Asian Journal of Research in Crop Science

Volume 9, Issue 3, Page 22-36, 2024; Article no.AJRCS.121595
ISSN: 2581-7167

Assessing Herbicide-Resistance and Yield Optimization in *Boro* Rice (cv. *BRRI* dhan29) through Post-emergence Herbicides Applications

Md. Nur-A-Alam [a], Md. Towkir Ahmed [a], Uttam Kumer Sarker [a], Md. Rashedur Rahman [a] and Md. Romij Uddin [a*]

[a] *Department of Agronomy, Faculty of Agriculture, Bangladesh Agricultural University, Mymensingh -2202, Bangladesh.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ajrcs/2024/v9i3285

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/121595

Original Research Article

Received: 17/06/2024
Accepted: 19/08/2024
Published: 28/08/2024

ABSTRACT

Effective weed management is crucial for achieving optimal crop performance and yield in rice cultivation. While post-emergence herbicides are commonly used to control weed population (WP), their effectiveness can vary based on the dosage and combinations applied. In this respect, an experiment was conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from December 2019 to May 2020 to predict herbicide-resistant weeds and assess the yield of *boro* (dry season irrigated) rice (cv. BRRI dhan29) in response to post-emergence

**Corresponding author: E-mail: romijagron@bau.edu.bd;*

Cite as: *Nur-A-Alam, Md., Md. Towkir Ahmed, Uttam Kumer Sarker, Md. Rashedur Rahman, and Md. Romij Uddin. 2024. "Assessing Herbicide-Resistance and Yield Optimization in Boro Rice (cv. BRRI dhan29) through Post-Emergence Herbicides Applications". Asian Journal of Research in Crop Science 9 (3):22-36. https://doi.org/10.9734/ajrcs/2024/v9i3285.*

herbicides. The experiment consisted of five post-emergence herbicides: Fenoxaprop-p-ethyl, Triafamone, Penoxsulam, Bispyribac-sodium, and Carfentrazone-ethyl, and four doses of herbicide: control, half of the recommended dose (RD), RD, and double the RD. Weed dry weight (DW), WP, and inhibition were significantly affected by different doses of herbicides. Ten weed species (WS) belonging to four families infested the experimental plots, with the most dominant being *Echinochloa crus-galli*, *Scirpus mucronatus*, and *Scirpus articulatus*. The lowest WP and DW, as well as the highest weed control efficiency (WCE), were achieved with double the RD of Penoxsulam and Triafamone, showing 91.09% and 90.13% efficiency, respectively, at 30 DAT. The tallest plants, highest number of effective tillers hill^{-1}, highest grain yield, straw yield, biological yield, and harvest index were found with double the RD of Penoxsulam. In contrast double the RD of Triafamone produced the second-highest grain yield. Although double doses of herbicides increased yield, the variation was not significantly greater than the RD. Some weeds, particularly *E. crus-galli*, *S. articulatus*, *Leersia hexandra*, and *Digitaria sanguinalis*, survived even with double the RD of herbicides. This indicates a potential for herbicide-resistant weeds.

Keywords: Resistant weeds; herbicides; Boro rice; grain yield; weed control efficiency.

1. INTRODUCTION

In Bangladesh, rice (*Oryza sativa* L.) is the most important crop and a vital agricultural product for both local and international markets. It serves as the raw material for various food items across the country. With an average annual per capita consumption of 144.5 kg, rice is the staple food in Bangladesh [1]. Agriculture contributes approximately 11.20% to the country's gross domestic product (GDP) [2]. Rice, a tropical crop, is cultivated throughout Bangladesh, with three primary growing seasons. Among these, boro rice is particularly significant, covering 4,852.29 thousand hectares and producing 2,076.76 thousand metric tons annually [2]. However, low-yielding varieties, heavy weed infestations, and inadequate crop management are causing a decline in average rice production.

Weed infestation is a prominent issue affecting *boro* rice production. Weeds are critical constraints to crop production worldwide, including in Bangladesh. Approximately 11.5% of global essential crop production is lost due to weed infestation [3]. Without weed control, rice production can decrease by 16 to 88%, or even up to 100% [4]. This significant yield loss indicates that weeds severely impact crop production and must be prevented or eliminated, posing a serious limitation for an overpopulated country like Bangladesh.

Proper weed management is essential for rice yield in Bangladesh. Various types of weeds exist in rice fields, generally categorized into three groups based on their morphological appearance: grasses, sedges, and broadleaf weeds. Traditional weed control methods, such as preparatory land tillage, hand weeding with a hoe, and hand pulling, are quite common. Hand weeding is particularly prevalent, typically requiring two or three sessions per crop depending on the weed type and infestation degree. However, adverse weather conditions like heavy rainfall, floods, high temperatures, or labor shortages can constrain weed control during critical periods using traditional methods [5].

The current study explores the integration of pre-emergence herbicides, applied within 1-5 days after planting rice seedlings, as a supplement to post-emergence treatments to improve crop competitiveness and yield in direct-seeded rice. Although pre-emergence treatments alone are insufficient, necessitating additional post-emergence applications to manage emerging weed threats, this dual approach promises enhanced economic benefits and crop health [6,7]. While post-emergence herbicides are readily available and beneficial in controlling weeds economically, their overuse risks fostering resistance and altering weed dynamics and soil microbiology [8].

To counteract these challenges, the study suggests using a rotation of herbicides with varying chemical properties to minimize environmental impact and resistance buildup. Despite occasional issues with herbicide phytotoxicity, which typically resolve over time, the environmental and ecological risks remain a concern [9]. The research thus evaluates different post-emergence herbicides for puddle-transplanted lowland rice during the rainy season, focusing on selecting those with diverse modes of action to prevent resistance and ensure sustainable weed management [10].

Assessing the performance of post-emergence herbicides is crucial to pinpoint those with varied modes of action suitable for rotating in puddle-transplanted rice, a strategy that fosters efficient weed suppression and curtails the risk of developing herbicide resistance. Consequently, this investigation focuses on identifying optimal post-emergence herbicides that can be rotated in lowland rice during the rainy season to maintain effective weed management and mitigate resistance. The study further aims to evaluate the effectiveness of these herbicides in managing a wide range of weed species in boro rice, highlighting the potential advantages of such herbicidal applications.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was conducted at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh, Mymensingh, from December 2019 to May 2020. This site lies within the coordinates of 90°50′ E longitude and 24°25′ N latitude, with an elevation of 18 meters, situated on the Old Brahmaputra floodplain (AEZ-9) [11]. The experimental field's soil was near neutral, with a pH of 6.82, and exhibited moderate levels of organic matter and fertility. The terrain was classified as medium high and featured a silty loam soil texture. The study provides a breakdown of the soil's physical and chemical properties in Table 1. The area experiences a sub-tropical climate with high temperatures and substantial rainfall during the Kharif season (April to September) and drier, cooler conditions in the Rabi season (October to March). Comprehensive data on monthly average daily maximum, minimum, and average temperatures, along with relative humidity, total rainfall, and sunshine duration at the station, are detailed in Table 2.

2.2 Experimental Treatments and Design

The experiment consisted of two components. Factor A included four doses of herbicides: Control (D_1), Half of RD (D_2), RD (D_3), and Double of the RD (D_4). Factor B included five herbicides: Fenoxaprop-p-ethyl (H_1), Triafamone (H_2), Penoxsulam (H_3), Bispyribac-sodium (H_4), and Carfentrazone-ethyl (H_5). The experiment was laid out in a split-plot design with three replications, where doses were assigned to the main plot and herbicides were allocated randomly to the sub-plot. There were 60 plots (5×4×3), each measuring 10 m² (4.0 m × 2.5 m), with a 0.5 m distance between individual plots and 1.0 m between replications.

2.3 Description of Herbicides

The common name, trade name, chemical composition, and mode of action of the herbicides used in the experiment are described in Table 3.

Table 1. The physical and chemical properties of the experimental field

Soil properties/constituents/Parameters	Values
1. Sand (%) (0.2-0.02 min):	20
2. Silt (%) (0.02-0.002 min):	67
3. Clay (%) (<0.002 min):	13
4. Soil textural class:	Silt loam
5. Particle density (g/cc):	2.60
6. Bulk density (g/cc):	1.35
7. Porosity (%):	46.67
8. pH	6.82
9. Soil texture	Silt loam
10. Organic carbon (%)	1.77
11. Total nitrogen	0.66
12. Carbon: Nitrogen	11.06
13. Available phosphorus (ppm)	15.67
14, Exchangeable potassium	0.087
15, Available Sulphur (ppm)	23.08

Source: Results obtain from the analysis of the initial soil sample done in the department of soil science, BAU, Mymensingh

Table 2. Monthly record of temperature, relative humidity, rainfall and sunshine during the period from December, 2019 to May, 2020 at BAU campus

Year	Month	Air temperature (º C)		Relative humidity (%)		Sunshine (hrs.)	Rainfall (mm)
		Max.	Min.	Max.	Min.		
2019	December	25.96	13.52	96.06	48.77	6.49	.29
2020	January	26.27	12.16	94.45	41.06	7.33	0.00
	February	27.02	15.55	94.57	46.64	5.98	29.20
	March	29.98	18.82	92.7	46.43	10	58.06
	April	31.78	22.23	92.36	70.01	6.45	66.8
	May	42.24	24.18	92.37	66.6	5.11	11.07

Source: Weather yard, department of irrigation and water management, BAU, Mymensingh

Table 3. Different forms of herbicides

Herbicides	Trade name	Chemical composition	Mode of action and use
Fenoxaprop-p-ethyl (H_1)	Eagle super	Ethyl 2-[4-[6-chloro-2-benzoxazolyl) oxy] phenoxy] propanoate	Selective herbicide used to control most of the narrow leaf weeds
Triafamone (H_2)	Council	Sulfonanilide	Selective systemic herbicide for control all kinds of weed of rice
Penoxsulam (H_3)	Grinite	The active ingredient is 2- (2,2-difluoroethoxy)—6-(trifluoromethyl-N-(5,8-dimethoxy [1,2,4] triazolo [1,5, -c] pyrimidin-2-yl)) benzene sulfonamide).	Acetolactate synthase inhibitor used to control annual, grasses and sedges.
Bispyribac - sodium (H_4)	Nominee 100 SC	Bispyribac-sodium 9.7% w/w	Acetolactase synthase inhibitor used to control leafy weed
Carfentrazone - ethyl (H_5)	Stingray	Ethyl 2-chloro-3-[2-chloro-4-fluoro-5-[4-(difluoromethyl)-4,5-diydro-3-methyl5-oxo-1H-1,2,4-trizol-1-yl)phenyl] propanoate.	Contact herbicide used to control broad leaf and sedge weed

2.4 Phytotoxicity of the Herbicides to Rice Plants

Phytotoxicity of the herbicides to rice plants was determined by visual observation (yellowing of leaves, burning of leaf tips, and stunting of growth) on the following scale: No toxicity, slight toxicity, moderate toxicity, severe toxicity, toxic [12].

2.5 Preparation of Plots and Crop Husbandry

A designated area was prepared for seedling cultivation, initially plowed with a traditional country plough and subsequently leveled with a ladder. This area was bisected to plant germinated seeds. On December 2, 2019, these sprouted seeds were carefully sown in a moist nursery bed to cultivate robust seedlings. Regular weeding and irrigation were maintained to ensure optimal growth. The main field was first plowed with a tractor-drawn disc plough, then extensively puddled using a power tiller for thorough mixing and cross plowing, and finally leveled. The experimental field layout was established on December 28, 2019, following the completion of land preparation, with all debris and weeds removed from each plot.

Chemical fertilizers were administered as follows: 270 kg of urea, 75 kg of triple super phosphate (TSP), 60 kg of muriate of potash (MoP), 10 kg of gypsum, and 5 kg of zinc sulphate per hectare. TSP, MoP, and gypsum were applied all at once during the last stage of field preparation, while urea was distributed in three separate doses at 15-, 30-, and 45-days post-transplanting (BRRI, 2020). The nursery bed was irrigated a day before the seedlings were uprooted to ensure their healthy removal on January 12, 2020, with minimal root damage. These 40-day-old seedlings were then transplanted into the prepared field at a density of three per hill, arranged in rows and hills spaced 25 cm and 15 cm apart, respectively.

2.6 Harvesting and Data Collection

Weed population data (30 DAT) were gathered using a 0.25 m x 0.25 m quadrate in each plot [13]. The total weeds within the quadrate were tallied and then calculated per square meter by multiplying by four. Following the density assessment, the weeds were meticulously uprooted from each quadrate, cleaned, and sorted by species. These weed samples were subsequently air-dried and then oven-dried for 72 hours at 80°C. The dry weight (DW) of each weed species was determined using an electric scale and recorded in grams per square meter (g m^{-2}). The weed control efficacy (WCE) of various treatments was assessed using the designated formula:

$$\text{WCE} = \frac{\text{DWC - DWT}}{\text{DWC}} \times 100$$

Here, WCE = Weed control efficiency, DWC = Dry weight of weeds in the weedy check, DWT = Dry weight of weeds in the weed management treatment

Harvesting was conducted once the crops reached optimal maturity. A 1 m² area in the central part of each plot was selected to measure the grain yield (GY) and straw yield (SY). The grain yield was adjusted to a moisture content of 14% and calculated in metric tons per hectare. The number of total tillers (NTT) hill^{-1}and total DW hill^{-1} were recorded for each plot, with five hills marked for tracking. Data collection occurred at 30 DAT. During harvest, several parameters were measured including plant height (PH), number of effective tillers (NET) hill^{-1}, panicle length (PL), number of grains panicle^{-1} (NGP), 1000-grain weight (TGW), grain yield (GY), and straw yield (SY). Following these measurements, the biological yield (BY) and harvest index (HI) were calculated.

2.7 Statistical Analysis

The recorded data were compiled and tabulated for statistical analysis. Analysis of variance was conducted using the MSTAT-C software package. Mean differences among treatments were evaluated using Duncan's Multiple Range Test [14].

3. RESULTS AND DISCUSSION

Ten WS from four families infested the experimental field. Among these species, five were grasses, two were broadleaves, and three were sedges. The local names, scientific names, family, morphological type, and life cycle of the weeds in the experimental plots are presented in Table 4. The significant weeds in the experimental plots included *Echinochloa crus-galli*, *Scirpus mucronatus*, and *Scirpus articulatus*. Other important weeds were *Panicum repens*, *Leersia hexandra*, *Polygonum hydropiper*, *Monochoria hastata*, *Oxalis europaea*, *Digitaria sanguinalis*, and *Digitaria ischaemum*.

3.1 Prediction of Herbicide Resistant Weeds Based on Weed Density

The study revealed that some WS (*E. crus-galli*, *L. hexandra*, *D. ischaemum*, *P. repens*, and *D. sanguinalis*) survived even with double doses of selected herbicides (Fig. 1). Weeds like

Table 4. Infesting WS in the experimental plots

Local name	Scientific name	Family	Morphological type	Life cycle
Shama	*E. crus-galli*	Poaceae	Grass	Annual
Boro angulee	*D. sanguinalis*	Poaceae	Grass	Annual
Choto angulee	*D. ischaemum*	Poaceae	Grass	Annual
Arail	*L. hexandra*	Poaceae	Grass	Perennial
Angta	*P. repens*	Poaceae	Grass	Perennial
Amrul	*O. europaea*	Oxalidaceae	Compound leaved	Perennial
Pani kachu	*M. hastata*	Pontederiaceae	Broad leaved	Perennial
Sabuj nakful	*C. difformis*	Cyperaceae	Sedge	Annual
Chechra	*S. mucronatus*	Cyperaceae	Sedge	Perennial
Noldug	*S articulates*	Cyperaceae	Sedge	Annual

D. ischaemum and S. mucronatus managed to survive in plots treated with Pretilachlor herbicide. *S. mucronatus*, *D. ischaemum*, and *E. crus-galli* survived in plots treated with Penoxsulam, Bispyribac-sodium, and Carfentrazone-ethyl (Fig. 2).

E. crus-galli was the most aggressive weed, surviving even with double the RD of Penoxsulam, Bispyribac-sodium, and Carfentrazone-ethyl. Following *E. crus-galli*, *S. articulatus* was found to be the next most destructive weed, surviving double doses of Penoxsulam, Bispyribac-sodium, Carfentrazone-ethyl, Fenoxaprop-p-ethyl, and Triafamone (Table 5).

Herbicides are crucial for weed control in modern agriculture, enabling optimum crop yields and the adoption of environmentally friendly practices such as conservation tillage.

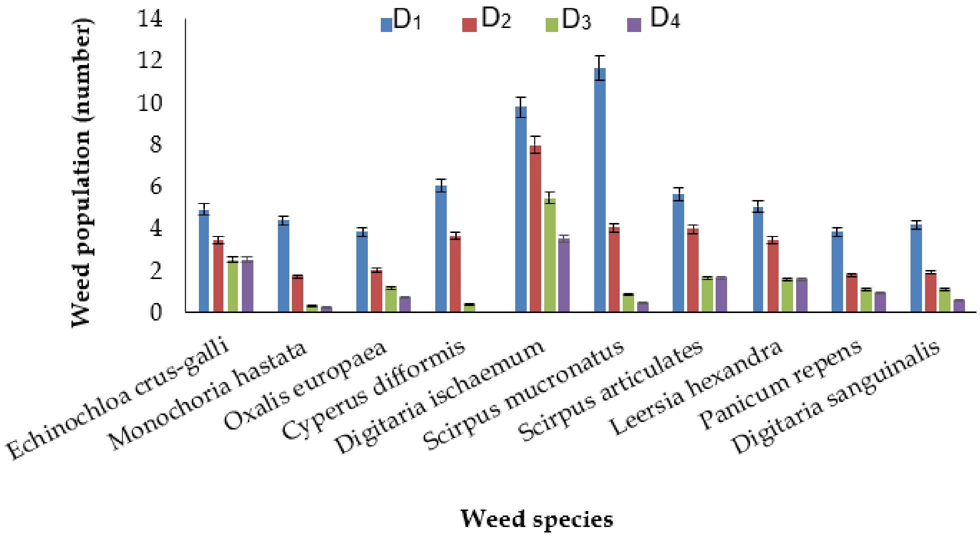

Fig. 1. Effect of different HD on WP

Here, D_1 - Control (No herbicide), D_2 - Half of RD, D_3 - RD, D_4 - Double of RD

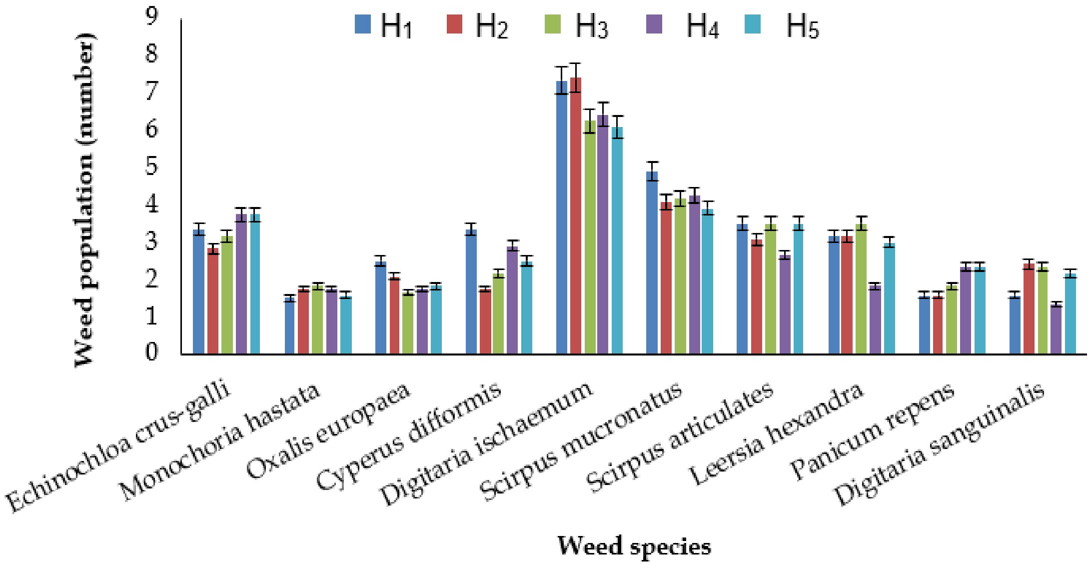

Fig. 2. Effect of different herbicides on WP

Here, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl

However, the evolution of herbicide-resistant WP is a significant concern. Despite the positive impact of herbicides, repeated use of the same or similar herbicides has led to widespread herbicide resistance in several WS.

Our findings are consistent with those reported in Cai et al., [15], where researchers identified two mefenacet-resistant populations and one susceptible population of *E. crus-galli* in Jiangsu Province paddy fields. The resistant populations demonstrated significantly higher resistance levels—2.8 and 4.1 times more pre-emergence and 10 and 6.8 times more early post-emergence resistance to mefenacet—than the susceptible group. These populations also showed cross-resistance or multiple resistance to several other herbicides, including acetochlor, pyraclonil, imazamox, and quinclorac. In contrast, commonly utilized herbicides for pre-emergence (clomazone, quinclorac) and post-emergence (propanil, quinclorac, imazethapyr, and fenoxaprop-ethyl) were ineffective against *E. colona*, as well as against *E. crus-galli* and *E. muricata* [16].

3.2 Effect of Herbicidal Doses on WP

WP and species were significantly influenced by different herbicidal doses (HD). The highest WP (11.66 m^{-2}) was found in the control treatment at 30 DAT, and the lowest (0.00 m^{-2}) in the double dose treatment at 30 DAT (Fig. 1). Similar findings were reported by Zahan et al., [17], who observed significant variation in WS with different herbicide doses.

3.3 Effect of Herbicide on WP

WP was significantly influenced by different herbicides. *S. mucronatus* and *S. articulates* exhibit the highest weed populations, indicating lower effectiveness of the herbicides against these species. Conversely, *E. crus-galli, M. hastata, O. europaea, C. difformis*, and *D. sanguinalis* show consistently low populations, suggesting better control by the herbicides. Moderate weed populations are observed for *D. ischaemum*, *L. hexandra*, and *P. repens*, indicating varying herbicide effectiveness. (Fig. 2). The study found that different herbicides significantly impacted weed production in transplanted Aman rice. Specifically, 2,4-D Ethyl Ester 30% EC (Champion) was highly effective during the first 60 days after transplanting, promoting taller rice plants by suppressing early weed growth. This early weed control is crucial as it enables rice plants to better utilize nutrients and light, reducing competition and positively influencing the crop's overall growth and final yield [18].

3.4 Interaction Effect between Herbicide and Doses on WP

WP was significantly influenced by the interaction between herbicide and its doses. The highest WP (14, 12.33, 10.66, 11.33, and 9.33 m^{-2}) were found in the control and Fenoxaprop-p-ethyl treatment at 30 DAT, and the lowest (0.00 m^{-2}) in the double dose treatments of Fenoxaprop-p-ethyl and Bispyribac-sodium at 30 DAT (Table 5). Similar findings were reported by Zahan et al., [17], who found significant variation in WS.

3.5 Effect of HD on WCE

There was a significant effect on WCE (%) at 30 DAT. The highest WCE (89.61%) was obtained in double of the RD of herbicide at 30 DAT. While the lowest WCE (0.00%) was found in control treatment at 30 DAT (Fig. 3). Fenoxoprop-P-ethyl 6.7 % w/w EC (Rice star) was highly effective during the later stages of rice growth, achieving the lowest weed biomass and a high weed control efficiency of 71.81%. This efficiency maintained low weed pressure, allowing better resource availability for rice plants, thereby supporting improved growth and higher yields [18].

3.6 Effect of Different Herbicide on WCE

Significant variation was found in WCE at 30 DAT. The highest WCE (52.77%) was obtained with Triafamone at 30 DAT, followed by Fenoxaprop-p-ethyl at 51.62% (Fig. 4). These results align with the findings of Dola et al., [19], who also documented significant disparities in weed control efficiency among different herbicide treatments.

3.7 Interaction Effect between Herbicide and Doses on WCE

Significant variation was found in WCE at 30 DAT. The highest WCE (91.09%) was found with double the dose of Penoxsulam at 30 DAT, while the lowest (0.00%) was found in the control treatment (Table 6). Similar findings were reported by Islam [20], who found significant variation in WCE influenced by different doses of herbicides.

Table 5. Interaction effect between herbicide and doses on WP

Interaction	*E. crus-galli*	*M. hastata*	*O. europaea*	*C. difformis*	*D. ischaemum*	*S. mucronatus*	*S. articulates*	*L. hexandra*	*P.repens*	*D. sanguinalis*
H_1D_1	4.66	3.33ab	4.66a	6.66ab	10.33ab	14.00a	4.33abcd	5.00abc	2.66	3.00cde
H_1D_2	3.66	1.66bc	3.00bcd	4.66bcd	9.00abc	5.66bc	4.00abcde	3.66abc	1.66	1.66defg
H_1D_3	2.66	0.66c	1.33e	2.00ef	6.66abcd	0.00d	2.66cdef	1.66abc	1.00	1.00fg
H_1D_4	2.33	0.33c	1.00e	0.00f	3.33cd	0.00d	3.00bcdef	2.33abc	1.00	0.66fg
H_2D_1	5.33	4.33a	4.33ab	3.66cde	8.33abcd	12.33a	5.33abc	5.66ab	2.33	5.33a
H_2D_2	2.66	1.33bc	2.00cde	3.33de	8.00abcd	2.33cd	4.66abc	4.00abc	1.33	2.33def
H_2D_3	1.66	0.33c	1.33e	0.00f	9.33abc	1.66cd	1.33def	1.66abc	1.00	1.33efg
H_2D_4	1.66	1.00c	0.66e	0.00f	4.00bcd	0.00d	1.00ef	1.33bc	1.66	0.66fg
H_3D_1	5.00	5.33a	3.33abc	5.33bcd	11.66a	10.66ab	6.00ab	6.00a	4.00	5.00ab
H_3D_2	3.33	2.00bc	1.66de	3.33de	8.00abcd	3.33cd	4.33abcd	4.33abc	1.66	2.33def
H_3D_3	2.33	0.00c	1.00e	0.00f	3.00cd	1.66cd	1.33def	2.00abc	1.00	1.33efg
H_3D_4	2.00	0.00c	0.66e	0.00f	2.33d	1.00cd	2.33cdef	1.66abc	0.66	0.66fg
H_4D_1	4.66	4.33a	3.66ab	8.66a	9.33abc	11.33a	6.66a	3.00abc	5.33	3.33bcd
H_4D_2	4.00	2.00bc	1.66de	3.00de	8.33abcd	3.33cd	3.00bcdef	2.00abc	2.00	1.00fg
H_4D_3	3.00	0.66c	1.00e	0.00f	3.66cd	1.00cd	0.33f	1.33bc	1.33	0.66fg
H_4D_4	3.33	0.00c	0.66e	0.00f	4.33bcd	1.33cd	0.66f	1.00c	0.66	0.33g
H_5D_1	5.00	4.66a	3.33abc	6.00bc	9.33abc	10.00ab	6.00ab	5.66ab	5.00	4.33abc
H_5D_2	3.66	1.66bc	2.00cde	4.00cde	6.66abcd	5.66bc	4.00abcde	3.33abc	2.33	2.33def
H_5D_3	3.00	0.00c	1.33e	0.00f	4.66bcd	0.00d	2.66cdef	1.33bc	1.33	1.33efg
H_5D_4	3.33	0.00c	0.66e	0.00f	3.66cd	0.00d	1.33def	1.66abc	0.66	0.66fg
Level of significance	NS	**	**	**	**	**	**	**	NS	**
CV%	24.15	21.28	24.84	22.90	18.08	17.22	15.85	20.98	21.15	23.60

*In a column, figures with the same letter do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl, D_1 - Control (No herbicide), D_2 - Half of RD, D_3 - RD, D_4 - Double of RD*

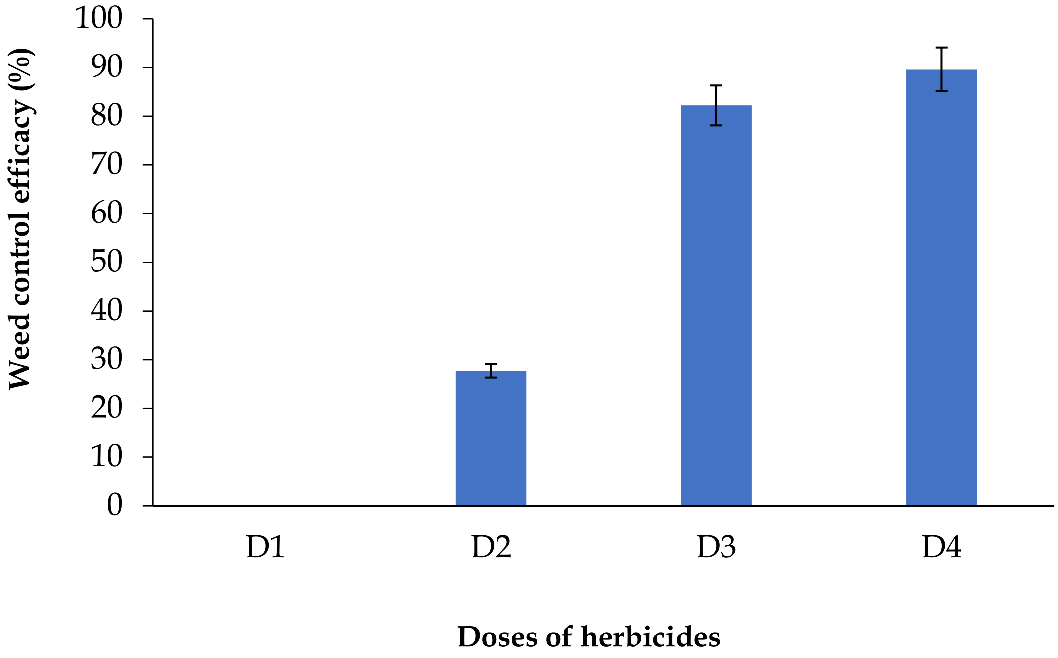

Fig. 3. Effect of HD on WCE

Here, D_1 - Control (No herbicide), D_2 - Half of RD, D_3 - RD, D_4 - Double of RD

Table 6. Interaction effect between different herbicide and its doses on weed DW

Interaction	Total weed dry weight	No. of Weed species	Weed control efficacy
H_1D_1	17.80	9.00ab	0.000h
H_1D_2	15.58	9.00ab	32.58e
H_1D_3	3.96	5.33ef	82.82bc
H_1D_4	2.05	6.33def	89.65a
H_2D_1	20.93	9.00ab	0.000h
H_2D_2	12.93	8.66abc	38.00d
H_2D_3	3.56	6.66cdef	82.96bc
H_2D_4	2.06	5.00ef	90.13a
H_3D_1	23.20	9.66a	0.000h
H_3D_2	14.13	8.33abcd	20.70g
H_3D_3	3.56	5.66ef	79.98c
H_3D_4	2.05	4.66f	91.09a
H_4D_1	16.91	9.33a	0.000h
H_4D_2	13.25	8.66abc	21.57fg
H_4D_3	3.00	7.00bcde	82.24c
H_4D_4	2.06	5.66ef	87.80ab
H_5D_1	21.52	10.00a	0.000h
H_5D_2	15.96	9.00ab	25.78f
H_5D_3	3.63	6.66cdef	83.09bc
H_5D_4	2.26	5.33ef	89.38a
Level of Significance	NS	**	**
CV%	9.32	16.86	5.77

*In a column, figures with the same letter do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl, D1 - Control (No herbicide), D2 - Half of RD, D3 - RD, D4 - Double of RD*

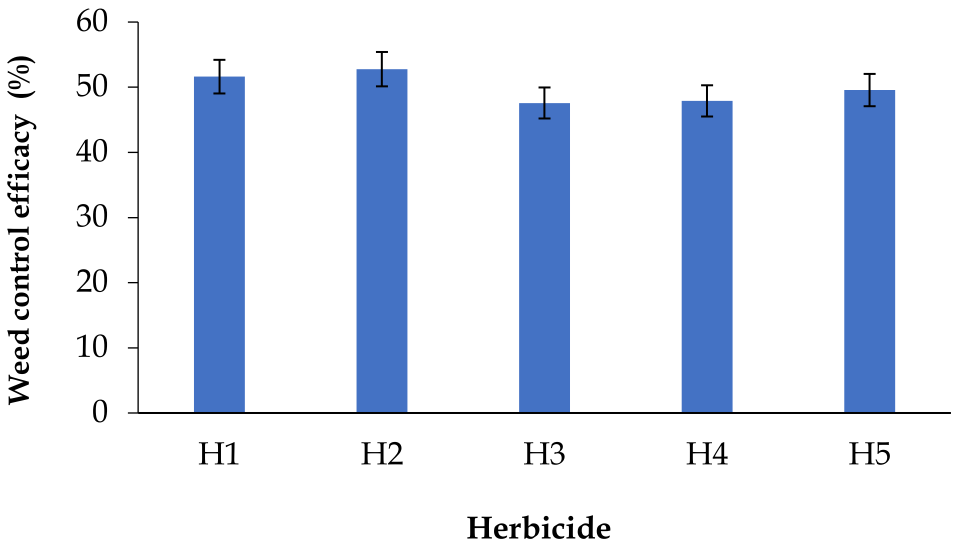

Fig. 4. Effect of different herbicides on WCE

Here, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl

Table 7. Rating of phytotoxicity of different herbicides along with different doses and symptoms developed on *boro* rice

Treatments	Rating	Observed Symptoms
H_1D_1	1.0	No observable toxicity symptoms
H_1D_2	1.0	No observable toxicity symptoms
H_1D_3	1.0	No observable toxicity symptoms
H_1D_4	1.1	Transient mild chlorosis of leaves, recovery within 5-7 days
H_2D_1	1.0	No observable toxicity symptoms
H_2D_2	1.0	No observable toxicity symptoms
H_2D_3	1.0	No observable toxicity symptoms
H_2D_4	1.1	Transient mild chlorosis of leaves, recovery within 7-10 days
H_3D_1	1.0	No observable toxicity symptoms
H_3D_2	1.0	No observable toxicity symptoms
H_3D_3	1.0	No observable toxicity symptoms
H_3D_4	1.1	Transient mild chlorosis of leaves, recovery within 5-7 days
H_4D_1	1.0	No observable toxicity symptoms
H_4D_2	1.0	No observable toxicity symptoms
H_4D_3	1.0	No observable toxicity symptoms
H_4D_4	1.1	Transient mild chlorosis of leaves, recovery within 5-7 days
H_5D_1	1.0	No observable toxicity symptoms
H_5D_2	1.0	No observable toxicity symptoms
H_5D_3	1.0	No observable toxicity symptoms
H_5D_4	1.1	Transient mild chlorosis of leaves, recovery within 7-8 days

Here, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl, D1 - Control (No herbicide), D2 - Half of RD, D3 - RD, D4 - Double of RD

3.8 Phytotoxicity of Herbicides to Rice Plants

The degree of toxicity of different herbicides and doses to rice plants and the symptoms produced are presented in Table 7. RD and half the RD showed no toxicity, but double doses caused slight toxicity, yellowing of leaves, and burning of growth, with plants requiring 5-10 days to recover.

Table 8. Effect of HD on yield and yield contributing characters of *boro* rice

Dose	PH (cm)	NET hill^{-1}	PL (cm)	NGP	TGW (g)	GY (t ha^{-1})	SY (t ha^{-1})	BY (t ha^{-1})	HI (%)
D_1	86.31b	6.74d	18.04d	77.02	24.53b	3.24d	5.22c	8.47c	38.29d
D_2	87.35b	7.24c	18.53c	79.84	24.95b	4.27c	6.64b	10.91b	39.18c
D_3	91.05a	8.55b	19.46a	83.18	26.05a	6.38b	7.75a	14.14a	45.12b
D_4	90.14a	8.96a	19.08b	80.88	26.27a	6.52a	7.63a	14.16a	46.08a
Level of significance	**	**	**	NS	**	**	**	**	**
CV%	1.57	3.00	2.12	19.72	3.39	2.76	2.72	2.73	3.02

*In a column, figures with the same letter do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, D_1 - Control (No herbicide), D_2 - Half of RD, D_3 - RD, D_4 - Double of RD*

Table 9. Effect of different herbicide on yield and yield contributing characters of *Boro* rice

Herbicide	PH (cm)	NET hill^{-1}	PL (cm)	NGP	TGW (g)	GY (t ha^{-1})	SY (t ha^{-1})	BY (t ha^{-1})	HI(%)
H_1	88.92	7.67b	18.67b	83.45a	25.58	4.95c	6.65b	11.61c	42.09d
H_2	88.64	7.94a	18.64b	80.56ab	25.53	5.13ab	6.90a	12.04a	41.98e
H_3	88.39	7.94a	18.96a	84.57a	25.48	5.24a	6.96a	12.20a	42.27a
H_4	88.78	7.89a	18.95a	82.14a	25.40	5.05bc	6.70b	11.76bc	42.23c
H_5	88.83	7.91a	18.65b	70.42b	25.26	5.14ab	6.85a	12.00ab	42.26b
Level of significance	NS	**	**	**	NS	**	**	**	**
CV%	1.47	2.82	1.34	14.29	2.03	2.46	2.21	2.32	2.02

*In a column, figures with the same letter do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl*

Table 10. Combined effect of herbicide and its dose on yield and yield contributing characters of *Boro* rice

Interaction	PH (cm)	NET hill^{-1}	PL (cm)	NGP	TGW (g)	GY (t ha^{-1})	SY (t ha^{-1})	BY (t ha^{-1})	HI (%)
H_1D_1	86.53fg	6.43h	18.03ghi	83.06	24.83def	3.16g	5.05hi	8.21h	38.45n
H_1D_2	87.50defg	7.03efg	18.63efg	86.96	25.26bcde	4.26e	6.60e	10.86e	39.21k
H_1D_3	92.16a	8.33d	19.36abcd	78.63	26.03abc	6.18d	7.54cd	13.72cd	45.04h
H_1D_4	89.50bcd	8.90ab	18.66efg	85.16	26.20ab	6.23cd	7.42d	13.66d	45.65e
H_2D_1	86.00fg	6.76fgh	18.00hi	75.96	24.71def	3.27g	5.30gh	8.57gh	38.16p
H_2D_2	87.06efg	7.13ef	18.56efgh	80.06	25.02def	4.37e	6.81e	11.18e	39.06l
H_2D_3	91.00ab	8.80abc	19.10bcde	82.03	26.29a	6.35bcd	7.81abc	14.16bcd	44.84i
H_2D_4	90.50ab	9.06a	18.90cdef	84.20	26.12ab	6.53b	7.70bcd	14.24bc	45.88d
H_3D_1	85.46g	6.90fg	17.93i	77.50	24.54ef	3.14g	4.99i	8.13h	38.60m
H_3D_2	87.46defg	7.30e	18.53efghi	85.16	24.73def	4.44e	6.83e	11.27e	39.37j
H_3D_3	90.63ab	8.50cd	19.60ab	87.36	26.20ab	6.48b	7.90ab	14.39b	45.05h
H_3D_4	90.00abc	9.06a	19.80a	88.26	26.45a	6.92a	8.10a	15.03a	46.08c
H_4D_1	86.43fg	6.73gh	18.13ghi	78.46	24.40ef	3.28g	5.35gh	8.63gh	38.00q
H_4D_2	86.76fg	7.40e	18.63efg	78.36	25.06cdef	3.93f	6.10f	10.03f	39.20k
H_4D_3	90.63ab	8.66bcd	19.76a	89.23	26.03abc	6.51b	7.88ab	14.40b	45.24g
H_4D_4	91.30ab	8.76abc	19.30abcd	82.50	26.10ab	6.50b	7.47d	13.97bcd	46.50a
H_5D_1	87.13efg	6.86fg	18.10ghi	70.13	24.20f	3.36g	5.43g	8.80g	38.24o
H_5D_2	87.96cdef	7.33e	18.30fghi	68.66	24.67ef	4.39e	6.84e	11.23e	39.06l
H_5D_3	90.83ab	8.46cd	19.46abc	78.63	25.70abcd	6.37bcd	7.65bcd	14.02bcd	45.46f
H_5D_4	89.40bcde	9.00ab	18.76def	64.26	26.47a	6.45bc	7.48d	13.93bcd	46.29b
Level of significance	**	**	**	NS	**	**	**	**	**
CV%	1.57	3.00	2.12	19.72	3.39	2.76	2.72	2.73	3.02

*In a column, figures with the same letter do not differ significantly as per DMRT, ** - Significant at 1% level of probability, NS - Not significant, H_1 - Fenoxaprop-p-ethyl, H_2 - Triafamone, H_3 – Penoxsulam, H_4 - Bispyribac - sodium, H_5 - Carfentrazone – ethyl, D_1 - Control (No herbicide), D_2 - Half of RD, D_3 - RD, D_4 - Double of RD*

3.9 Effect of Herbicide Doses on Yield and Yield-Contributing Characters of *Boro* Rice

Herbicide doses had a non-significant effect on the NGP. The highest NGP (83.18) was found with the RD of herbicide, and the lowest (77.02) in the control condition. PH, NET hill^{-1}, PL, TGW, GY, SY, BY, and HI were significantly influenced by different weed management treatments. The highest PH, NET, PL, TGW, GY, SY, BY, and HI (91.05 cm, 8.96, 19.46 cm, 26.27 g, 6.52 t ha^{-1}, 7.75 t ha^{-1}, 14.16 t ha^{-1}, 46.08%) were produced with the recommended and double doses of herbicide. The lowest values were found in the control treatment (Table 8). Similar findings were reported by Rahman [21].

3.10 Effect of Herbicides on Yield and Yield Contributing Characters of *Boro* Rice

Herbicides had a non-significant effect on PH and TGW. However, NET, PL, NGP, GY, SY, BY, and HI were significantly influenced by different weed management treatments. The highest NET, PL, NGP, GY, SY, BY, and HI (7.94, 18.96 cm, 84.57, 5.24 t ha^{-1}, 6.96 t ha^{-1}, 12.20 t ha^{-1}, 42.27%) were produced with Penoxsulam. The lowest values were produced with other herbicides (Table 7).

3.11 Combined Effect of Herbicide and Dose on Yield and Yield Contributing Characters of *Boro* Rice

PH and PL were significantly influenced by the interaction between herbicide and its doses. The tallest plant (92.16 cm) was obtained with the RD of Pretilachlor, and the shortest (85.46 cm) in the control condition (Table 10). The highest NET hill^{-1} (9.06) was produced with double the dose of Penoxsulam, and the lowest (6.43) in the control treatment (Table 10). Similar findings were reported by Dola et al., [19], who found significant variation in plant height by using different herbicides.

The highest PL (19.76 cm) was obtained with the RD of Bispyribac-sodium, and the lowest (17.93 cm) with control and Penoxsulam (Table 10). Similar findings were reported by Islam [20], who found a significant variation in panicle length influenced by different herbicides and their doses. The NGP and TGW were non-significantly influenced by the combined effect of herbicides and doses on BRRI dhan29. The highest number of NGP (89.23) was obtained with the RD of Bispyribac-sodium, and the lowest (64.26) with double the RD of Carfentrazone-ethyl (Table 10). Similar results were reported by Kundu et al., [22] and Das et al., [23] who found significant variations in NGP. The highest TGW (26.47 g) was obtained with double the RD of Carfentrazone-ethyl, and the lowest (24.20 g) in the control condition of Carfentrazone-ethyl (Table 10). The proper dosage of combined herbicides significantly improved boro rice yield. Metsulfuron Methyl 10% + Chlorimuron Ethyl 10% (Almix) was the most effective, resulting in the highest number of tillers, spikelets, and filled grains, and a 20.29% higher yield of 68.98 quintals per hectare compared to control plots. This emphasizes the importance of correct herbicide selection and dosing to optimize yield [18].

GY, SY, BY and HI of BRRI dhan29 were significantly influenced by the combined effect of herbicides and doses. The highest GY (6.92 t ha^{-1}) was obtained with double the RD of Penoxsulam, and the lowest (3.14 t ha^{-1}) in the control condition of Penoxsulam (Table 10). A similar result was also reported by Hasanuzzaman et al., [24] and Harding et al., [25], who found a significant variation in grain yield using different herbicides and their doses.

The highest SY (8.10 t ha^{-1}) was observed with double the RD of Penoxsulam, and the lowest (4.99 t ha^{-1}) in the control condition of Penoxsulam (Table 10). A Similar finding was reported by Rahman [21] and Rashid et al., [26], who found significant variation in straw yield using different herbicides and their doses.

The highest BY (15.03 t ha^{-1}) was observed with double the RD of Penoxsulam, and the lowest (8.13 t ha^{-1}) in the control condition of Penoxsulam (Table 10). These findings are consistent with those reported by Onwuchekwa-Henry et al., [27], who also observed significant variations in BY. The highest HI (46.50%) was observed with double the RD of Bispyribac-sodium, and the lowest (38.00%) in the control condition of Bispyribac-sodium (Table 10). These results corroborate the findings of Onwuchekwa-Henry et al., [28], who reported significant variations in the HI.

4. CONCLUSION

The application of double the recommended dose of Penoxsulam was most the effective among the weed management treatments, producing the highest grain yield. Although double- doses of herbicides increased yield, the variation was not significantly greater than the recommended doses. Temporary slight phytotoxic effects were observed with all double dose herbicide treatments. Some weeds, especially *E. crus-galli*, *S. articulatus*, *L. hexandra*, and *D. sanguinalis*, survived even with double the recommended dose of herbicides. While recommended doses of herbicides are generally effective, the survival of these weeds suggests the potential for herbicide resistance. Further molecular tests are needed to confirm whether these weeds are resistant to the specific herbicides used.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge to the Ministry of Education (MOE), Project number 2019/12/MOE, Government Peoples' Republic of Bangladesh for financial support and co-operation during study period.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Yunus M, Rashid S, Chowdhury S. Per capita rice consumption in Bangladesh: Available estimates and IFPRI's validation survey results. Washington DC: International Food Policy Research Institute; 2019;15738.
2. BBS. Statistical Year Book of Bangladesh Bureau of Statistics. Statistics and information division, ministry of planning, Government of People's Republic of Bangladesh, Dhaka, Bangladesh. 2023;52.
3. Proceedings of ISWS biennial conference on “Weed management for enhancing farmers' income and food security”, ICAR-CCARI, Goa, Indian Society of Weed Science, India. 2020;270.
4. Khanh TD, Linh LH, Linh TH, Quan NT, Cuong DM, Hien VTT, Ham LH, Xuan TD. Integration of Allelopathy to Control Weeds in Rice; 2013.
DOI: 10.5772/56035.
5. Chauhan BS, Ahmed S, Awan TH, Jabran K, Manalil S. Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. Crop Prot. 2015;71:19-24.
6. Rahman MM, Adhikary V, Ahmad MH. Weed suppression ability and yield performance of rainy season rice varieties under different planting spacing. J Bangladesh Agric Univ. 2020;18:227-33.
7. Rajput P, Singh A, Rajput RK, Shukla G, Kumar P. Effect of pre and post emergence herbicides on weeds and productivity of aerobic basmati rice (Oryza sativa L): A review. Int J Curr Microbiol Appl Sci. 2020;9:2085-97.
8. Gitsopoulos TK, Froud-Williams RJ. Effects of oxadiargyl on direct-seeded rice and *Echinochloa crus-galli* under aerobic and anaerobic conditions. Weed Res. 2004;44:329-34.
9. Anwar MP, Juraimi AS, Puteh A, Man A, Rahman MM. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. Acta Agric Scand B Soil Plant Sci. 2012;62:604-15.
10. Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice-wheat cropping system in the indo-gangetic plains of the indian subcontinent: Problems, opportunities, and strategies. In: Sparks DL, editor. Advances in Agronomy. Netherlands: Elsevier Inc.; 2012; 315-69.
11. FAO and UNDP. Land Resources Appraisal of Bangladesh for Agricultural Development Rep. 2. Agroecological Regions of Bangladesh. BARC/UNDP, New Airport Road, Farmgate, Dhaka-1207. 1988;212-21.
12. IRRI. Annual report for 1963. International Rice Research Institute, Los Banos, Philippines. 1965;467.
13. Cruz ED, Moody K, Ramos MB. Reducing variability sampling weeds in upland rice (*Oryza sativa*). Philipp J Weed Sci. 1986;13:56-9.
14. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Willey and Sons; 1984;68.
15. Cai X, Chen J, Wang X, Gao H, Xiang B, Dong L. Mefenacet resistance in multiple herbicide-resistant *Echinochloa crus-galli*

L. populations. Pestic Biochem Physiol. 2022;182:105038.

16. Liu R, Singh V, Abugho S, Lin HS, Zhou XG, Bagavathiannan M. Morphophysiological diversity and its association with herbicide resistance in *Echinochloa ecotypes*. Weed Sci. 2022;70(1):26-35.
17. Zahan T, Rahman MM, Hashem A. Growth and yield response of transplanted aman rice varieties to herbicides in strip tilled unpuddled soil. Int Proc 2nd Conf Conserv Agric Smallholders (CASH-II), 14-16 February, 2017, Mymensingh, Bangladesh. 2017;48-9.
18. Heisnam P, Moiranthem A, Keisham A, Singh NI, Singh AH, Singh LN. Efficacy of some promising weedicides on shallow land transplanted rice (*Oryza sativa* L.) under rainfed conditions. Bioscan. 2015;10(1):459-63.
19. Dola NA, Sarker UK, Ahmed MT, Upama SA, Rashid MHO, Uddin MR. Comparative advantages of aqueous extract of mustard crop residues with herbicide to weed control and crop performance of wheat. Arch Agric Environ Sci. 2024;9(2): 294-301. Available:https://dx.doi.org/10.26832/24566632.2024.0902013.
20. Islam MF. Herbicide resistant weeds and yield response of boro rice (cv. BRRI dhan28) to pre-emergence herbicides. MS Thesis, Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2022;1-96.
21. Rahman MM. Effect of weeding regime on the performance of transplant aman rice. MS Thesis, Department of Agronomy, Bangladesh Agricultural University, Mymensingh. 2014;1-82.
22. Kundu R, Mondal M, Garai S, Mondal R, Poddar R. Bio-efficacy of post-emergence herbicides in boro rice nursery as well as main field and their residual effects on non-target microorganisms. Oryza - Int J Rice. 2020;57(3):113-7.
23. Das S, Ray M, Barat S, Roy AS. Post-emergence chemical weed control in direct-seeded rice (*Oryza sativa* L.) in the new alluvial zone of West Bengal. J Adv Biol Biotechnol. 2024;27(7):954-963. Available:https://doi.org/10.9734/jabb/2024/v27i71056.
24. Hasanuzzaman M, Ali MH, Alam MM, Akther M, Alam KF. Evaluation of preemergence herbicide and hand weeding on the weed control efficiency and performance of transplanted aus rice. Am-Eurasian J Agron. 2009;2(3):138-43.
25. Harding SS, Taylor DR, Jalloh AB, Mahmood N, Dixon CA, Johnson SD. Evaluation of the efficacy of different rates of herbicides on weed growth and grain yield of two rice varieties in two rice ecologies in Sierra Leone. J Exp Agric Int. 2012;2(4):607-615. Available:https://doi.org/10.9734/AJEA/2012/1611.
26. Rashid MH, Alam MM, Rao AN, Ladha JK. Comparative efficacy of pretilachlor and hand weeding in managing weeds and improving the productivity and net income of wet-seeded rice in Bangladesh. Field Crops Research. 2012;128:17-26. Available:https://www.sciencedirect.com/science/article/abs/pii/S0378429011003911
27. Onwuchekwa-Henry CB, Coe R, Van Ogtrop F, Roche R, Tan DKY. Efficacy of pendimethalin rates on barnyard grass (*Echinochloa crus-galli* (L.) Beauv) and their effect on photosynthetic performance in rice. Agronomy. 2023;13:582. Available:https://doi.org/10.3390/agronomy13020582.
28. Onwuchekwa-Henry CB, Van Ogtrop F, Roche R, Tan DKY. Seeding rate, fertilizer and herbicide effects on canopy growth and productivity of direct-seeded rice (DSR) under different management practices. Field Crops Res. 2022;284: 108565. Available:https://doi.org/10.1016/j.fcr.2022.108565.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/121595