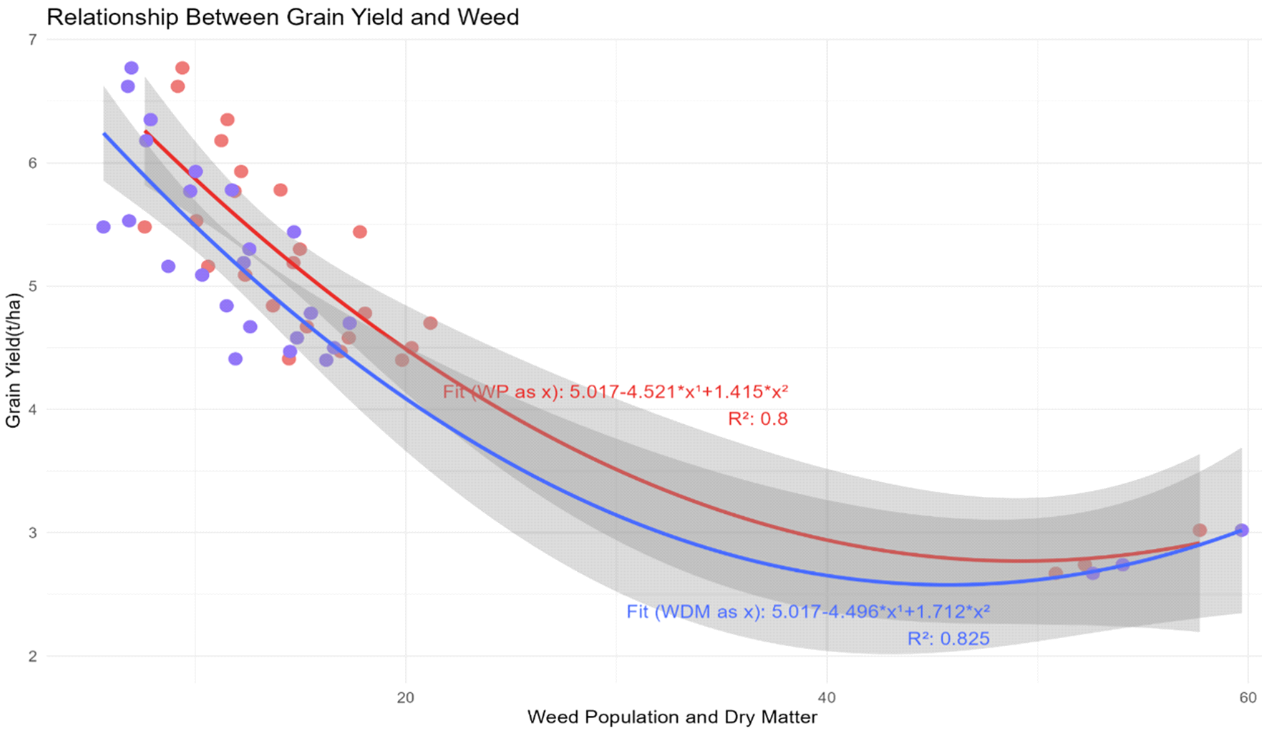

Figure 1. Relationship between grain yield and weed parameters

0.70 kg/ha PE *fb* passing of conoweeder and pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE. Similar increase was observed earlier by Kaur and Singh (2015), Singh *et al.* (2016), Saha *et al.* (2021) and Mitra *et al.* (2022). The recorded minimum grain yield was observed in the weedy control due to the unweeded weeds competition for essential resources (Choudhary *et al.* 2021).

The rice yield reduction due to weed interference ranged from 1% to 58.39% (**Table 3**) across the treatments tested with maximum yield loss of 58.39% in weedy check. Pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder recorded lower yield loss of 1% followed by pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha PoE with 4.29% yield loss due to uncontrolled weeds. Grain yield exhibits a negative correlation with weed density and biomass. To capture this relationship, a second order polynomial model was employed to describe the variation of grain yield concerning changes in weed density and dry weight. The model yielded an R-squared value of 0.8 and 0.825 (**Figure 1**).

Conclusions

It may be concluded that in transplanted rice grown at the new alluvial zone of West Bengal, the effective weed management and increased rice yield can be obtained with pretilachlor 0.70 kg/ha PE *fb* bispyribac-Na 25 g/ha as PoE or with pretilachlor 0.70 kg/ha PE *fb* passing of conoweeder.

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