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Dose Response of Post-emergence Herbicides for Prediction of Herbicide Resistant Weeds and Yield of *Boro* rice (cv. BRRI dhan58)

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Abstract: Weed management is vital for achieving optimal crop performance and yield in rice cultivation. Post-emergence herbicides are widely used to control weed populations, but their effectiveness can vary with different dosages and combinations. In this phenomenon, an experiment conducted at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh, from December 2019 to May 2020, studied the dose response of post-emergence herbicides on herbicide-resistant weeds and *boro* rice (cv. BRRI dhan58). The herbicides tested included H_1-Ethoxysulfuron, H_2-Penoxsulam + Escape 35 WP, H_3-Sentry 25 EC + Escape 35 WP, H_4-Agroxone, and H_5-Cut out 10 WP, at four dosages: D_1-no herbicide, D_2-half the recommended dose, D_3-recommended dose, and D_4-double the recommended dose. Using a split-plot design with three replications, herbicide doses were the main plot and herbicide types the subplot. Results showed significant effects on weed dry weight, population, and inhibition. Twelve weed species from five families, including *Echinochloa crus-galli, Monochoria hastata, Leersia hexandra, Cyperus difformis*, and *Scirpus mucronatus*, infested the plots. H_2 (Penoxsulam + Escape 35 WP) and H_3 (Sentry 25 EC + Escape 35 WP) demonstrated superior weed control and rice growth. The recommended (D_3) and double doses yielded the best results. The H_5D_4 combination achieved the highest weed control efficiency (90.58%), and H_1D_4 interaction observed in the maximum grain yield (6.05 t ha^{-1}), straw yield (7.20 t ha^{-1}), biological yield (13.25 t ha^{-1}), and harvest index (45.67%). Weed density results indicated that *Echinochloa crus-galli, Scirpus articulates, Leersia hexandra*, and *Digitaria sanguinalis* survived even at double doses. So, post emergence herbicides can be effectively used for identification of herbicide resistant weeds and yield of *boro* rice.

Keywords: Resistant weeds; Herbicides; *Boro* rice; Grain yield.

INTRODUCTION

In Bangladesh, rice (*Oryza sativa*) is the most important crop and a crucial 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 (Yunus *et al*. 2019). Agriculture contributes approximately 11.20% to the country's gross domestic product (GDP) (BBS, 2023). 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 (BBS, 2023). 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 aus rice production. Weeds are critical constraints to crop production worldwide, including in Bangladesh. According to the ISWS conference (2020), approximately 11.5% of global essential crop production is lost due to weed infestation. Without weed control, rice production can decrease by 16 to 88%, or even up to 100% (Khanh *et al*. 2013). 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 at critical periods using traditional methods (Chauhan *et al*. 2015).

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 (Rahman, 2020; Rajput *et al*. 2020). 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 (Gitsopoulos and Froud-Williams *et al*. 2004).

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 (Anwar *et al.* 2012). 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 (Chauhan *et al*. 2012).

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.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Agronomy Field Laboratory (AFL), Bangladesh Agricultural University (BAU), Mymensingh, from December 2019 to June 2020. The study location is situated at 90°50′ E longitude, 24°25′ N latitude, and an elevation of 18 meters above sea level. It is part of the Old Brahmaputra floodplain (AEZ-9) (FAO & UNDP, 1988) (Figure. 1). The soil of the experimental field was nearly neutral with a pH value of 6.8, moderate in organic matter, and had a moderate fertility level. The land type was medium high, with a silty loam texture. The climate of the locality is sub-tropical, characterized by high temperatures and heavy rainfall during the Kharif season (April to September) and minimal rainfall with moderately low temperatures during the Rabi season (October to March). Detailed information on the monthly mean values of daily maximum, minimum, and average temperatures, relative humidity, monthly total rainfall, and sunshine hours received at the experimental station during the study period was recorded.

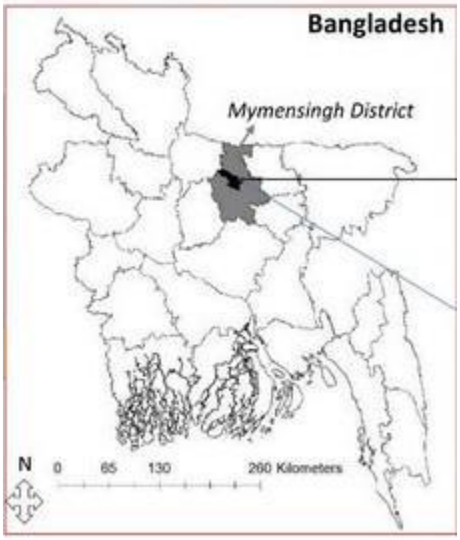

Figure 1. Map of the study area

Experimental treatments and design

The experiment consists of two components. Factor A contains four doses of herbicides such as: Control (D_1), Half of RD of herbicide (D_2), RD of herbicide (D_3), Double of the RD of herbicide (D_4). Factor B formed, viz. Ethoxysulfuron (H_1), Penoxsulam+ Escape 35 WP (H_2), Sentry 25 EC + Escape 35 WP (H_3), Agroxone (H_4), Cut out 10 WP (H_5). The experiment was laid out in a split plot design with 3 replications where doses of herbicide were in the main plot and herbicide were in the sub plot. Total numbers of plots were 5×4×3= 60 and each plot size was 4.0 m × 2.5 m. The distance maintained between the individual plots was 0.5 m and that between the replications 1.0 m.

Preparation of plots and Crop husbandry

A section of land was selected for cultivating seedlings, thoroughly puddled with a country plough and leveled using a ladder. This area was evenly split into two parts for planting sprouted seeds. On December 1, 2019, these seeds were sown in a wet nursery bed with meticulous attention to nurturing robust seedlings. Weeding and necessary irrigation were consistently managed. The field was initially broken up with a power tiller and subsequently ploughed four times with a country plough, followed by laddering. Post this intensive preparation, the field's layout

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was designed, and all weeds and stubbles were cleared from each plot.

For fertilization, 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 were applied. The complete quantities of TSP, MoP, and gypsum were administered during the final stage of land preparation. Urea was distributed in three equal parts at 15, 30, and 45 days after transplanting (DAT) (BRRI, 2013). The nursery bed was moistened a day prior to uprooting the seedlings to minimize mechanical damage to the roots. These seedlings were uprooted on January 11, 2020 and promptly moved to the main field.

On the same day, 40-day-old seedlings were transplanted into the meticulously prepared puddled field at a density of three seedlings per hill, with rows and hills spaced at 25 cm and 15 cm apart, respectively.

Harvesting and data collection

Data on weed population (30 DAT) were collected from each plot of the rice plants using a 0.50 m × 0.50 m quadrate, as described by Cruz *et al*. (1986). The weeds within the quadrate were counted and converted to the number per square meter (m^2) by multiplying by four. After measuring the weed density, the weeds inside each quadrate were uprooted, cleaned, and separated by species. The weed samples were then dried in the sun and subsequently placed in an electric oven for 72 hours at a temperature of 80°C. The dry weight (DW) of each species was measured using an electric balance and expressed in grams per square meter (g m^2). The 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 was conducted once the crops reached optimal maturity, and a 1 m^2 area in the central part of each plot was designated for assessing 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 per hill (NTT) and total dry weight per hill (DW) were also recorded for each plot, with five hills marked for tracking. This data was gathered at 30 days after transplanting (DAT). During harvest, several parameters were measured including plant height (PH), number of effective tillers per hill (NET), panicle length (PL), number of grains per panicle (NG), 1000-grain weight (TGW), grain yield (GY), and straw yield (SY). Following these measurements, the biological yield (BY) and harvest index (HI) were calculated.

Statistical analysis

The recorded data were compiled and tabulated for statistical analysis. Analysis of variance was done with the help of computer package, MSTAT-C. The mean differences among the treatments were adjudged by Duncan's Multiple Range Test (Gomez and Gomez, 1984).

RESULT AND DISCUSSION

Twelve weed species from six families were present in the experimental field. Among these species, five are grasses, three are broadleaf species, and four are sedges. The local names, scientific names, morphological forms, and life cycles of weeds in the experimental plots are presented in Table 1. The significant weeds in the experimental plots included *Echinochloa crus-galli*, *Monochoria hastata*, *Leersia hexandra*, *Cyperus difformis*, *Scirpus mucronatus*, *Scirpus articulatus*, *Panicum repens*, *Digitaria ischaemum*, *Digitaria sanguinalis*, *Enhydra fluctuans*, *Spilanthes acmella*, and *Oxalis europaea*. Dola *et al*. (2024) and Akondo *et al*. (2024) found the similar weed species in the crop field.

Table 1. Infested weed species were found in the experimental rice plots

Local name	Scientific name	Family	Morphological type	Life cycle
Shama	*E. cruss-galli*	Poaceae	Grass	Annual
Boro angulee	*D. sanguinalis*	Poaceae	Grass	Annual
Chotoangulee	*D. ischaemum*	Poaceae	Grass	Annual
Arail	*L. hexandra*	Poaceae	Grass	Perennial
Angta	*P. repens*	Poaceae	Grass	Perennial
Amrul	*O. europaea*	Oxalidaceae	Leaves	Perennial
Panikachu	*M. hastata*	Pontederiaceae	Broad leaved	Perennial
Sabujnakful	*C. difformis*	Cyperaceae	Sedge	Annual
Helencha	*E. fluctuans*	Onagraceae	Broad leaves	Annual
Chechra	*S. mucronatus*	Cyperaceae	Sedge	Perennial
Noldug	*S. articulatus*	Cyperaceae	Sedge	Annual
Holodnakful	*S. acmella*	Cyperaceae	Sedge	Annual

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Effect of herbicides on density of weed species

Most of the weed species showed no significant differences across treatments, *Sagittaria articulatus* and *Spilanthes acmella* were significantly affected. Specifically, *Sagittaria articulatus* had the highest density under the Ethoxysulfuron treatment, while *Spilanthes acmella* showed increased density with Penoxsulam + Escape 35 WP and Agroxone treatments. The lowest weed population (1.33 m^{-2}) was found with Ethoxysulfuron, and the highest weed population (7.08 m^{-2}) was observed with Sentry 25 EC + Escape 35 WP (Table 2). Similar findings were reported by Zahan *et al.* (2017), who noted significant variations in weed species under different herbicide applications.

Table 2. Effect of doses of herbicide on density of weed

Herbicide	*E. cruss-galli*	*M. hastata*	*O. europaea*	*C. difformis*	*D. ischaemum*	*S. mucronatus*	*S. articulatus*	*L. hexandra*	*P. repens*	*E. fluctuans*	*D. sanguinalis*	*S. acmella*
H_1	2.58	1.66	2.91	2.41	1.75	6.58	3.25 a	1.66	2.00	1.58	1.66	1.33 b
H_2	2.41	1.66	2.58	2.16	1.75	6.41	2.66 b	1.75	1.66	1.66	1.75	1.83 a
H_3	2.25	1.66	2.66	2.41	2.08	7.08	2.66 b	1.75	1.66	1.91	2.00	1.58 ab
H_4	2.50	1.75	2.33	2.66	1.83	6.75	2.75 ab	2.00	1.91	1.58	1.58	1.75 a
H_5	2.16	1.75	2.5	2.33	1.91	6.5	3.00 ab	1.83	1.83	1.75	1.91	1.75 a
$LSD_{(0.05)}$	0.51	0.49	0.73	0.54	0.34	1.10	0.56	0.83	0.58	0.51	0.63	0.34
Level of Sig.	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	**
CV%	22.82	20.85	19.69	23.91	19.56	17.56	21.00	19.04	24.45	21.99	17.44	22.47

Here, means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant, H_1- Ethoxysulfuron, H_2- penoxsulam+ Escape 35 WP, H_3- Sentry 25 EC + Escape 35 WP, H_4- Agroxone, H_5- Cut out 10 WP

Effect of herbicidal doses on density of weed species

Weed density (m^{-2}) was significantly influenced by the herbicidal doses. The highest weed density (18.93 m^{-2}) was found in the control treatment, and the lowest weed population (0.33 m^{-2}) was observed with the double dose of herbicide treatment (Table 3). Weed density was highest in the control condition, whereas it decreased under different herbicidal dose treatments. Similar findings were reported by Dola *et al.* (2024) and Akondo *et al.* (2024), who found significant variation on weed species.

Table 3. Effect of different herbicides on density of weed species

Dose	*E. cruss-galli*	*M. hastata*	*O. europaea*	*C. difformis*	*D. ischaemum*	*S. mucronatus*	*S. articulatus*	*L. hexandra*	*P. repens*	*E. fluctuans*	*D. sanguinalis*	*S. acmella*
D_1	5.66 a	4.06 a	6.53 a	5.93 a	4.26 a	18.93 a	7.86 a	4.20a	4.20 a	4.06 a	4.06 a	3.86 a
D_2	2.40 b	1.66 b	2.46 b	2.46 b	2.06 b	6.26 b	2.33 b	1.86b	2.00 b	1.66 b	1.86 b	1.73 b
D_3	1.06 c	0.73 c	1.00 c	0.86 c	0.80 c	1.13 c	0.93 c	0.80c	0.73 c	0.73 c	0.86 c	0.66 c
D_4	0.40 d	0.33 c	0.40 d	0.33 d	0.33 c	0.33 d	0.33 d	0.33d	0.33 c	0.33 c	0.33 d	0.33 c
$LSD_{(0.05)}$	0.47	0.53	0.44	0.48	0.47	0.69	0.49	0.42	0.46	0.42	0.48	0.45
Level of Sig.	**	**	**	**	**	**	**	**	**	**	**	**
CV%	26.72	12.28	12.57	27.07	24.12	13.92	23.26	13.54	24.57	23.10	16.44	26.70

Here, means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose

Interaction effect between doses and herbicides on density of weed species

Weed density (per m²) was significantly influenced by the interaction between doses and herbicides. The highest weed density (19.33 m²) was found in the Agroxone with no herbicide treatment, while the lowest weed density (0.33 m²) was observed in the Sentry 25 EC + Escape 35 WP with double the recommended dose, Agroxone with double the recommended dose, and cut out 10 WP with double the recommended dose treatments. (Table 4). Similar findings

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were reported by Zahan *et al*. (2017) who found significant variation on weed species.

Table 4. Interaction effect between doses and herbicides on density of weed species

Interaction	*E. cruss-galli*	*M. hastata*	*O. europaea*	*C. difformis*	*D. ischaemum*	*S. mucronatus*	*S. articulatus*	*L. hexandra*	*P. repens*	*E. fluctuans*	*D. sanguinalis*	*S. acmella*
H_1D_1	6.00 a	4.00 a	7.00 a	5.66 b	4.00	19.00 ab	9.00 a	4.00	4.66 a	3.66 a	4.00 a	3.33
H_1D_2	2.66 b	1.66 b	2.66 c	2.66 c	2.00	5.66 c	2.66 d	1.66	2.33 b	1.66 bc	1.66 bc	1.33
H_1D_3	1.33 cde	0.66 bc	1.33 de	1.00 d	0.66	1.33 d	1.00 ef	0.66	0.66 de	0.66 de	0.66 cd	0.33
H_1D_4	0.33 e	0.33 c	0.66 e	0.33 d	0.33	0.33 d	0.33 f	0.33	0.33 e	0.33 e	0.33 d	0.33
H_2D_1	5.66 a	4.00 a	7.00 a	5.33 b	4.00	18.33 ab	7.66 bc	4.33	4.00 a	4.00 a	4.00 a	4.00
H_2D_2	2.33 bc	1.66 b	2.33 cd	2.33 c	2.00	6.00 c	2.00 de	1.66	1.66 bcd	1.66 bc	1.66 bc	2.00
H_2D_3	1.00 de	0.66 bc	0.66 e	0.66 d	0.66	1.00 d	0.66 f	0.66	0.66 de	0.66 de	1.00 cd	1.00
H_2D_4	0.66 e	0.33 c	0.33 e	0.33 d	0.33	0.33 d	0.33 f	0.33	0.33 e	0.33 e	0.33 d	0.33
H_3D_1	5.33 a	4.00 a	6.66 ab	6.00 ab	4.66	20.00 a	7.00 c	4.00	4.00 a	4.33 a	4.33 a	3.66
H_3D_2	2.33 bc	1.66 b	2.66 c	2.33 c	2.33	7.00 c	2.33 d	1.66	1.66 bcd	2.00 b	2.33 b	1.66
H_3D_3	1.00 de	0.66 bc	1.00 e	1.00 d	1.00	1.00 d	1.00 ef	1.00	0.66 de	1.00 cde	1.00 cd	0.66
H_3D_4	0.33 e	0.33 c	0.33 e	0.33 d	0.33	0.33 d	0.33 f	0.33	0.33 e	0.33 e	0.33 d	0.33
H_4D_1	6.00 a	4.33 a	5.66 b	7.00 a	4.66	19.33 ab	7.33 bc	4.33	4.33 a	4.00 a	4.00 a	4.33
H_4D_2	2.66 b	1.66 b	2.33 cd	2.33 c	1.66	6.00 c	2.33 d	2.33	2.33 b	1.33 bcd	1.33 bcd	1.66
H_4D_3	1.00 de	0.66 bc	1.00 e	1.00 d	0.66	1.33 d	1.00 ef	1.00	0.66 de	0.66 de	0.66 cd	0.66
H_4D_4	0.33 e	0.33 c	0.33 e	0.33 d	0.33	0.33 d	0.33 f	0.33	0.33 e	0.33 e	0.33 d	0.33
H_5D_1	5.33 a	4.00 a	6.33 ab	5.66 b	4.00	18.00 b	8.33 ab	4.33	4.00 a	4.33 a	4.00 a	4.00
H_5D_2	2.00 bcd	1.66 b	2.33 cd	2.66 c	2.33	6.66 c	2.33 d	2.00	2.00 bc	1.66 bc	2.33 b	2.00
H_5D_3	1.00 de	1.00 bc	1.00 e	0.66 d	1.00	1.00 d	1.00 ef	0.66	1.00 cde	0.66 de	1.00 cd	0.66
H_5D_4	0.33 e	0.33 c	0.33 e	0.33 d	0.33	0.33 d	0.33 f	0.33	0.33 e	0.33 e	0.33 d	0.33
LSD $_{(0.05)}$	1.05	1.19	1.11	1.08	0.98	1.73	1.11	1.16	1.08	0.95	1.13	0.94
Level of Significance	**	**	**	**	NS	**	**	NS	**	**	**	NS
CV%	26.72	12.28	12.57	27.07	24.12	13.92	23.26	13.54	24.57	23.10	16.44	26.70

Means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability, *= Significant at 5% level of probability, NS = Not significant, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose, H_1- Ethoxysulfuron, H_2- penoxsulam+ Escape 35 WP, H_3- Sentry 25 EC + Escape 35 WP, H_4- Agroxone, H_5- Cut out 10 WP

Prediction of herbicide resistant weeds based on weed density

Weed density results from this study showed that certain weed species, including *Echinochloa crus-galli, Monochoria hastata, Leersia hexandra, Cyperus difformis, Scirpus mucronatus, Scirpus articulates, Panicum repens, Digitaria ischaemum, Digitaria sanguinalis, Enhydra fluctuans, Spilanthes acmella*, and *Oxalis europaea*, were able to withstand even double doses of certain herbicides. Notably, the herbicides Sentry 25 EC + Escape 35 WP and Penoxsulam + Escape 35 WP were effective against most weeds at recommended doses, except for Scirpus mucronatus and Scirpus articulatus. However, weeds such as *Echinochloa crus-galli, Monochoria hastata*, and *Panicum repens* persisted in plots treated with these herbicides (Table 2).

Echinochloa crus-galli and *Oxalis europaea* were particularly aggressive, surviving even when exposed to double the recommended dose of Sentry 25 EC + Escape 35 WP and Penoxsulam + Escape 35 WP. Following *Echinochloa crus-galli*, *Scirpus articulatus* was the next most resilient, managing to endure double doses of Sentry 25 EC + Escape 35 WP, Ethoxysulfuron, and Penoxsulam + Escape 35 WP (Table 3).

Herbicides are crucial for managing weeds in modern agriculture, helping farmers achieve optimal yields and support sustainable practices such as conservation tillage. However, the emergence of herbicide-resistant weed populations poses a significant challenge in major crop-producing regions worldwide. Although herbicides have facilitated efficient and sustainable food production, repeated use of the same or chemically similar herbicides

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over multiple growing seasons has led to widespread resistance in various weed species.

Our findings align with those of Cai *et al*. (2022), who identified two mefenacet-resistant and one susceptible Echinochloa crus-galli population in Jiangsu Province's paddy fields. They found that compared to the susceptible population, the resistant populations exhibited significantly higher resistance to mefenacet both before emergence (2.8 and 4.1 times) and in early post-emergence stages (10 and 6.8 times). These populations also showed cross-resistance or multiple resistances to other herbicides like acetochlor, pyraclonil, imazamox, and quinclorac (Liu *et al*. 2022).

Effect of herbicide on total weed dry weight

In the experiment, the result exposed that total weed dry weight showed not-significant variation due to the effect of different herbicide treatments (Figure 1). The maximum total weed dry weight (10.98 g) was recorded from Cut out 10 WP. The minimum total weed dry weight (9.84 g) was recorded from penoxsulam+ Escape 35 WP. At earlier growth stage spraying herbicide is effective to control total weed dry weight. Similar findings were reported by Islam, 2022, who found significant variation on weed dry weight under different herbicides application.

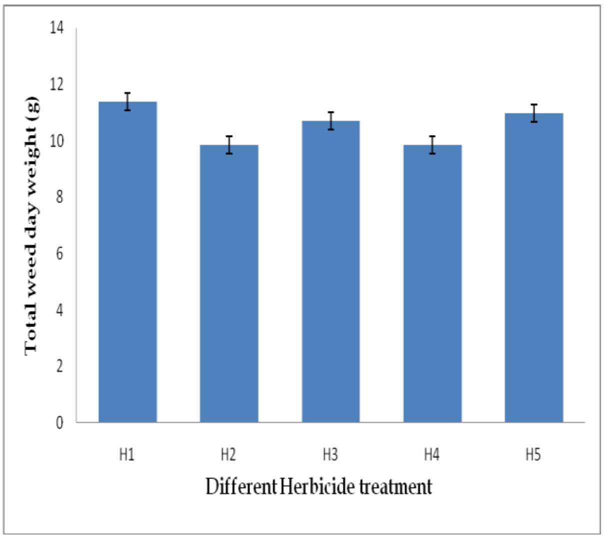

Figure 1. Effect of different herbicide treatment on total weed dry weight of *boro* rice

Here, H_1- Ethoxysulfuron, H_2- penoxsulam+ Escape 35 WP, H_3- Sentry 25 EC + Escape 35 WP, H_4- Agroxone, H_5- Cut out 10 WP

Effect of herbicide doses on total weed dry weight

Different herbicide doses showed significant variation on total weed dry weight of rice at growth stages (Figure 2). Results showed that the highest total weed dry weight (21.59 g) was found from the treatment D1 (No Herbicide application) whereas the lowest total weed dry weight (2.51 g) was found from the treatment D4 (Double of the Recommended Dose). Similar findings were reported by Islam, 2022, who found significant variation on weed dry weight under different doses herbicides application.

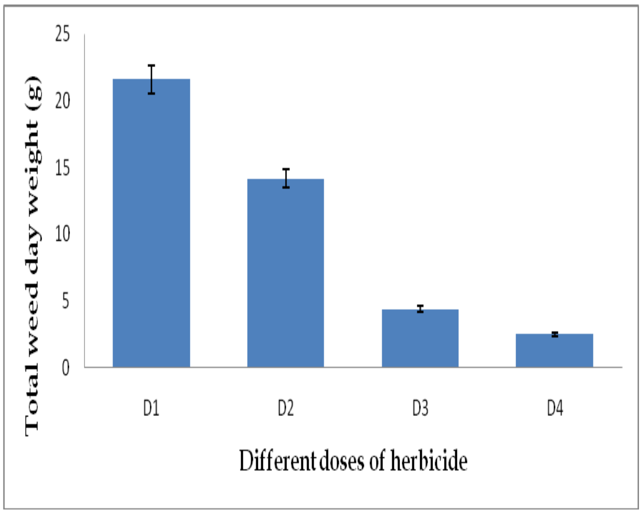

Figure 2. Effect of different doses of herbicide on total weed dry weight of *boro* rice

Here, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose

Effect of herbicide on weed control efficiency

In the experiment, the result exposed that weed control efficiency showed not-significant variation due to the effect of different herbicide treatments (Figure 3). The maximum weed control efficiency (51.06%) was recorded from H3 (Sentry 25 EC + Escape 35 WP). The minimum weed control efficiency (49.29%) was recorded from H1 (Ethoxysulfuron).

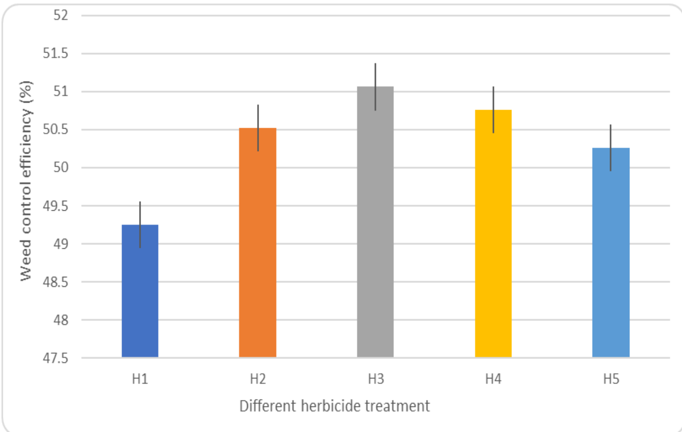

Figure 3. Effect of different herbicide treatment on weed control efficiency of *boro* rice

Here, H_1- Ethoxysulfuron, H_2- penoxsulam+ Escape 35 WP, H_3- Sentry 25 EC + Escape 35 WP, H_4- Agroxone, H_5- Cut out 10 WP

Effect of herbicide doses on weed control efficiency

Different herbicide doses showed significant variation on weed control efficiency of rice at growth stages (Figure 4). Results showed that the highest weed control efficiency

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(88.42%) was found from the treatment double of the Recommended Dose) whereas the lowest weed control efficiency (0.00%) was found from the treatment no Herbicide application.

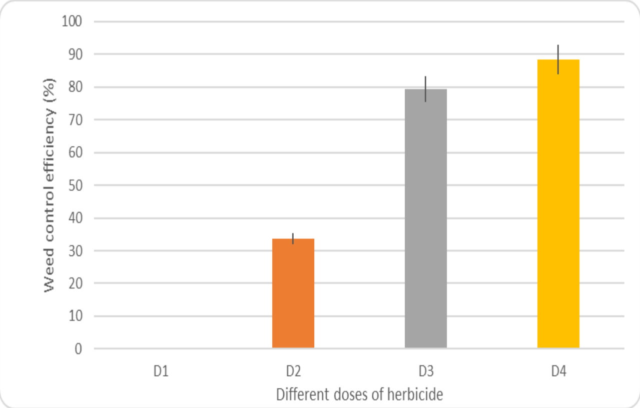

Figure 4. Effect of different doses of herbicide on weed control efficiency of *boro* rice

Here, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose

Interaction effect between herbicide and herbicide doses on weed control efficiency

The herbicide and dosage combinations exhibited significant variations in weed control efficiency across growth stages (Table 5). The highest weed control efficiency (90.58%) was recorded with the combination of Cut out 10 WP at double the recommended dose, which was statistically comparable to Ethoxysulfuron at double the recommended dose, Penoxsulam + Escape 35 WP at double the recommended dose, Sentry 25 EC + Escape 35 WP at double the recommended dose, and Agroxone at double the recommended dose. The lowest weed control efficiency (0.00%) was observed with the combination of Cut out 10 WP with no herbicide applied, which was statistically similar to Ethoxysulfuron with no herbicide, Penoxsulam + Escape 35 WP with no herbicide, Sentry 25 EC + Escape 35 WP with no herbicide, and Agroxone with no herbicide.

Table 5. Interaction effect between different herbicide and weed parameter

Interaction	No. of Weed species	Total weed dry weight (g)	Weed control efficacy (%)
H_1D_1	74.33 a	23.46	0.00 g
H_1D_2	28.66 b	15.85	32.72 f
H_1D_3	10.33 c	5.51	76.60 d
H_1D_4	4.33 d	2.91	87.68 a
H_2D_1	72.33 a	20.27	0.00 g
H_2D_2	27.33 b	12.16	36.38 e
H_2D_3	9.33 c	4.48	77.97 cd
H_2D_4	4.33 d	2.47	87.74 a
H_3D_1	74.00 a	22.17	0.00 g
H_3D_2	30.00 b	14.52	34.40 ef
H_3D_3	11.00 c	3.62	81.28 bc
H_3D_4	4.00 d	2.53	88.58 a
H_4D_1	75.33 a	20.07	0.00 g
H_4D_2	28.00 b	13.43	33.00 ef
H_4D_3	10.33 c	3.48	82.54 b
H_4D_4	4.00 d	2.44	87.51 a
H_5D_1	72.33 a	22.01	0.00 g
H_5D_2	30.00 b	14.94	32.01 f
H_5D_3	10.66 c	4.75	78.47 cd
H_5D_4	4.00 d	2.21	90.58 a
$LSD_{(0.05)}$	4.23	3.20	3.55
Level of Significance	**	NS	**
CV%	8.64	11.48	3.39

Here, means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability. *= Significant at 5% level of probability, NS = Not significant, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose, H_1- Ethoxysulfuron, H_2- penoxsulam+ Escape 35 WP, H_3- Sentry 25 EC + Escape 35 WP, H_4- Agroxone, H_5- Cut out 10 WP

Effect of different herbicide on growth and yield parameter of *boro* rice

Plant height did not show significant variation among treatments. The number of total tillers was significantly higher in H_1, H_2, H_3, and H_4 compared to H_5, with H_2

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having the highest number of effective tillers (8.00). Non-effective tillers were slightly higher in H_3 (3.06) compared to other treatments. Panicle length did not show significant differences among treatments. The number of grains per panicle and the number of sterile grains per panicle also did not show significant variation. The 1000-grain weight varied significantly, with H2 showing the highest weight (26.17 g), while H_3 had the lowest (25.30 g). Grain yield was highest in H_5 (4.34 t ha^{-1}), followed by H_4 (4.22 t ha^{-1}), with H_2 having the lowest yield (3.98 t ha^{-1}). Straw yield and biological yield were highest in H_1 and H_4, with the lowest values observed in H_2 and H_3. (Table 6). Similar findings were reported by Zahan *et al.* (2017) who found significant variation on weed species.

Table 6. Effect of different herbicide on growth and yield parameter 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	89.05	7.70 ab	19.12	86.2	25.83 ab	4.22ab	5.95 a	10.18 a	40.44 b
H_2	89.25	8.00 a	18.77	86.35	26.17 a	3.98c	5.80 b	9.78 b	39.92 b
H_3	89.41	7.65 ab	18.97	86.25	25.30 b	4.05bc	5.74bc	9.80 b	40.84 b
H_4	89.51	7.70 ab	18.75	86.42	25.40 b	4.22ab	5.96 a	10.19 a	40.62 b
H_5	89.55	7.31 b	19	86.34	25.76 ab	4.34a	5.70 c	10.04 ab	42.73 a
LSD $_{(0.05)}$	0.51	0.43	0.68	1.05	0.71	0.23	0.09	0.27	1.05
Level of Sig.	NS	**	NS	NS	**	**	**	**	**
CV%	0.61	5.90	3.83	1.29	2.93	5.76	1.61	2.97	2.72

Means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability. *= Significant at 5% level of probability, NS = Not significant, H1- Ethoxysulfuron, H2- penoxsulam+ Escape 35 WP, H3- Sentry 25 EC + Escape 35 WP, H4- Agroxone, H5- Cut out 10 WP

Effect of different doses of herbicide on growth and yield parameter of *boro* rice

The highest plant height (93.39 cm) was recorded in recommended dose, closely followed by Double of the recommended dose at 92.27 cm, with the lowest height observed in no herbicide at 85.22 cm. The number of total tillers and effective tillers also peaked in D3 and D4, with D_3 having 11.38 total tillers and 8.52 effective tillers, and D_4 having 11.49 total tillers and 8.30 effective tillers. D_1 exhibited the lowest values in these categories. Non-effective tillers were slightly higher in D_4 (3.18) compared to other treatments. Panicle length showed no significant difference among the treatments. The number of grains per panicle was highest in D_3 (91.40), while D_1 had the lowest (82.39). The 1000-grain weight did not vary significantly across treatments. Grain yield significantly increased with herbicide dose, with D_4 achieving the highest yield (5.56 t ha^{-1}), followed by D_3 (5.28 t ha^{-1}), and D_1 having the lowest yield (2.46 t ha^{-1}). Straw yield and biological yield were also highest in D_3 and D_4, with D_1 being the lowest. The harvest index showed significant improvement with increased herbicide dose, peaking at 44.65% in D_4 and being lowest at 36.66% in D_1. This comprehensive analysis demonstrates that applying herbicides at the recommended or double the recommended dose significantly enhances the growth and yield parameters of *boro* rice.

Table 7. Effect of different doses of herbicide on growth and yield parameter 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	85.22d	6.38 c	19	82.39 c	25.88	2.46 d	4.27 c	6.73 c	36.66 d
D_2	86.54 c	7.48 b	18.93	83.17 c	25.55	3.35 c	5.15 b	8.51 b	39.42 c
D_3	93.39 a	8.52 a	18.82	91.40 a	25.45	5.28 b	7.03 a	12.32 a	42.90 b
D_4	92.27b	8.30 a	18.94	88.28 b	25.89	5.56 a	6.88 a	12.44 a	44.65 a
LSD $_{(0.05)}$	0.52	0.27	0.60	1.08	0.59	0.16	0.17	0.29	0.84
Level of Sig.	**	**	NS	**	NS	**	**	**	**
CV%	0.79	4.83	4.26	1.69	3.08	5.32	4.06	3.97	2.76

Here, means with the same letters or without letters within the same column do not differ significantly, ** = Significant at 1% level of probability. *= Significant at 5% level of probability, NS = Not significant, D_1- No Herbicide, D_2- Half of Recommended Dose, D_3- Recommended Dose, D_4- Double of the Recommended Dose

Interaction effect between herbicide and herbicide doses on growth and yield parameter of *boro* rice

Plant Height: Significant variation in plant height was observed with the combination of herbicide and herbicide doses (Table 8). The highest plant height (94.33 cm) was recorded in the treatment with Agroxone at double the recommended dose, while the lowest (84.19 cm) was found in the treatment with Sentry 25 EC + Escape 35 WP at no herbicide dose.

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Number of Effective Tillers: The number of effective tillers showed significant variation (Table 8). The highest number (8.86) was recorded in the treatment with penoxsulam + Escape 35 WP at the recommended dose, while the lowest (6.30) was observed in the treatment with Ethoxysulfuron at no herbicide dose, similar to the treatments with Sentry 25 EC + Escape 35 WP at no herbicide dose, Agroxone at no herbicide dose, and cut out 10 WP at no herbicide dose (Ferdous *et al*. 2021).

Panicle Length: Panicle length did not show significant variation (Table 8). The highest panicle length (19.50 cm) was recorded in the treatment with Ethoxysulfuron at the recommended dose, while the lowest (18.23 cm) was found in the treatment with Agroxone at double the recommended dose (Akondo *et al.* 2024).

Number of Grains Panicle^{-1}: The number of grains per panicle showed significant variation (Table 8). The highest number (92.00) was recorded in the treatment with Sentry 25 EC + Escape 35 WP at the recommended dose, similar to the treatments with penoxsulam + Escape 35 WP at the recommended dose, Agroxone at the recommended dose, and cut out 10 WP at the recommended dose. The lowest (81.66) was found in the treatment with penoxsulam + Escape 35 WP at no herbicide dose (Devkota *et al.* 2019).

1000-Grain Weight: Significant variation in 1000-grain weight was observed (Table 8). The highest weight (26.71 g) was recorded in the treatment with Cut out 10 WP at double the recommended dose, while the lowest (24.42 g) was found in the treatment with Sentry 25 EC + Escape 35 WP at the recommended dose (Benedicta *et al.* 2023).

Grain Yield: Grain yield showed significant variation (Table 8). The highest yield (6.05 t ha^{-1}) was recorded in the treatment with Ethoxysulfuron at double the recommended dose, while the lowest (2.37 t ha^{-1}) was found in the treatment with Ethoxysulfuron at no herbicide dose, similar to the treatments with penoxsulam + Escape 35 WP at no herbicide dose, Sentry 25 EC + Escape 35 WP at no herbicide dose, Ethoxysulfuron at no herbicide dose, and cut out 10 WP at no herbicide dose (Hasanuzzaman *et al*. 2008).

Straw Yield: Significant variation in straw yield was observed (Table 8). The highest yield (7.20 t ha^{-1}) was recorded in the treatment with Ethoxysulfuron at double the recommended dose, while the lowest (3.69 t ha^{-1}) was found in the treatment with Cut out 10 WP at no herbicide dose (Senthilkumar *et al*. 2022).

Biological Yield: Significant variation in biological yield was noted (Table 8). The highest yield (13.25 t ha^{-1}) was recorded in the treatment with Ethoxysulfuron at double the recommended dose, while the lowest (6.28 t ha^{-1}) was found in the treatment with Cut out 10 WP at no herbicide dose (Dola *et al*. 2024).

Harvest Index: Significant variation in the harvest index of BRRI dhan58 was observed (Table 8). The highest index (45.75%) was recorded in the treatment with Cut out 10 WP at double the recommended dose, similar to the treatment with Ethoxysulfuron at double the recommended dose. The lowest index (34.11%) was found in the treatment with Ethoxysulfuron at no herbicide dose, similar to the treatment with penoxsulam + Escape 35 WP at no herbicide dose (Tahsin *et al*. 2017).

Table 8. Interaction effect between different herbicide and its doses on growth and yield parameter 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	85.84hij	6.30g	18.9	81.83de	26.62ab	2.37g	4.58fgh	6.95f	34.11i
H_1D_2	86.64gh	7.26ef	18.96	84.20d	25.36bcd	3.19f	4.91ef	8.11e	39.42fg
H_1D_3	91.71ef	8.73ab	19.5	90.13ab	25.65abcd	5.28cde	7.13ab	12.41b	42.56bcd
H_1D_4	92.02def	8.53ab	19.13	88.63bc	25.71abcd	6.05a	7.20a	13.25a	45.67a
H_2D_1	85.13ijk	6.60fg	18.6	81.66e	26.11abc	2.37g	4.51gh	6.89fg	34.43i
H_2D_2	86.28ghi	7.73cde	19.1	83.33de	26.10abc	3.22f	4.86efg	8.08e	39.85fg
H_2D_3	93.40abc	8.86a	18.63	91.80a	26.23abc	5.02e	6.99ab	12.01bc	41.82cde
H_2D_4	92.18def	8.80ab	18.76	88.60bc	26.25abc	5.31cde	6.86abc	12.17bc	43.60bc
H_3D_1	84.19k	6.33g	19.2	82.70de	25.59abcd	2.51g	4.28h	6.79fg	36.93h
H_3D_2	87.01g	7.46e	18.6	82.03de	25.49abcd	3.45f	5.20de	8.66de	39.90efg
H_3D_3	93.50abc	8.66ab	18.66	92.00a	24.42d	5.12de	6.91abc	12.03bc	42.55bcd
H_3D_4	92.97bcd	8.13bcd	19.43	88.26bc	25.69abcd	5.15de	6.57c	11.72c	43.97ab
H_4D_1	85.07jk	6.36g	18.96	82.36de	25.42abcd	2.46g	4.28h	6.75fg	36.55h
H_4D_2	85.93ghij	7.43e	19.16	82.90de	25.34bcd	3.38f	5.49d	8.87d	38.09gh
H_4D_3	94.33a	8.66ab	18.63	91.76a	25.74abcd	5.50bcd	7.12ab	12.63ab	43.57bc
H_4D_4	92.70cde	8.33abc	18.23	88.66bc	25.08cd	5.55bc	6.97ab	12.53b	44.30ab
H_5D_1	85.86hij	6.33g	19.36	83.40de	25.64abcd	2.59g	3.69i	6.28g	41.30def
H_5D_2	86.83gh	7.53de	18.83	83.40de	25.45abcd	3.52f	5.32d	8.84d	39.86fg
H_5D_3	94.04ab	7.66cde	18.66	91.33a	25.24cd	5.51bcd	7.00ab	12.51b	44.02ab
H_5D_4	91.49f	7.73cde	19.13	87.23c	26.71a	5.73ab	6.79bc	12.53b	45.75a
$LSD_{(0.05)}$	1.17	0.68	1.35	2.34	1.32	0.39	0.35	0.64	1.93
Level of Sig.	**	**	NS	**	**	**	**	**	**
CV%	0.79	4.83	4.26	1.69	3.08	5.32	4.06	3.97	2.76

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CONCLUSION

Based on the study, it can be concluded that the application of Ethoxysulfuron and Cut out 10 WP with double of the recommended dose showed superiority over other herbicide treatments in producing higher rice yields and weeds control efficiency. The recommended dose of herbicide application proved to be the best and most budget-friendly for rice yield compared to other dose treatments. The combination of Ethoxysulfuron and the double recommended dose performed the best overall. While it is expected that all weeds can be successfully controlled by applying herbicides at the indicated doses, some weeds may develop resistance if not managed properly. Therefore, further molecular studies are needed to confirm whether the proposed herbicide is resistant to specific weeds.

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Conflict of Interest

The authors have declared no conflicts of interest.

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