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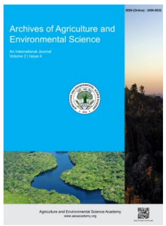

ORIGINAL RESEARCH ARTICLE

CrossMark

Effectiveness of pre-emergence herbicides on weed population and yield of *boro* rice (cv. BRRI dhan58) under different dose

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ABSTRACT

Weed management is crucial for optimal crop performance in rice cultivation. In this respect, an experiment was conducted at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh, from December 2019 to May 2020 and aimed to evaluate the effectiveness of various herbicide treatments on weed management and crop performance in rice cultivation, focusing on the variety BRRI dhan58. The study included a control group and various herbicide treatments: half the recommended dose (RD), RD, and a double dose of pendimethalin, bensulfuron methyl + acetachlor, bensulfuron methyl + bispyribac sodium, pretilachlor, and butachlor. Eleven weed species from six families infested the plots. The results showed that double doses of pre-emergence herbicides resulted in lower weed populations (WP) (m^{-2}), reduced weed dry weight (DW) (gm^{-2}), and higher weed control efficiency (WCE %). The highest weed control efficiencies at 30 DAT were 94.58% for B ensulfuron methyl + Acetachlor and 94.38% for Pretilachlor. The double dose of Bensulfuron methyl + Acetachlor achieved the lowest WP and DW and the highest WCE. Crop performance improved significantly with the double dose of Bensulfuron methyl + Acetachlor, resulting in the highest PH, a more significant number of effective tillers (NET) $hill^{-1}$, 1000-grain weight (TGW), grain yield (GY), straw yield (SY), biological yield (SY), and harvest index (HI). The second-highest GY was observed with the double dose of Bensulfuron methyl + Bispyribac sodium. The study concluded that the double dose of Bensulfuron methyl + Acetachlor was the most effective weed management strategy, leading to the highest grain yield in *boro* rice. These findings highlight that using a double dose of Bensulfuron methyl + Acetachlor not only offers superior weed control but also maximizes grain yield, making it the most effective weed management strategy for boro rice cultivation and a practical recommendation for farmers seeking to optimize productivity through targeted herbicide application.

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INTRODUCTION

In Bangladesh, rice (*Oryza sativa* L.) is the most important crop and one of the most delicate agricultural goods for local and international markets. The most important product's raw material is rice, which is also used to make some food items in the entire country. Rice is the staple food, with an average annual consumption rate per capita of 144.5 kg $year^{-1}$ (Yunus *et al.*, 2019). Bangladesh earns about 11.20% of its gross domestic product (GDP) from agriculture (BBS, 2023). Rice is a tropical crop cultivated in almost all parts of Bangladesh. There are three primary growing seasons for rice. Among the rice groups grown in our country, boro rice, in particular, covers 4852.29 thousand hectares of land with a production of 2076.76 thousand MT year^{-1} (BBS, 2023). Due to low-yielding varieties, heavy weed infestations, and inadequate crop management, the average rice production is declining. Weed infestation is the most prominent problem causing poor aus rice output among these issues. Weeds, including in Bangladesh, are among the most critical constraints to crop production worldwide. According to the ISWS conference (2020), approximately 11.5% of the global production of essential crops is lost as a result of weed infestation, according to estimates. Without weed control, rice production can be decreased by 16 to 88% or even 100% (Khanh *et al.*, 2013). The massive loss in yield presupposes weeds are seriously detrimental to crop production and must be prevented from growing or eliminated. It is a severe limitation of crop production for an overpopulated small country such as Bangladesh. Proper weed management is crucial for optimizing rice yields in Bangladesh, where various weeds, typically classified as grasses, sedges, and broadleaf weeds, commonly infest fields. Traditional weed control methods include preparatory land tillage, hand weeding with hoes, and hand pulling, with hand weeding being the most prevalent. Typically, two to three hand weedings are conducted per rice crop cycle, depending on the type and severity of weed infestation. However, heavy rainfall, flooding, high temperatures, or labor shortages can impede these traditional methods during critical periods (Chauhan *et al.*, 2015). The current reliance on post-emergence herbicides alone by rice growers has proven ineffective, highlighting the need for an integrated weed management strategy incorporating pre-emergence herbicides. Such strategies offer initial benefits by reducing weed pressure, enhancing crop competitiveness, and yielding economic benefits. A lot of research has shown that pre-emergence herbicides like pendimethalin, oxadiazon, butachlor, and pretilachlor work to get rid of weeds (Stickler *et al.*, 1969; Yang & Holmen, 2007; He *et al.*, 2013).

Pendimethalin is a dinitroaniline herbicide that breaks down microtubules needed to make microfibrils in the cell wall. This stops cells from growing and chromosomes from moving during mitosis in germinating seeds and young weed shoots (Appleby & Valverde, 1989). Oxadiazon stops protoporphyrinogen oxidase, an important enzyme for plant growth, which breaks down plant tissues (Dayan *et al.*, 2001). Butachlor and other chloroacetanilide herbicides, like pretilachlor, hinder enzymes from synthesizing chlorophyll and fatty acids (Gotz & Boger, 2004). Despite their proven efficacy, detailed information on the performance of pre-emergence herbicides still needs to be provided. Recent studies have reported significant increases in GY and effective weed control with these herbicides. For instance, a study found a 22% increase in GY with an 80 kg ha^{-1} seeding rate using pretilachlor (Onwuchekwa-Henry *et al.*, 2022). Awan *et al.* (2016) reported complete control of *E. colona*, *E. crus-galli*, and *Leptochloa chinensis* with oxadiazon. However, instances of phytotoxicity in rice from oxadiazon and pendimethalin have been noted, particularly in smallholder fields, which could adversely affect rice plant metabolism, morphology, and physiology (Awan *et al.*, 2016; Ryu *et al.*, 2020; Onwuchekwa-Henry *et al.*, 2023). However, the potential risks associated with herbicide overuse necessitate a deeper exploration of integrated weed management strategies.

Despite the proven efficacy of pre-emergence herbicides, further research is needed to compare their performance with traditional practices that omit them, especially under different post-emergence herbicide applications. This study aims to evaluate how pre-emergence herbicides impact weed biomass, rice growth, and yield, hypothesizing that their use will enhance grain yield (GY) and reduce weed biomass compared to fields without them. The research will explore various combinations of pre- and post-emergence treatments and seeding rates to provide crucial insights into optimal weed management strategies. Ultimately, the findings will inform best practices for sustainable agriculture, improving rice productivity, and ensuring food security in Bangladesh.

MATERIALS AND METHODS

Experimental site

The experiment at AFL, BAU, Mymensingh from December 2019 to May 2020, located at 90°50' E, 24°25'N, 18 m elevation, was conducted in the Old Brahmaputra floodplain (AEZ-9) (FAO & UNDP, 1988). The soil was silty loam, nearly neutral pH (6.82), moderate organic matter and fertility. The subtropical climate features high temperatures and heavy rainfall during Kharif (April-September) and low rainfall with moderate temperatures during Rabi (October-March). Detailed soil and climate data are in Tables 1 and 2.

Experimental design and treatment factors

Two components made up the experimental treatment, viz. Factor A contains name of herbicide, such as: Pendimethalin (H_1), Bensulfuron methyl + Acetachlor (H_2), Bensulfuron methyl + Bispyriback Sodium (H_3), Pretilachlor (H_4), Butachlor (H_5). Factor B formed: Control (D_1), Half of RD (D_2), RD (D_3), Double of RD (D_4). The experiment was conducted with a RCBD, arranged in a factorial way using three replications. Total number of plots were 60 and each plot size was 4.0 m × 2.5 m.

Phytotoxicity of herbicides to rice plants

The phytotoxicity of herbicides to rice plants was assessed through visual observation, noting symptoms such as leaf yellowing, leaf-tip burning, and stunted growth, following the IRRI (1965) guidelines. The observed toxicity levels were categorized as no, slight, moderate, severe, and toxic.

Preparation of plots and crop husbandry

A designated plot was meticulously prepared for seedling cultivation. Initially, the soil was thoroughly puddled using a traditional country plough and levelled using a ladder. The plot was partitioned into two symmetrical sections for the sowing of sprouted seeds in a wet nursery bed on December 2, 2019. Measures were implemented to promote the healthy

Table 1 (a-c). The morphological, physical and chemical properties of the experimental field.

(a) Morphological characteristics of the soil.

Parameters	Characteristics
Location	AFL, BAU, Mymensingh.
Soil tract	Old Brahmaputra Alluvium
Land type	Medium high land
General soil type	Non-calcareous dark grey floodplain
Soil series	Sonatola
Agro-ecological zone	Old Brahmaputra Floodplain (AEZ-9)
Topography	Fairly level
Flood level	Above flood level
Soil colour	Dark grey
Drainage	Moderate
Vegetation	Cropped with rice, wheat, maize etc.

(b) Physical characteristics of the soil.

Soil properties/constituents	Values
Sand (%) (0.2-0.02 min)	20
Silt (%) (0.02-0.002 min)	67
Clay (%) (<0.002 min)	13
Soil textural class	Silt loam
Particle density (g/cc)	2.60
Bulk density (g/cc)	1.35
Porosity (%)	46.67

(b) Chemical characteristics of the soil

Parameters	Value
pH	6.82
Soil texture	Silt loam
Organic carbon (%)	1.77
Total nitrogen	0.66
Carbon: Nitrogen	11.06
Available phosphorus (ppm)	15.67
Exchangeable potassium	0.087
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 (°C)		Relative humidity (%)		Sunshine (hrs.)	Rainfall (mm)
		Max.	Min.	Max.	Min.		
2019	December	25.96	13.52	96.06	48.77	6.49	0.29
	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
2020	March	29.98	18.82	92.7	46.43	10.00	58.06
	April	31.78	22.23	92.36	70.01	6.45	66.80
	May	42.24	24.18	92.37	66.60	5.11	11.07

Source: Weather Yard, Department of Irrigation and Water Management, BAU, Mymensingh.

development of seedlings, including regular weeding and necessary irrigation. Preparation of the experimental land commenced with a tractor-drawn disc plough, followed by intensive puddling achieved through multiple rounds of ploughing and cross ploughing with a power tiller. Subsequent levelling was performed using a ladder. The experimental setup was finalized on December 28, 2019, with precise adherence to the experimental design, which included removing all weeds and stubbles from each plot. Fertilization of the experimental plots involved the application of urea, triple super phosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulphate at rates of 220, 120, 150, 85, and 10 kg ha^{-1}, respectively. The total quantities of TSP, MoP, gypsum, and zinc sulphate were incorporated during the final land preparation phase. According to BRRI (2013), urea was strategically top-dressed in three equal installments at three crucial growth stages: 15 days after transplanting (DAT), during tillering, and at panicle initiation. To ensure minimal disruption during transplantation, the nursery bed was irrigated one day before the uprooting of the seedlings, which facilitated their easy extraction with minimal mechanical damage to the roots. The seedlings, aged forty days, were transplanted into the well-prepared, puddled field on January 12, 2020. Planting was executed at a density of three seedlings per hill, with rows spaced 25 cm apart and hills spaced 15 cm apart, ensuring optimal growth conditions.

Harvesting and data collection

Data regarding WP at 30 DAT were systematically gathered from each experimental plot utilizing a 0.50 m × 0.50 m quadrat in accordance with the methodology outlined by Cruz *et al.* (1986). Weeds within each quadrat were enumerated and subsequently converted to a density per square meter by multiplying by a factor of four. Following the WP assessment, the weeds from each quadrat were meticulously uprooted, cleaned, and classified by species. The collected weed samples were then subjected to sun drying followed by dehydration in an electric oven maintained at 80°C for a duration of 72 hours. The DW of each species was determined using an electronic balance and recorded in grams per square meter, ensuring the accuracy and reliability of the data. Weed control efficiency of different weed control treatments was calculated using the following formula:

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

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

The harvesting process was carried out when the crops reached the appropriate level of maturity for harvesting and 1 m^2 area was chosen in the central section of each plot to measure the GY and SY. The GY was converted to a moisture content of 14% and translated to metric tons hectare^{-1}. No. of total tiller hill^{-1}, and total DW hill^{-1}were recorded for each plot, with five hills being tagged. The data was collected 30 DAT. During the harvest, many measurements were taken, including PH, NET hill^{-1}, panicle length (PL), number of grains panicle^{-1} (NG), 1000-grain weight (TGW), GY, and SY. Subsequently, the BY and HI were computed.

Statistical analysis

The recorded data were compiled and tabulated for statistical analysis. Variance analysis was performed using the MSTAT-C software package. The mean differences among the treatments were evaluated using Duncan's Multiple Range Test (Gomez & Gomez, 1984).

RESULTS AND DISCUSSION

Eleven weed species belonging to six families infested in the experimental field. Among the eleven species of weeds five were grasses, three were broad leaves and four were sedges: Local name, scientific name, family, morphological type and life cycle of the weed in the experimental plot have been presented in (Table 3).

Effect of herbicidal doses on WP and species

Total WP and species m^{-2} was influenced by weed management practices. The highest WP (m^{-2}) was found in control treatment, showing the highest WP values of 3.66, 3.66, 3.73, 3.80, 20.60, 4.13, 3.93, 3.66, 4.0 and 3.93 m-2 at 30 DAT and the lowest WP (m^{-2}) was found in the double dose of treatment, showing the values 0.4, 0.46, 0.73, 0.66, 0.73, 0.6, 0.4, 0.6 and 0.6m^{-2} at 30 DAT (Figure 1). Weed density was the highest in control condition where under different herbicidal dose treatments weed density were decreased. Despite the effectiveness of herbicides, excessive use can result in herbicide resistance among weed species, as observed in *Echinochloa crus-galli* and *Digitaria sanguinalis*, which survived even under high doses (Nur-A-Alam *et al.*, 2024).

Effect of herbicide on WP and species

WP and species m^{-2} was influenced by weed management practices. The lowest WP (m^{-2}) was found in Bensulfuron methyl + Acetachlor and Pretilachlor herbicide treatment m-2 at 30 DAT followed by the treatment of Pendimethalin, Bensulfuron methyl + Bispyriback sodium and Butachlor herbicide m^{-2} respectively at 30 DAT (Figure 2). The findings of this study align with other research emphasizing the importance of pre-emergence and post-emergence herbicides for effective weed management in rice cultivation. Pre-emergence herbicides, such as Bensulfuron methyl and Acetachlor, have proven effective in controlling weed populations and enhancing crop yield, particularly in boro rice (Nur-A-Alam *et al.*, 2024; Rahman *et al.*, 2024).

Table 3. Infested weed species were found in the experimental rice plots.

Local name	Scientific name	Family	Morphological type	Life cycle
Boro shama	*Echinochola cruss-galli*	Gramineae	Grass	Annual
Boro angulee	*Digitaria sanguinalis*	Gramineae	Grass	Annual
Choto angulee	*Digitaria ischaemum*	Gramineae	Grass	Annual
Arail	*Leersia hexandra*	Gramineae	Grass	Perennial
Angta	*Panicum repens*	Gramineae	Grass	Perennial
Amrul	*Oxalis europaea*	Oxalidaceae	Compound leaved	Perennial
Pani kachu	*Monochoria hastata*	Pontederiaceae	Broad leaved	Perennial
Sabuj nakful	*Cyperus difformis*	Cyperaceae	Sedge	Annual
Helencha	*Enhydra fluctuans*	Onagraceae	Broad leaves	Annual
Chechra	*Scirpus mucronatus*	Cyperaceae	Sedge	Perennial
Nolchaise	*Scirpus articulatus*	Cyperaceae	Sedge	Annual

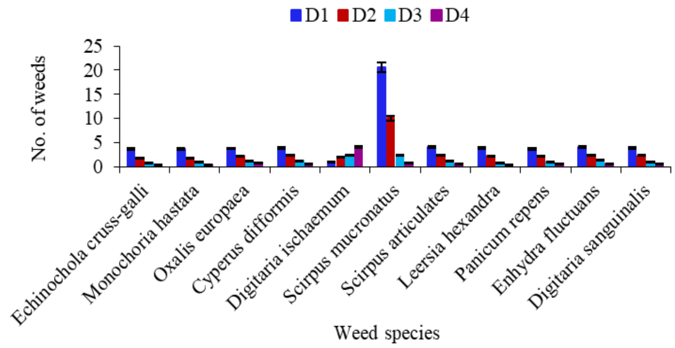

Figure 1. *Effect of different herbicidal dose on different weed species. Here, D_1- No herbicide, D_2-Half of recommended dose, D_3-Recommended dose, D_4-Double of the recommended dose.*

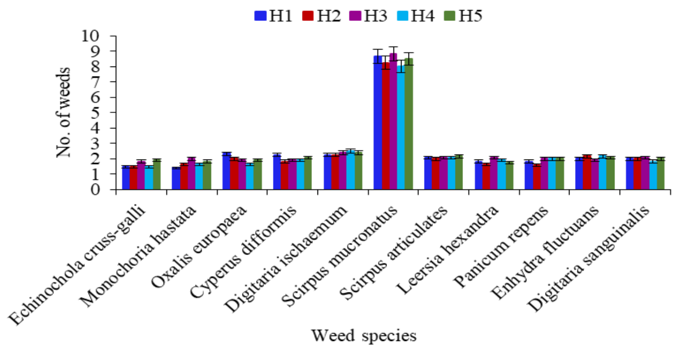

Figure 2. *Effect of herbicides on different weed species. Here, H_1-Pendimethalin, H_2-Bensulfuron methyl+ Acetachlor, H_3-Bensulfuron methyl + Bispyriback sodium, H_4- Pretilachlor, H_5-Butachlor*

Interaction effect between herbicide and doses on WP and species

WP and species m^{-2} was influenced by weed management practices. The highest WP (m^{-2}) was found in control treatment at 30 DAT and the lowest WP (m^{-2}) was found in the double dose of treatment Bensulfuron methyl + Acetachlor followed by pretilachlor, pendimethalin, Bensulfuron methyl Bispyriback sodium and Butachlor at 30 DAT (Table 4). However, the increased reliance on herbicides also raises concerns about the potential for herbicide resistance, as highlighted by cases where certain weed species survived even with double herbicide doses (Rahman *et al.*, 2024; Zinnat *et al.*, 2024).

Effect of herbicidal dose on WCE

There was significant effect on WCE (%) at 30 DAT. The highest WCE (%) was found in double of the RD showing the highest values of 93.13% at DAT and 0.00 (%) was found in control treatment at 30 DAT (Figure 3). Herbicide management strategies must consider the ecological impact and the risk of resistance buildup. Excessive herbicide use has been associated with environmental degradation and shifts in weed dynamics, posing challenges for long-term sustainability (Akondo *et al.*, 2024). As a result, many studies recommend integrating herbicides with non-chemical weed control methods, such as the use of crop residue extracts, to achieve sustainable weed management (Tonni *et al.*, 2024). For example, aqueous extracts from grass pea residues, when combined with post-emergence herbicides, have been shown to enhance weed control efficiency (WCE) and yield performance in boro rice (Zinnat *et al.*, 2024).

Table 4. Interaction effect between herbicide and doses on WP and species.

Interaction	*E. crussgalli*	*M. hastata*	*O. europaea*	*C. difformis*	*D. ischaemum*	*S. mucronatus*	*S. articulates*	*L. hexandra*	*P. repens*	*E. fluctuans*	*D. sanguinalis*
H_1D_1	3.33ab	3.33	4.00a	4.00a	4.00a	20.66b	5.00	4.00a	3.33ab	4.00	4.00a
H_1D_2	1.33cd	1.00	3.00abc	3.33ab	2.33bc	10.33c	2.33	2.33b	2.33bc	2.33	2.33b
H_1D_3	0.66de	1.00	1.33def	1.00d	1.66bcd	3.00d	0.66	0.66cd	1.00de	1.33	1.00c
H_1D_4	0.66de	0.33	1.00ef	0.66d	1.00de	0.66e	0.33	0.33d	0.66de	0.33	0.66c
H_2D_1	4.00a	3.66	4.00a	4.00a	4.00a	19.00b	4.00	4.00a	3.33ab	4.33	4.00a
H_2D_2	1.33cd	1.66	2.00cde	1.66cd	2.00bcd	10.00c	2.00	1.66bc	1.66cd	2.33	2.33b
H_2D_3	0.66de	1.00	1.33def	1.00d	1.66bcd	3.00d	1.33	0.66cd	0.66de	1.33	1.00c
H_2D_4	0.00e	0.33	0.66f	0.66d	1.33cde	1.00e	0.66	0.33d	0.66de	0.66	0.66c
H_3D_1	3.66a	4.00	4.00a	3.33ab	4.00a	23.33a	4.00	4.00a	4.00a	3.66	4.00a
H_3D_2	2.33bc	2.33	2.00cde	2.33bc	2.33bc	9.66c	2.33	2.33b	2.33bc	2.33	2.33b
H_3D_3	0.66de	1.00	1.00ef	1.33cd	2.00bcd	1.66de	1.33	1.33bcd	1.00de	1.00	1.33bc
H_3D_4	0.66de	0.66	0.66f	0.66d	1.33cde	0.66e	0.66	0.66cd	0.66de	0.66	0.66c
H_4D_1	3.66a	4.00	3.33ab	3.66a	4.00a	19.66b	4.00	4.00a	3.66a	4.00	4.00a
H_4D_2	1.66cd	1.66	1.66def	2.33bc	2.66b	9.66c	2.33	2.33b	2.33bc	2.33	2.33b
H_4D_3	0.66de	0.66	1.00ef	1.00d	2.00bcd	2.00de	1.33	1.00cd	1.33cde	1.66	0.66c
H_4D_4	0.00e	0.33	0.66f	0.66d	1.33cde	0.66e	0.66	0.33d	0.66de	0.66	0.33c
H_5D_1	3.66a	3.33	3.33ab	4.00a	4.33a	20.33b	3.66	3.66a	4.00a	4.00	3.66a
H_5D_2	2.33bc	2.33	2.33bcd	2.33bc	2.66b	10.66c	2.66	2.33b	2.33bc	2.33	2.33b
H_5D_3	1.00de	1.00	1.33def	1.33cd	2.33bc	2.33de	1.66	0.66cd	1.33cde	1.33	1.33bc
H_5D_4	0.66de	0.66	0.66f	0.66d	0.33e	0.66e	0.66	0.33d	0.33e	0.66	0.66c
$LSD_{(0.05)}$	1.07	1.32	1.27	1.16	1.27	1.97	1.33	1.16	1.04	1.23	1.31
Level of Significance	**	NS	**	**	**	**	NS	**	**	NS	**
CV%	20.40	21.01	19.02	12.49	12.88	11.93	16.49	18.01	17.34	23.94	20.13

Here, means with the same letters within the same column do not differ significantly, ** - Significant at 1% level of probability, NS – Non significant, H_1 -Pendimethalin, H_2-Bensulfuron methyl + Acetachlor, H_3- Bensulfuron methyl + Bispyriback sodium, H_4-Pretilachlor, H_5-Butachlor, D_1- No herbicide, D_2-Half of recommended dose, D_3-Recommended dose, D_4-Double of the recommended dose.

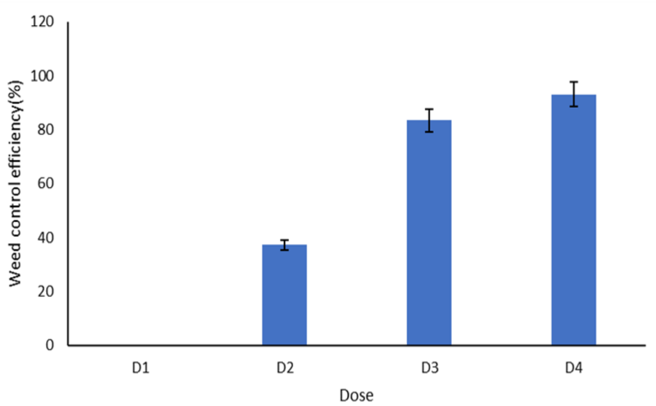

Figure 3. *Effect of dose of herbicide on weed control efficiency. Here, D_1- No herbicide, D_2-Half of recommended dose, D_3-Recommended dose, D_4-Double of the recommended dose.*

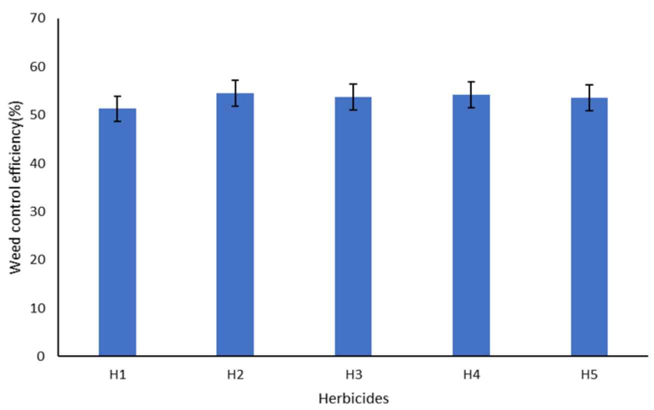

Figure 4. *Effect of different herbicide on weed control efficiency. Here, H_1-Pendimethalin, H_2-Bensulfuron methyl+ Acetachlor, H_3- Bensulfuron methyl + Bispyriback sodium, H_4-Pretilachlor, H_5- Butachlor*

Effect of different herbicide on WCE

Significant variation was found on WCE (%) at 30 DAT. The highest WCE (%) was found in Bensulfuron methyl + Acetachlor treatment achieving the highest efficiency of 54.49% at 30 DAT followed by Pretilachlor, Bensulfuron methyl + Bispyriback Sodium, Butachlor and Pendimethalin (Figure 4). Herbicides play a pivotal role in enhancing weed control efficiency (WCE), directly impacting crop productivity by reducing competition between crops and weeds. The application of both pre-emergence and post-emergence herbicides has proven to be an effective strategy to suppress weed populations, minimizing their impact on yield. Nur-A-Alam *et al.* (2024) reported that using double the recommended dose (RD) of herbicides such as Penoxsulam and Triafamone achieved the highest WCE, reaching 91.09% and 90.13%, respectively, in boro rice fields. These results demonstrate that higher doses of herbicides significantly reduce weed density and biomass, promoting favorable conditions for crop growth.

Effect of doses of herbicide on yield and yield contributing characters of boro rice

Herbicidal doses had a non-significant effect on PL, NGP, and TGW. However, the highest PL, NGP, and TGW (18.93 cm, 86.96, 25.89 g) were observed with double herbicide doses. PH, NET hill^{-1}, GY, SY, BY, and HI were significantly influenced by weed management treatments. The highest PH and NET hill^{-1} (93.33 cm, 7.92) were achieved with the RD of herbicide. The highest GY, SY, BY, and HI (5.10 t ha^{-1}, 6.47 t ha^{-1}, 11.57 t ha^{-1}, 44.07%) were with double herbicide doses (Table 5). Herbicide efficacy varies based on the timing and dosage of application. The combined use of pre- and post-emergence herbicides improves crop competitiveness by reducing early weed pressure (Mostafa *et al.*, 2024). The integration of pre-emergence applications, such as Bensulfuron methyl and Acetachlor, with post-emergence herbicides has shown enhanced weed control and yield performance, particularly in boro rice (Rahman *et al.*, 2024; Dola *et al.*, 2024).

Effect of herbicides on yield and yield contributing characters of boro rice

Effect of herbicide were found non-significant on PL, NGP. PH, NET hill^{-1}, TGW, GY, SY, BY and HI were significantly influenced by different weed management treatments. The highest PH, NET hill^{-1}, TGW, GY, BY and HI (91.60 cm, 7.86, 26.17 g, 4.10 t ha^{-1}, 9.53 t ha^{-1}, 42.72%) were produced when Pendimethalin were applied. Conversely, the lowest PH (90.80 cm) was observed with Butachlor, although this treatment also resulted in a high SY (5.70 t ha^{-1}) and BY (9.71 t ha^{-1}). Pretilachlor showed lower effectiveness in terms of GY (3.61 t ha^{-1}) and HI (40.58%), despite having comparable plant height and panicle length to other treatments (Table 6). Pre-emergence and post-emergence herbicides have been identified as essential tools in this regard. For instance, Mostafa *et al.* (2024) found that double the recommended dose (RD) of Penoxsulam and Triafamone achieved the highest weed control efficiency (WCE), with significant improvements in grain yield (GY) and other yield attributes.

Table 5. Effect of herbicidal dose 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	88.20d	7.20b	19	85.46	25.88	2.89d	4.37d	7.26d	39.64d
D_2	91.26c	7.74a	18.93	85.19	25.55	3.28c	4.82c	8.10c	40.49c
D_3	93.33a	7.78a	18.82	86.44	25.45	4.22b	5.85b	10.07b	41.94b
D_4	92.40b	7.92a	18.93	86.96	25.89	5.10a	6.47a	11.57a	44.07a
LSD $_{(0.05)}$	0.84	0.31	0.59	1.28	0.59	0.13	0.18	0.29	0.54
Level of significant	**	**	NS	NS	NS	**	**	**	**
CV%	1.23	5.45	4.24	2.00	3.08	4.59	4.49	4.33	1.77

Here, means with the same letters or without letters within the same column do not differ significantly as per DMRT, ** -Significant at 1% level of probability, * - Significant at 5% level of probability, NS – Non significant, D_1- No herbicide, D_2-Half of recommended dose, D_3-Recommended dose, D_4 -Double of recommended dose.

Table 6. 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	91.30ab	7.80ab	19.12	87.68	25.83ab	3.61b	5.04c	8.66b	41.37bc
H_2	91.60a	7.86a	18.77	86.42	26.17a	4.10a	5.43b	9.53a	42.72a
H_3	91.40a	7.64ab	18.96	86.21	25.30b	4.02a	5.50b	9.53a	41.99ab
H_4	91.38ab	7.49b	18.75	84.56	25.40b	3.61b	5.21c	8.83b	40.58d
H_5	90.80b	7.51b	19	85.22	25.76ab	4.00a	5.70a	9.71a	41.00cd
LSD $_{(0.05)}$	0.57	0.34	0.69	3.49	0.71	0.24	0.20	0.44	0.77
Level of significant	**	**	NS	NS	**	**	**	**	**
CV%	0.67	4.78	3.89	4.31	2.93	6.80	3.95	5.07	1.99

Here, means with the same letters within the same column do not differ significantly as per DMRT. ** - Significant at 1% level of probability, NS – Non significant, H_1-Pendimethalin, H_2-Bensulfuron methyl + Acetachlor, H_3- Bensulfuron methyl + Bispyriback sodium, H_4-Pretilachlor, H_5-Butachlor.

Table 7. Combined effect of herbicide and dose on yield and yield contributing characters of *boro* rice.

Interaction	Herbicide	PH (cm)	NET hill^{-1}	PL (cm)	NGP	TGW (g)	GY (t ha^{-1})	SY (t ha^{-1})	BY (t ha^{-1})
H_1D_1	87.93g	6.93g	18.88	87.89	26.62	2.24g	3.56k	5.80i	38.56i
H_1D_2	92.76abc	7.80abcdef	18.98	90.13	25.36	3.24ef	4.46ij	7.70gh	42.01cd
H_1D_3	91.30cde	8.00abc	19.49	88.87	25.65	4.12d	6.01c	10.13d	40.67ef
H_1D_4	93.23ab	8.46a	19.13	83.83	25.71	4.86c	6.13c	11.00bc	44.25a
H_2D_1	88.73fg	7.60bcdefg	18.6	85.30	26.11	3.36e	4.82ghi	8.18efg	41.12cdef
H_2D_2	91.30cde	7.86abcd	19.12	86.62	26.1	3.36e	4.90fgh	8.26efg	40.69ef
H_2D_3	93.70ab	7.73bcdef	18.63	86.20	26.23	4.33d	5.43de	9.76d	44.37a
H_2D_4	92.66abc	8.26ab	18.76	87.56	26.25	5.33a	6.60ab	11.93a	44.70a
H_3D_1	88.43g	7.20defg	19.18	86.53	25.59	3.24ef	5.03efgh	8.28efg	39.20ghi
H_3D_2	91.16cde	7.80abcdef	18.59	82.54	25.49	3.50e	5.08efg	8.58ef	40.74def
H_3D_3	93.50ab	7.83abcde	18.66	87.93	24.42	4.26d	5.56d	9.83d	43.40ab
H_3D_4	92.53abcd	7.73bcdef	19.41	87.83	25.69	5.10abc	6.33abc	11.43ab	44.61a
H_4D_1	88.13g	7.16efg	18.98	82.28	25.42	2.36g	3.80k	6.16i	38.40i
H_4D_2	90.83de	7.73bcdef	19.15	87.89	25.34	2.93f	4.36j	7.30h	40.17efg
H_4D_3	94.23a	7.66bcdef	18.64	90.13	25.74	4.23d	6.00c	10.23d	41.36cde
H_4D_4	92.33bcd	7.40cdefg	18.24	88.87	25.08	4.93bc	6.70a	11.63ab	42.40bc
H_5D_1	87.76g	7.13fg	19.38	83.83	25.64	3.23ef	4.66hij	7.90fgh	40.90def
H_5D_2	90.26ef	7.53cdefg	18.81	85.30	25.45	3.36e	5.30def	8.66e	38.85hi
H_5D_3	93.93ab	7.66bcdef	18.66	86.62	25.24	4.16d	6.26bc	10.43cd	39.90fgh
H_5D_4	91.26cde	7.73bcdef	19.14	86.20	26.71	5.26ab	6.60ab	11.86a	44.37a
LSD $_{(0.05)}$	1.87	0.69	1.35	4.27	1.34	0.35	0.41	0.72	1.22
Level of significant	**	**	NS	NS	NS	**	**	**	**
CV%	1.23	5.45	4.24	2.00	3.08	4.59	4.49	4.33	1.77

Here, means with the same letters within the same column do not differ significantly, ** - Significant at 1% level of probability, NS – Non significant, H_1 -Pendimethalin, H_2-Bensulfuron methyl + Acetachlor, H_3- Bensulfuron methyl + Bispyriback sodium, H_4-Pretilachlor, H_5-Butachlor, D_1- No herbicide, D_2-Half of recommended dose, D_3-Recommended dose, D_4-Double of the recommended dose.

Combined effect of herbicide and dose on yield and yield contributing characters of boro rice

The interaction between herbicide types and doses significantly influenced PH, NET hill^{-1}, GY, SY, BY, and HI, but not PL, NGP, and TGW. The highest PH (94.23 cm) was with the RD of Pretilachlor, and the lowest (87.76 cm) with no herbicide. NET hill^{-1} was highest (8.46) with the RD of Pendimethalin. The highest GY (5.33 t ha^{-1}) was achieved with double doses of Bensulfuron methyl + Acetachlor, while the lowest (2.24 t ha^{-1}) was in the control treatment. Double doses also maximized BY confirming their superior effectiveness in boro rice (Nur-A-Alam *et al*., 2024, Mim *et al*., 2024). The findings from recent studies highlight the significance of herbicides in achieving optimal yield and managing weeds in rice cultivation. Effective weed management is critical for minimizing competition between crops and weeds, which significantly impacts yield and yield-contributing characters, such as the number of effective tillers, 1000-grain weight (TGW), and straw yield (Zinnat *et al*., 2024).

Conclusion

The experimental findings demonstrated that the BRRI dhan58 variety achieved maximum yields when grown with double the recommended dose (RD) of Bensulfuron methyl + Acetachlor, applied at 5 days after transplanting (DAT). This treatment proved to be the most effective weed management strategy, significantly reducing weed infestation and enhancing crop performance. However, further trials across different Agro-ecological zones in Bangladesh are recommended to validate these results and ensure their broader applicability.

DECLARATIONS

Author contribution statement

Conceptualization: M.Z.H., U.K.S., M.D.H. and M.R.U.; Methodology: M.Z.H., M.T.A.; Software and validation: M.T.A.; Formal analysis and investigation: M.Z.H.; Resources: M.Z.H.; Data curation: M.Z.H.; Writing—original draft preparation: M.Z.H. and M.T.A.; Writing—review and editing: M.D.H., M.S.R., U.K.S. and M.R.U; Visualization: M.Z.H..; Supervision: M.R.U.; Project administration: M.R.U.; Funding acquisition: M.R.U. All authors have read and agreed to the published version of the manuscript.

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