Plant Archives Vol. 26, Supplement 1, 2026 pp. 810-815 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.107

PERFORMANCE OF POST-EMERGENCE HERBICIDES ON GROWTH, YIELD AND PRODUCTION ECONOMICS OF *BORO* RICE (*ORYZA SATIVA* L.)

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(Date of Receiving : 14-09-2025; Date of Acceptance : 09-11-2025)

ABSTRACT

The effect of post-emergence herbicides on growth, yield and production economics of *boro* rice was evaluated in the New Alluvial Zone of West Bengal during the *boro* seasons of 2021-2022 and 2022-2023. The result revealed that the twice hand-weeding treatment had the highest crop growth parameters (plant height, leaf area index, dry matter accumulation, and crop growth rate), yield attributes (panicles/m2 and filled grain per panicle), grain yield (4.86 t/ha in 2021-22, 5.02 t/ha in 2022-23), straw yield (6.90 t/ha in 2021-22, 7.19 t/ha in 2022-23) and net return (Rs. 46031/ha in 2021-22 and Rs. 54125/ha in 2022-23), followed by quinchlorac 35% SC @ 244.76 a.i. g/ha. The lowest crop growth parameters, yield, yield attributes and net return were observed for the weedy check. But so far, the benefit-cost ratio was concerned, the highest was observed for quinchlorac @ 244.76 a.i. g/ha treatment (1.99 in 2021-22 and 2.14 in 2022-23), followed by quinchlorac @209.79 a.i. g/ha and quinchlorac @174.83 a.i. g/ha. The twice hand-weeded treatment had the lowest benefit-cost ratio (1.83 in 2021-22 and 1.98 in 2022-23) than the three herbicidal treatments and this was due to the unavailability of labours in the peak season and the highest cost associated with it. Thus, considering the crop growth and yield parameters along with the production economics, the result suggested that quinchlorac with the dose 244.76 a.i. g/ha was the most efficient and cost-effective strategy for controlling weeds and enhancing productivity in *boro* rice.
Keywords: Herbicides, New alluvial zone, Rice, Weeds, West Bengal.

Introduction

India is the second-largest producer of rice in the world after China, contributing approximately 24% to the global rice production (FAO, 2023). Within the country, rice occupies about 43.79 million hectares, accounting for over one-third of the total cropped area (Government of India, 2023). The eastern region of India, including states like West Bengal, Bihar, Odisha, and Assam, serves as the rice bowl of the nation. Among the different rice-growing seasons, *boro rice* cultivated during the dry winter season with irrigation has gained increasing importance, especially in eastern India. West Bengal is the leading producer of *boro* rice, accounting for nearly 55% of its total *boro* rice area and contributing significantly to the state's overall rice output (Government of West Bengal, 2022). The *boro* season provides an opportunity to intensify rice cultivation, enhance productivity, and stabilize food grain supply. However, weed infestation possess a major challenge to *boro* rice productivity (Bhattacharyya *et al*., 2018). In *boro rice*, unchecked weed competition can lead to substantial yield losses ranging from 30% to 60%, depending on the intensity and type of weed flora, crop variety, and management practices (Rao *et al*., 2007; Chinnusamy & Singh, 2014). In West Bengal, where *boro* rice is extensively grown under irrigated conditions, yield losses of 40–55% due to weed competition have been reported in the absence of timely weed control (Mondal *et al*., 2016). *Echinochloa crusgalli* and *Cyperus difformis* are the most predominant and highly competitive weeds in transplanted rice ecosystem (Arthanari *et al*., 2017). In India, manual hand weeding remains the most commonly adopted practice among farmers, primarily due to its perceived safety, effectiveness, and reliance on family labour (Chinnusamy & Singh, 2014). However, this method is increasingly becoming less viable due to rising labour costs, acute labour shortages during peak agricultural seasons, and the time-intensive nature of the practice (Rao *et al.*, 2007).

To address these challenges, chemical weed control using herbicides has gained popularity as a more time and cost-efficient alternative. The use of selective herbicides, either singly or in combination, enables early-stage weed suppression, improved crop establishment, and reduced crop-weed competition (Bhattacharyya *et al.*, 2018). Despite their proven effectiveness, the indiscriminate, improper and repetitive use of same herbicides can lead to negative consequences, such as reduced crop productivity, increased cost of cultivation, development of herbicide-resistant weed biotypes, phytotoxicity and accumulation of residues in soil and harvested produce (Yaduraju, 2001; Singh *et al.*, 2020). The use of the same herbicides year after year is hence, not prescribed. Therefore, farmers need herbicides having high efficiency and no phyto-toxicity to rice. Against this backdrop, a field experiment was conducted during the *boro* seasons of 2021–22 and 2022–23 to evaluate the efficacy of post-emergent herbicides on weed flora and crop performance in transplanted rice using the variety IET 4786 (Satabdi), in comparison to manual hand-weeding.

Materials and Method

Two years of field study was conducted during the *boro* seasons of 2021–22 and 2022–23 in the new alluvial zone of Nadia, West Bengal (22°56' N latitude, 86°48' E longitude, and 9.75 m above mean sea level). The soil of the experimental site was sandy clay loam, pH (6.7) with 0.60% (medium) organic carbon and available N, P_2O_5 and K_2O was 196.91(low), 27.58 (medium), 169.17 (medium) kg/ha, respectively. The seeds (50 kg/ha) of rice variety, *Satabdi* (120 days duration) were sown at 20 cm × 15 cm during both the years. The crop was subjected to 120:60:60 kg/ha of N, P_2O_5 and K_2O, where P_2O_5 and K_2O applied at basal and N at three splits (25% as basal, 50% at 21 DAT and 25% at 21 DAT). The experimental design employed in this experiment was randomized block design consisting of seven treatments, replicated thrice. Each plot is of size 4m x 3 m, defined by bunds that were 0.5 m wide and 0.2 m high. Between the blocks, an irrigation channel with a 1 m width was created to provide drainage as well as irrigation. From transplanting to maximum tillering stage, a shallow water depth of 2-3 cm was maintained. The depth of the water was thereafter increased to 5 cm up to flowering stage. Then the depth of irrigation was decreased gradually and ultimately at 10 days. The herbicide was sprayed at 15 DAT using knapsack sprayer on the experimental plot. The treatment details are presented in Table 1.

Table 1: Treatment details

Treatment No.	Treatments	Dosage of herbicide Formulated dose (ml ha^{-1})
T_1	Quinchlorac 35 % SC @ 174.83 g a.i. ha^{-1}	500
T_2	Quinchlorac 35 % SC @ 209.79 g a.i. ha^{-1}	600
T_3	Quinchlorac 35 % SC @ 244.76 g a.i. ha^{-1}	700
T_4	Standard Bispyribac Sodium 10% SC @ 25 g a.i. ha^{-1}	250
T_5	Quinchlorac 35 % SC @ 489.51 g a.i. ha^{-1}	1400
T_6	Hand weeding twice at 20 and 40 DAT	
T_7	Weedy Check	

The biometric observations for plant height, leaf area index, and dry matter accumulation were noted at 30,60 and 90 DAT. Crop Growth Rate (CGR) at 30-60 DAT and 60-90 DAT were calculated using the formula (Watson, 1952):

$$CGR = \frac{W_2 - W_1}{T_2 - T_1}$$

(W_1 = Crop dry weight per unit area at T_1 time W_2 = Crop dry weight per unit area at T_2 time, $T_2 - T_1$ = Time interval in days)

At 30, 60 and 90 DAT, from each plot, 3 hills were selected and total leaf areas of each hill were measured using Leaf Area Meter (model: Systronics Leaf Area Meter 211) in cm^2. The average leaf area was recorded and divided with the plant spacing to obtain the LAI.

$$LAI = \frac{\text{Total leaf area of plants on given area (cm}^2\text{)}}{\text{Ground Area (cm}^2\text{)}}$$

The harvest index can be calculated by using the following formula (Donald, 1968):

$$\text{Harvest index (\%)} = \frac{\text{Economic (grain) yield}}{\text{Biological (grain + straw) yield}}$$

The data were statistically analysed using "Analysis of variance test". The critical difference at 5% level of significance was calculated to find out the significance of different treatments over each other (Panse and Sukhatme, 1989).

Result and Discussion

Weed count: In both the seasons**, t**he highest weed population (grassy, sedge and broad-leaf weeds) was in weedy check (T_7) and the lowest in twice hand-weeded treatment (T_6), followed by T_5 and T_3 at 30, 60 and 90 DAT as presented in Table 2. The manual weeding can effectively control weed population, followed by the increased dose of herbicide application. The same result was also reported by Arthanari *et al*. (2017).

Plant height and Leaf Area Index (LAI): The plant height of rice was increased progressively up to 90 DAT, but leaf area index was declined 60 DAT onwards due to the senescence of leaves in all treatments. Plant height and leaf area index were varied significantly among different weed control treatments at all observations (Table 3), except the non-significant effect on plant height was observed at early stage (30 DAT) in 2021-22. The tallest plants were recorded in twice hand-weeding treatment followed by T_3 and the shortest plants in weedy check. Also, T_3 was statistically at par with hand-weeded treatment (twice) at 30 DAT in 2022-23 and at 60, 90 DAT in both the seasons.

Similarly, the maximum LAI was obtained in twice hand-weeded treatment and the minimum values in weedy check in all observations. Among the herbicidal treatments, T_3 showed higher LAI, which was statistically at par with twice hand weeding at 30 and 60 DAT. Also, T_2 and T_1 were statistically at par with each other at 30, 60 and 90 DAT. The taller plants and greater LAI in hand weeding treatment might be due to the lower population and growth of weeds, leading to more availability of growth resources like nutrients, moisture and solar radiation to the plants, which in turn enhanced cell division and cell enlargement in meristematic region. The results were in congruity with the findings of Singh *et al*. (2004) and Anusha *et al*. (2016).

Dry matter accumulation: Weedy check treatment recorded the lowest dry matter accumulation whereas the hand-weeding treatment registered the highest dry matter at 30, 60 and 90 DAT (Table. 4). Among different herbicidal treatments, T_3 showed the highest dry matter accumulation and the lowest in T_5. At 30 and 60 DAT, T_2 and T_1 were statistically at par with each other. In transplanted rice, the critical period for crop-weed competition is generally between 20 to 40 DAT (Mukherjee *et al.,* 2008), therefore, hand weeding twice during the critical period reduced the weed growth and the crop-weed competition, which resulted in the increased plant height, LAI and CO_2 assimilation, leading to more production of dry matter.

Crop growth rate (CGR): It was calculated at an interval of 30 days from 30-60 DAT and from 60-90 DAT (Table. 4). Irrespective of the treatments, it was seen that the CGR at the vegetative stages (30-60 DAT) was comparatively higher than the reproductive stage (60-90 DAT), which indicated the faster rate of dry matter production during tillering stage. The highest and lowest CGR was obtained in hand-weeded treatment and weedy check respectively. Among different herbicidal treatments, T_3 had the highest CGR during these intervals. The faster crop growth rate in hand weeded treatment indicated the effective utilization of the growth resources and higher production of dry matter due to the less crop-weed competition than other treatments.

Yield, yield attributes and harvest index: The number of panicles per m², filled grains per panicle, and test weight were significantly higher in twice hand-weeding, likely due to reduced weed competition and improved nutrient uptake, followed by T_3 (Table. 5). The lowest number of panicles was observed in weedy check. However, test weight was not significantly influenced by weed control measures, as it is largely governed by genetic factors. This in line with (Singh *et al*., 2004). Likewise, the increased panicles per square metre and filled grains per panicle with the increasing doses of quinchlorac were also reported by Reddy *et al*. (2006) and Bahar *et al*. (2013). Grain and straw yields were also highest in twice hand-weeding (Table 5), followed by T_3 while the lowest yields were recorded in weedy check, and followed by T_5. The harvest index (HI) ranged from 34.73% to 40.98%, with the highest value in twice hand-weeding, indicating more efficient translocation of assimilates under low weed density. These findings align with those of Chandra *et al*. (2003), Kumar *et al*. (2017) and Dey *et al*. (2020). The lowest HI in the weedy check.

Production economics: The production economics under different weed control methods are presented (Table. 6). Among the treatments, twice hand-weeding showed the maximum cost of cultivation, gross return and net return but comparatively the lower benefit: cost ratio due to high cost of labours. Among all treatments, the highest benefit: cost ratio was recorded in T_3 and the lowest in weedy check, which indicated the importance of weed control measures in *boro* rice cultivation. The higher gross return and BCR owing to the control of rice weeds by quinchlorac was achieved by Reddy *et al*. (2006).

Conclusion

From the experiment, it can be concluded that the hand weeding twice at 20 and 40 DAT can effectively control all types of weeds and recorded highest grain and straw yield followed by the quinchlorac treatment having dose 489.51 g a.i. ha-[1] (T_5). But, due to high cost and unavailability of the labours the twice hand-weeding treatment had lower benefit-cost ratio (B:C ratio) than T_3 treatment, quinchlorac (244.76 a.i. g/ha). On the other hand, the treatment T_5 with high quinchlorac dose had effectively control weeds but lowest in grain and straw yield after weedy check. Therefore, the study concludes that quinchlorac @ 244.76 a.i. g/ha applied at 15 DAT can be recommended for *boro* rice for better yield and profitability

Table 2: Effect of weed control methods on grassy, sedge and broad-leaf weed density

Treat-ments	Weed density (no. m^{-2})																	
	Grassy weed density						Sedge weed density						Broad-leaf weed density					
	30 DAT		60 DAT		90 DAT		30 DAT		60 DAT		90 DAT		30 DAT		60 DAT		90 DAT	
	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23
T_1	2.03 (3.62)	2.18 (4.25)	4.71 (21.68)	4.78 (22.35)	6.86 (46.56)	5.92 (34.55)	3.34 (10.66)	2.89 (7.85)	6.09 (36.59)	5.24 (26.96)	7.27 (52.30)	6.54 (42.27)	2.03 (3.62)	1.88 (3.03)	2.48 (5.65)	2.81 (7.40)	4.49 (19.66)	4.32 (18.16)
T_2	1.95 (3.30)	2.01 (3.54)	4.35 (18.42)	4.13 (16.56)	6.59 (42.93)	5.63 (31.20)	3.28 (10.26)	2.34 (4.98)	5.76 (32.68)	4.83 (22.83)	7.20 (51.34)	6.09 (36.59)	1.93 (3.22)	1.52 (1.81)	2.40 (5.26)	2.62 (6.36)	4.26 (17.65)	4.01 (15.58)
T_3	1.41 (1.49)	1.48 (1.69)	4.06 (15.98)	3.72 (13.34)	5.37 (28.34)	4.72 (21.78)	2.18 (4.25)	1.89 (3.07)	4.63 (20.94)	4.21 (17.22)	6.46 (41.23)	5.59 (30.75)	1.52 (1.81)	1.29 (1.16)	1.89 (3.07)	2.32 (4.88)	3.29 (10.32)	3.52 (11.89)
T_4	2.61 (6.31)	2.21 (4.38)	5.31 (27.70)	4.68 (21.40)	8.18 (66.41)	7.41 (54.41)	4.14 (16.64)	3.21 (9.80)	6.64 (43.59)	5.72 (32.22)	8.11 (65.27)	7.36 (53.67)	2.48 (5.65)	1.93 (3.22)	2.97 (8.32)	2.91 (7.97)	5.07 (25.20)	5.19 (26.44)
T_5	1.37 (1.38)	1.38 (1.40)	3.69 (13.12)	2.94 (8.14)	5.11 (25.61)	4.13 (16.56)	1.93 (3.22)	1.08 (0.67)	4.34 (18.34)	3.69 (13.12)	6.25 (38.56)	5.05 (25.00)	1.46 (1.63)	1.11 (1.73)	1.74 (2.53)	1.82 (2.81)	3.13 (9.30)	3.37 (10.86)
T_6	1.05 (0.60)	1.05 (0.60)	1.46 (1.63)	1.12 (0.75	3.62 (12.60)	2.83 (7.51)	1.46 (1.63)	1.21 (0.96)	2.40 (5.26)	1.81 (2.78)	4.81 (22.64)	3.78 (13.79)	1.09 (0.69)	1.09 (0.69)	1.33 (1.27)	1.66 (2.26)	2.66 (6.58)	2.68 (6.68)
T_7	5.27 (27.27)	4.21 (17.22)	7.05 (49.20)	6.78 (45.47)	9.15 (83.22)	8.34 (69.06)	6.94 (47.66)	5.79 (33.02)	8.24 (67.40)	7.72 (59.10)	10.89 (118.09)	9.54 (90.51)	3.49 (11.68)	2.93 (8.08)	4.66 (21.22)	4.32 (18.16)	6.09 (36.59)	6.28 (38.94)
SEm (±)	0.10	0.07	0.16	0.11	0.22	0.17	0.13	0.12	0.12	0.18	0.10	0.23	0.12	0.09	0.13	0.12	0.14	0.15
CD= 0.05	0.30	0.20	0.46	0.32	0.65	0.49	0.39	0.35	0.34	0.52	0.31	0.67	0.34	0.26	0.37	0.35	0.42	0.43

Data are subjected to square root transformation ($\sqrt{x}+0.5$); values in parentheses represent the original data

Table 3: Effect of weed control methods on plant height and LAI of boro rice

Treatments	Plant height (cm)						LAI					
	30 DAT		60 DAT		Harvest		30 DAT		60 DAT		Harvest	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	45.44	46.80	78.48	73.52	88.90	89.25	2.20	2.14	4.66	4.55	2.81	2.83
T_2	46.79	49.06	79.42	80.35	89.03	92.72	2.24	2.17	4.67	4.57	2.83	2.86
T_3	49.72	50.69	83.90	82.42	93.13	95.53	2.48	2.46	4.81	4.67	2.91	2.93
T_4	42.01	48.40	75.31	79.71	84.60	90.93	2.06	2.11	4.55	4.53	2.74	2.77
T_5	41.24	37.10	70.46	70.05	80.78	80.47	1.72	2.02	3.83	4.41	2.28	2.72
T_6	52.77	54.95	86.71	86.38	97.77	98.70	2.52	2.62	4.89	4.81	2.98	3.01
T_7	40.38	36.01	65.81	62.14	77.70	75.43	1.49	1.71	3.47	3.77	2.12	2.22
SEm (±)	4.51	1.93	1.00	1.90	1.18	1.68	0.02	0.08	0.03	0.06	0.02	0.04
CD= 0.05	NS	5.70	2.96	5.60	3.47	4.95	0.05	0.17	0.10	0.12	0.06	0.09

Table 4: Effect of weed control methods on dry matter accumulation and crop growth rate of *boro* rice

Treatments	Dry matter accumulation (g m^{-2})						Crop growth rate (g m^{-2} day^{-1})			
	30 DAT		60 DAT		Harvest		30-60 DAT		60-90 DAT	
	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23
T_1	209.71	230.45	491.69	507.28	699.41	713.51	9.40	9.23	6.92	6.87
T_2	213.78	235.32	498.07	515.11	708.66	721.84	9.48	9.33	7.02	6.89
T_3	227.44	245.89	512.96	530.02	726.91	740.34	9.52	9.47	7.13	7.01
T_4	192.9	210.39	463.06	480.11	658.36	673.18	9.01	8.99	6.51	6.44
T_5	166.47	188.63	376.48	382.08	500.98	506.26	7.00	6.45	4.15	4.14
T_6	283.75	305.11	583.91	600.21	822.67	858.38	10.01	9.84	7.96	8.61
T_7	105.49	122.32	322.92	290.31	444.89	415.09	7.25	5.60	4.07	4.16
SEm (±)	2.47	4.05	2.57	5.88	1.79	7.12	0.11	0.09	0.15	0.15
CD= 0.05	7.28	11.84	7.58	17.19	5.28	20.82	0.31	0.27	0.45	0.43

Table 5: Effect of weed control methods on yield attributes, yield and harvest index of *boro* rice

Treatments	Crop yield attributes						Yield (t/ha)				Harvest Index (%)	
	No. of panicles/m^2		Number of filled grain per panicle		1000 seed weight (g)		Grain		Straw			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	244.93	248.38	83.50	91.32	21.69	21.32	4.14	4.25	5.95	6.12	41.03	40.98
T_2	247.97	253.19	84.43	88.62	21.40	21.51	4.20	4.36	6.03	6.27	41.06	41.02
T_3	255.17	259.11	87.80	91.59	21.62	21.44	4.38	4.52	6.26	6.45	41.17	41.20
T_4	236.21	238.32	80.37	86.73	22.52	22.39	4.05	4.17	5.84	6.01	40.95	40.96
T_5	202.06	206.21	71.13	79.49	21.47	22.07	2.78	3.09	4.48	5.11	38.29	37.68
T_6	268.83	268.31	91.26	94.11	22.69	22.13	4.86	5.02	6.9	7.19	41.33	41.11
T_7	188.11	191.41	62.13	71.64	21.21	21.83	2.35	2.49	4.08	4.68	36.55	34.73
SEm (±)	2.31	2.54	0.59	0.63	0.43	0.45	0.04	0.06	0.03	0.07	---	---
CD (P=0.05)	6.83	7.42	1.75	1.84	NS	NS	0.08	0.17	0.10	0.20	---	---

Table 6: Effect of weed control methods on production economics of *boro* rice

Treatments	Production economics							
	Cost of cultivation (Rs. /ha)		Gross return (Rs. /ha)		Net Return (Rs. /ha)		B:C ratio	
	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022- 23	2021-22	2022-23
T_1	45813	46,133	86266	92820	40453	46687	1.88	2.01
T_2	45745	46,065	87510	95214	41765	49149	1.91	2.07
T_3	45817	46,137	91232	98658	45415	52521	1.99	2.14
T_4	53313	53,633	84410	91078	31097	37445	1.58	1.70
T_5	46321	46,641	58412	68146	12091	21505	1.26	1.46
T_6	55153	55,473	101184	109598	46031	54125	1.83	1.98
T_7	44001	44,321	49670	55476	5669	11155	1.13	1.25

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