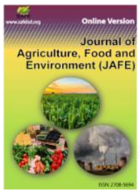
Vol 3 No 3 September 2022 Pages 32-39 e-ISSN 2708-5694

Journal of Agriculture, Food and Environment (JAFE)

Journal Homepage: http://journal.safebd.org/index.php/jafe

https://doi.org/10.47440/JAFE.2022.3307



Original Article

Efficacy and Economics of Different Weed Control Practices in *boro* Rice under High Ganges River Floodplain of Bangladesh

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Article History

Received: 10 June 2022

Revised: 27 July 2022

Accepted: 06 August 2022

Published online: 30 September 2022

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Keywords

Benefit Cost Ratio, *Boro* rice, Herbicides, Relative Abundance value (%) and Weed control efficiency (%)

How to cite: Monira S, Ali MI, Sarker UK, Islam MS, Zaman F, Begum M and Uddin MR (2022). Efficacy and economics of different weed control practices in *boro* rice in High Ganges River Floodplain of Bangladesh. J. Agric. Food Environ. 3(3): 32-39.

ABSTRACT

Weed management practices are crucial for controlling weeds as they reduce yield, increase the production cost as well as deteriorate the grain quality. So, an experiment was conducted at Monirampur, Jashore, Bangladesh during July 2020 to June 2021 to find out the appropriate weed management practices in *boro* rice. BRRI dhan29 was selected as planting material to see the effect of seven different weed management practices such as no weeding, pre-emergence, post-emergence, pre-emergence followed by (fb) hand weeding (HW) at 40 DAT, post-emergence fb HW at 40 DAT, pre-emergence fb post-emergence and two HW at 20 and 40 DAT following single factor randomized complete block design (RCBD) with three replications. The study revealed that Poaceae and Cyperaceae contributed more weeds among 15 different families. *Monochoria vaginalis, Fimbristylis miliacea, Echinochloa crus-galli, Cyperus rotundus and Alternanthera sessilis* were more abundant among 34 weed species. The highest weed density (98.22 m^{-2}) and dry weight (51.36 g m^{-2}) were found in no weeding condition but that of the lowest value (weed density: 9.93 m^{-2} and dry weight: 3.59 g m^{-2}) was observed in pre-emergence fb one HW at 40 DAT. The highest grain yield (6.52 t ha^{-1}), net income (91571 Tk ha^{-1}) and B:C ratio (1.9) were recorded in pre-emergence fb HW at 40 DAT followed by pre-emergence fb post-emergence treatment. The lowest value of grain yield (3.29 t ha^{-1}), net income (12290 TK ha^{-1}) and B:C ratio (1.14) were found in no weeding treatment. As per results, it can be concluded that pre-emergence fb HW at 40 DAT has been revealed as the best weed management practice for BRRI dhan29.

Introduction

Rice (*Oryza sativa*) is the most preferred staple food for more than half of the population worldwide. About 497.69 million metric tons of rice was obtained from 162.06 million ha of land throughout the world in 2020 (FAO, 2021). In Bangladesh, rice is grown under rainfed, deep water and irrigated conditions in the three distinct seasons namely; *aus*, *aman* and *boro*. Among the three distinct seasons, *boro* rice covers the second largest area of 11.72 million ha (74% of total land area) with a production of 37.61 million metric tons of rice (52.84% of total rice production) (BBS, 2021).
Globally, weed is one of the main biological obstacles to increased rice production. High competitive ability of weeds exerts a serious negative effect on crop production. Normally, weeds cause about 45% of yield reduction (Katiyar and Singh, 2015) but it may reach up to 34% in wheat, 50% in pulses, 72% in sugarcane, and around 90% in almost all vegetables due to higher crop-weed competition. Whereas, crop-weed competition reduced rice yield about 40-60% and it can rise to 94-96% due to season-long competition (Ramana *et al*., 2007; Chauhan and Johnson, 2011; Islam *et al*., 2017). The climatic and edaphic condition regulates the extent of weed infestation of a particular region, which causes the difference in rice yield loss from nation to nation. In Australia, the estimated grain yield losses at national level was 2.7 m ton per every year (Llewellyn *et al*., 2016). Other studies reported that weeds could reduce the rice grain output up to 30-40% in Sri Lanka (Abeysekera, 2001) and 10-35% in Malaysia (Karim *et al*., 2004). In contrast, weed infestation lowered seed yields in Bangladesh by 70-80% in *aus* rice, 30-40% in T. *aman* rice, and 22-36% in *boro* rice (BRRI, 2008). Crop-weed competition occurs for different growth limiting factors for example light, air, water, space and nutrients during the crop growing period

(Ashiq and Aslam, 2014) and negatively influences the height, leaf structure, tillering behavior, and advancement of crop plants (Miah *et al*., 1990). In addition, weeds indirectly influence crop productivity by providing a harbor for agricultural pests, interfering with irrigation systems, decreasing yields and quality, and consequently driving up processing costs (Zimdahl, 2013). Therefore, weed-controlling approaches are crucial for boosting rice productivity.

Recently, herbicide-based weed control approaches have become popular in Bangladesh over other approaches due to controlling weeds more easily and effectively at low price (Rashid *et al*., 2007; Hussain *et al*., 2008). In addition, around 60-82% increase in rice yield could be obtained from herbicide-based farming approaches in comparison to weedy plots (Ahmed and Chauhan, 2014). Anwar *et al*. (2012) revealed that herbicidal weed suppression approaches are acknowledged as the smartest and most feasible preference in large scale farming due to manpower shortage as well as their wage inflation. It drives the rice growers for applying herbicides more frequently to control weeds. But, herbicide-based farming approaches cannot be a sustainable alternative in a long run due to producing herbicide-tolerant weed and shifting of weed vegetation (Chauhan and Opeña, 2013), and showing toxicity to crop plants (Blackshaw *et al*., 2005) and it might affect the situation going forward (Bastiaans *et al*., 2000). Furthermore, herbicide usage is commonly highlighted as endangering biodiversity and raising environmental concerns (Marshall *et al*., 2003). Farmers are becoming increasingly interested in less pesticide reliant farming practices as they are now highly worried about the environmental risks of using herbicides (Mahmood *et al*., 2009). Among rice farmers, integrated weed management (IWM) is currently gaining sufficient attention (Anwar *et al*., 2013; 2014) which includes various agronomic tools like manual weeding, tillage, competitive cultivar, crop rotation, seeding date, seeding density, fertilizer management, plant geometry, and so on for managing weed stress in paddy in an integrated way (Juraimi *et al*., 2013). Additionally, combination of two methods, such as chemical or manual weeding, is always better than single method. Due to diverse nature of weed flora, IWM approaches that prioritize on the fusion of management techniques and scientific knowledge, may also save expenditures and boost weed control efficacy (WCE).

In this back drop, the present study has combined hand weeding with herbicide-based farming approaches employing pre-emergence and post-emergence weedicides. As, integration of hand weeding with different pre-emergence or post-emergence herbicides amplifies their efficacy which is supported by Popy *et al*. (2017) and Dhakal *et al*. (2019). In addition, pre-emergence herbicides can eliminate weeds emerging at the initial stages of crop development, while post-emergence herbicides can suppress weeds growing at later crop growth stages. As, soil weed seed banks continuously emerge weeds throughout the growing period, the highest weed growth reduction and maximum yield increase could be obtained from the consecutive utilization of pre-emergence herbicide (pendimethalin) with post-emergence herbicide (bispyribac-sodium bazimsulfuron) or manual weeding (Singh *et al*., 2016). Besides, information regarding IWM approaches of the current study area is not available in literature. Therefore, the latest investigation was carried out to estimate the efficiency and cost effectiveness of different herbicide-based weed control approaches in *boro* rice.

Materials and Methods

Experimental site

The experiment was conducted at Manirampur, Jashore, Bangladesh (latitude: 23° 01' 0.12" N and longitude: 89° 13' 59.88" E) from July 2020 to June 2021. The study area was belongs to calcareous dark grey floodplain soil under the series of calceric combosols and Gleysols of High Ganges River Floodplain that falls under Agro-Ecological Zone-11 (AEZ- 11) (UNDP and FAO, 1988). The soil of the study area was slightly alkaline in reaction with pH value 8.0 with 2.4% organic matter. The land type was high to medium high with silty loam in texture. The study area is predominantly suitable for *boro* rice cultivation.

Treatments and Design

The current study was a single factor experiment designed using RCBD and replicated for three times. This experiment comprised the following herbicidal treatments such as No weeding, Pre-emergence, Post-emergence, Pre-emergence fb hand weeding (HW) at 40 DAT, Post-emergence fb HW at 40 DAT, Pre-emergence fb post-emergence, and Two HW at 20 and 40 DAT. BRRI dhan29, modern high yielding variety of *boro* rice, was selected to observe the impacts of abovementioned treatments. It was released by the Bangladesh Rice Research Institute (BRRI) in 1994 and the expected seed yields of BRRI dhan29 is 7.5 t ha^{-1} (BRRI, 2016). An overview about the weedicides employed in the recent experiment is provided in Table 1.

Table 1. A short description of the herbicides used in the experiment.

Trade Name	Generic Name	Mode of action	Selectivity	Recomm-ended dose	Time of application	Field condition
Talon 52 WP	Pretilachlor + Triasulfuron	Systemic	Selective for grass, sedge and broadleaf	741 g ha^{-1}	Pre-emergence (At 5 DAT)	Require 5-6 cm standing water
Clean maste 18 WP	Acetachlor + Bensulfuron	Systemic	Selective for grasses and sedges	500 g ha^{-1}	Post-emergence (At 25 DAT)	Require 5-6 cm standing water

Agronomic practices

Rice seeds were collected from Agronomy Field Laboratory, Bangladesh Agricultural University, Bangladesh. On December 5, 2020, pre-germinated seeds were spread in a nursery bed, and seedlings were nurtured with the appropriate care. The experimental setup was designed in puddled condition on 13 January 2021. The study plots were fertilized with 300, 100, 120, 110 and 10 kg ha^{-1} urea, triple super phosphate, muriate of potash, gypsum and zinc sulphate, respectively, (BRRI, 2016). Urea was top dressed at 15, 30 and 45 days after transplanting (DAT). But, other fertilizers excluding urea were applied with full doses at the end of field preparation. Seedlings were transplanted in the experimental plots as per lay out with two seedlings $hill^{-1}$

following 25 cm × 15 cm spacing. The experimental plots were irrigated for six times. BRRI dhan29 was harvested on 13 May 2021.

Data collection

The weed species were collected from the experimental area at 50 DAT. Weed density (WD) and dry weight (DW) were estimated. Relative abundance value was determined following the methodology of Thomas (1985). Based on weed DW, WCE was calculated using the formula developed by Sawant and Jadav (1985):

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

Where, WCE = Weed control efficacy, DWC = Dry weight of weeds in weedy check, and DWT = Dry weight of weeds in each treatment.

Susceptibility of various weed types owing to several weed control techniques were graded based on WCE as suggested by Mian and Gaffer (1968) (Table 2).

Table 2. Susceptibility grading of various weed flora based on WCE as suggested by Mian and Gaffer (1968).

Degrees of weed susceptibility	Weed control Efficacy	Grades of weed control
Completely susceptible (CS)	100	Completely control (CC)
Very highly susceptible (VHS)	90-99	Excellent control (EC)
Highly Susceptible (HS)	70-89	Good control (GC)
Moderately susceptible (MS)	40-69	Fair control (FC)
Poorly susceptible (PS)	20-39	Poor control (PC)
Slightly susceptible (SS)	1-19	Slightly control (SC)
Completely resistant (CR)	0	No control (NC)

Before harvesting, five hills (except boundary lines) were pulled from every plot following random selection to collect information about the yielding parameters. Additionally, to gather yield data, the harvested crops from middle one square meter of each plot was manually threshed. Following sun drying, the grains were thoroughly cleaned. Lastly, the grain weight was adjusted to 14% moisture content (MC) by following formula:

$$MC\% = \frac{WF - WO}{WF} \times 100$$

$$YA = \frac{WF \times (100 - MC\%)}{100 - 14} \times 100$$

Where, MC (%) = Moisture content (%), WF = fresh weight (g), WO = oven dry weight (g), and YA = Adjusted yield at 14% moisture content.

Benefit cost ratio of different weed control practices was estimated using following formula:

$$\text{BCR} = \frac{\text{Gross income}}{\text{Total cost of production}}$$

Statistical Analysis

Analysis of variance (ANOVA) was done with the aid of computer package MSTAT-C. Duncan's Multiple Range Test was employed for comparing the treatment means (Gomez and Gomez, 1984). The cost of each individual agro-input was utilized to compute the cultivation expense.

Results

Infested weed flora in *boro* rice fields at 50 DAT

Thirty four weed species belonging to 15 families infested the *boro* rice fields (Table 3). Poaceae family topped the list with eight weed species and Cyperaceae family ranked second with seven species. Amaranthaceae and Commelinaceae contributed four and three weed species, respectively. The following families such as Compositae, Onagraceae and Pontederiaceae contributed two weeds each. While other families i.e. Lythraceae, Marsileaceae, Oxalidaceae, Phyllanthaceae Polygonaceae, and Scrophulariaceae represented only one species each. The results also showed that the most abundant and predominant weed flora based on their relative abundance (RA) value in descending order were *Monochoria vaginalis* (21.7) > *Fimbristylis miliacea* (18.68) > *Echinochloa crus-galli* (16.80) > *Cyperus rotundus* (15.40) > *Alternanthera sessilis* (12.95) and rest of the 29 species represented 214.47 of total relative abundance value (Fig.1). The least abundant weed species were broadleaf weed *Oxalis europaea* (1.94) followed by *Phyllanthus niruri* (2.43). The annual weeds were dominant over perennial weeds but the perennials (RA-164.68) were more abundant than annuals (RA-135.32). In my study, the RA value of broadleaves, grasses, and sedges were 148.31, 83.21, and 68.48, respectively (Fig. 2).

Weed density and total dry weight

Weed control techniques exerted significant impact on WD and DW at 50 DAT (Table 4). No weeding treatment produced the maximum WD (98.22 m^{-2}) and DW (51.36 g m^{-2}) in BRRI dhan29 owing to unchecked weed infestation, that provides unlimited competition to crop (Table 4). On the contrary, the lowest WD (9.93 m^{-2}) and DW (3.59 g m^{-2}) were recorded in BRRI dhan29 under pre-emergence fb HW at 40 DAT, and pre-emergence fb post-emergence treatment ranked second (Table 4). Application of post-emergence fb HW at 40 DAT, and two HW were statistically similar but two HW produced lower weed biomass than post-emergence fb HW at 40 DAT. Solo use of pre-emergence herbicide (WD: 75.43 m^{-2} and DW: 34.05 gm^{-2}) performed better than solo application of post-emergence herbicide (WD: 85.43 m^{-2} and DW: 41.11 g m^{-2}).

Weed control efficacy (%)

WCE (%) of various weed control practices along with their grades, and degrees of weed susceptibility has been documented in Table 4. The results showed that pre–emergence (Talon 52WP) fb HW at 40 DAT provided "excellent control" over weeds. Whereas, post-emergence fb HW, pre–emergence fb post-emergence, and two hand weeding showed "good control". Conversely, a single application of pre–emergence and post-emergence herbicide exhibited poor control. According to WCE scale as suggested by Mian and Gaffer (1968), highly susceptible weed flora were observed in aforementioned post-emergence fb hand weeding, pre–emergence fb post-emergence, and two hand weeding treatments. Whereas, weeds treated with single application of pre–emergence and post-emergence herbicide, were poorly susceptible.

Table 3. List of infested weed species with their morphology, common name, scientific name, family name and life cycle and relative abundance value identified in *boro* rice field at 50 DAT.

Common Name	English Name	Scientific Name	Family Name	Life cycle	*RA
Grasses					
Durba	Bermuda grass	*Cynodon dactylon* L.	Poaceae	Perennial	9.98
Shama	Burnyard grass	*Echinochloa crus-galli* L.	Poaceae	Perennial	16.80
Khudeshama	Jungle grass	*Echinochloa colonum* L.	Poaceae	Annual	11.86
Angta	Joint grass	*Panicum distichum* Lam.	Poaceae	Annual	10.28
Arail	Swamp rice grass	*Leersia hexandra* Sw.	Poaceae	Perennial	10.32
Angulighash	Crab grass	*Digitaria sanguinalis* L.	Poaceae	Perennial	9.27
Jhora dhan	Wild rice	*Oryza rufipogon*	Poaceae	Annual	9.42
Chira ghash	Slim flower love grass	*Eragrotis gangetica*	Poaceae	Annual	5.28
Sedges					
Joina	Grass like fimbry	*Fimbristylis miliacea* L.	Cyperaceae	Perennial	18.68
Borochucha	Rice flat sedge	*Cyperus iria* L.	Cyperaceae	Perennial	7.55
Mutha	Purple nut sedge	*Cyperus rotundus*	Cyperaceae	Perennial	15.40
Gucca mutha	Slendar flat grass	*Cyperus nemoralis*	Cyperaceae	Perennial	2.52
Chechra	Purple spike rush	*Eleocharisatro purpurea*	Cyperaceae	Perennial	10.36
Sobujnakful	Small flower umbrella grass	*Cyperus difformis* L.	Cyperaceae	Perennial	10.82
Matichaize	Tall fringe rush	*Fimbristylis diphylla*	Cyperaceae	Perennial	3.15
Broadleaves					
Chanchi	Joyweed	*Alternanthera sessilis* R.Br.	Amaranthaceae	Annual	12.95
Maloncho	Alligator weed	*Alternanthera philoxeroides*	Amaranthaceae	Annual	8.34
Shaknotey	Slender amaranth	*Amaranthus viridis* L.	Amaranthaceae	Annual	8.31
Katanotey	Spiny amaranth	*Amaranthus spinosus* L.	Amaranthaceae	Annual	7.36
Kesuti	False daisy	*Eclipta alba* Hassk.	Compositae	Annual	10.54
Holud nakful	Toothache plant	*Spilanthes acmella* L.	Compositae	Perennial	7.18
Monayna	Spreading day flower	*Commelina diffusa* Burn.f.	Commelinaceae	Annual	9.83
Kanaibashi	Tropical spiderwort	*Commelina benghalensis* L.	Commelinaceae	Annual	7.89
Kanainala	Spreading dayflower	*Cyanotis axillaris* L.	Commelinaceae	Annual	4.67
Acid pata	Lowland rotala	*Rotala ramosior* L.	Lythraceae	Annual	5.41
Shushnishak	Pepperwort	*Marsilea crenata* Pressl.	Marsileaceae	Annual	6.85
Panilong	Winged water primerose	*Ludwigia hyssopifolia* L.	Onagraceae	Perennial	8.92
Keshoredam	Water primrose	Ludwigia adscendens	Onagraceae	Perennial	3.18
Amrul	Indian sorrel	*Oxalis europaea* Jord	Oxalidaceae	Annual	1.94
Hazardana	Gale of the wind	*Phyllanthus niruri* L.	Phyllanthaceae	Annual	2.43
Bishkataly	Smart weed	*Polygonum hydropiper* L.	Polygonaceae	Annual	4.51
Panikochu	Pickerel weed	*Monochoria vaginalis*	Pontederiaceae	Perennial	21.7
Kochuripana	Water hyacinth	*Eichhornia Crassipes*	Pontederiaceae	Perennial	8.85
Panimorich	False pimpernel	*Lindernia hysopioides* L.	Scrophulariaceae	Annual	7.45

*RA = Relative Abundance Value

Effect of weed control practices on the yield contributing attributes and yields of *boro* rice (BRRI dhan29)

Weed control practices exerted substantial impact on the yield contributing attributes and yields of *boro* rice (Table 5). In BRRI dhan29, the pre-emergence fb HW at 40 DAT topped the list with 17.10 effective tiller hill^{-1}, 108.68 grains panicle^{-1}, 25.43 g 1000-grain weight , 6.52 t ha^{-1}grain yield, 7.6 t ha^{-1} straw yield, 14.12 t ha^{-1} biological yield and 46.16% harvest index (Table 5). Pre- fb post-emergence treatment ranked second with 15.79 effective tiller hill^{-1}, 103.08 grains panicle^{-1}, 23.32 g 1000-grain weight, 5.98 t ha^{-1} grain yield, 7.21 t ha^{-1} straw yield, 13.19 t ha^{-1} biological yield and 45.34% harvest index. The straw yield and harvest index were statistically similar with the result of Pre-emergence fb HW at 40 DAT but other yield contributing attributes and yield were statistically dissimilar. The treatments like post-emergence herbicide fb HW at 40 DAT, and two HW revealed statistically similar results in relation to yield contributing attributes and grain yield except straw yield, biological yield and harvest index. Straw yield and biological yield were higher in two HW, whereas the maximum harvest index was recorded from the post-emergence fb HW treatment. Single application of pre–emergence or post-emergence herbicide produced statistically similar results which outperformed no weeding treatment. The lowest number of effective tiller hill^{-1} (8.46), number of grains panicle^{-1} (70.92), 1000-grain weight (17.35 g), grain yield (3.29 t ha^{-1}), straw yield (5.11 t ha^{-1}), biological yield (8.4 t ha^{-1}) and harvest index (39.42%) were recorded in no weeding treatment.

Table 4. Effect of weed control practices on the weed parameters with susceptibility grading of weeds based on WCE.

Treatments	Weed density No. m^{-2}	Weed dry weight gm^{-2}	WCE %	Grades	Susceptibility
	At 50 DAT	AT 50 DAT			
No weeding	98.22a	51.36a	0.00	NC	CS
Pre-emergence	75.43c	34.05c	33.7	PC	PS
Post-emergence	85.43b	41.11b	19.96	PC	PS
Pre-emergence fb HW at 40 DAT	9.93f	3.59f	93.01	EC	VHS
Post-emergence fb HW at 40 DAT	23.19d	10.60d	79.36	GC	HS
Pre- fb post-emergence	14.36e	7.46e	85.48	GC	HS
Two HW at 20 and 40 DAT	19.60d	9.30d	81.89	GC	HS
Level of significance	**	**			
CV %	4.63	7.59			

In column, figures with similar letter (s) do not differ significantly while figures with dissimilar letter differ significantly (according to DMRT), ** = Significant at 1% level of probability, CV = Co-efficient of variance.

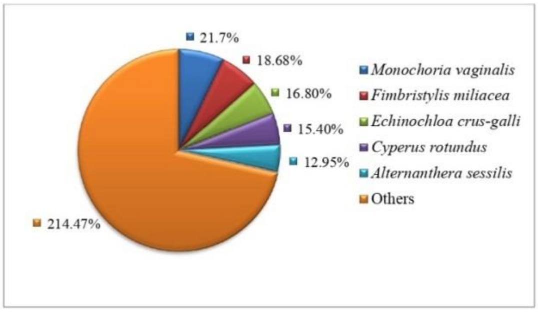

Figure 1. Five most abundant weed species in *boro* rice field at 50 DAT.

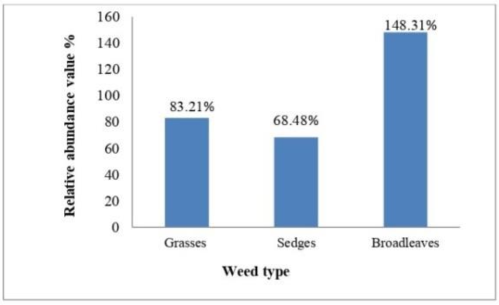

Figure 2. Relative abundance value of Grass, Sedge, and Broadleaf weeds in *boro* rice.

Table 5. Effect of weed control practices on the yield contributing attributes and yields of *boro* rice.

Treatments	No. of effective tiller hill^{-1}	No. of grains panicle^{-1}	1000-grain weight g	Grain yield t ha^{-1}	Straw yield t ha^{-1}	Biological yield t ha^{-1}	Harvest index %
No weeding	8.46e	70.92e	17.35e	3.29e	5.11d	8.40e	39.42d
Pre-emergence	11.06d	89.08d	19.54d	3.91d	4.63c	8.54d	45.79a
Post-emergence	10.28d	76.76e	19.11d	3.75d	4.53cd	8.29d	45.33a
Pre-emergence fb HW at 40 DAT	17.10a	108.68a	25.43a	6.52a	7.60a	14.12a	46.16a
Post-emergence fb HW at 40 DAT	14.28c	94.67c	21.49bc	5.40c	6.8b	12.20c	44.26a
Pre- fb post-emergence	15.79b	103.08ab	23.32b	5.98b	7.21a	13.19b	45.34a
Two HW at 20 and 40 DAT	15.21c	96.18c	21.75bc	5.56c	7.30a	12.86b	43.24b
Level of significance	**	**	**	**	**	**	**
CV %	4.87	4.92	4.90	2.56	4.89	2.92	2.86

In column, figures with similar letter (s) do not differ significantly while figures with dissimilar letter differ significantly (according to DMRT), ** = Significant at 1% level of probability, CV = Co-efficient of variance.

Economics of weed control practices

The budget analysis of several weed control practices has been provided in the Table 6. According to the partial budget analysis of BRRI dhan29, pre-emergence fb HW at 40 DAT had the biggest net income (91571 Tk ha^{-1}) and B:C ratio (1.9) among all the treatments. Whereas, the treatment of pre-emergence fb post emergence herbicide produced the second largest net profit (84221 Tk ha^{-1}) and B:C ratio (1.89). Besides, higher net profit was also obtained from the treatment of post-emergence herbicide fb HW at 40 DAT (net income: 60600 Tk ha^{-1} and B:C ratio: 1.60) than two hand weeding (net income: 59800 Tk ha^{-1} and B:C ratio:1.55). The lowest profit (12290 Tk ha^{-1}) and B:C (1.14) ratio were achieved from the no weeding treatment.

Table 6. Partial budget analysis of various weed control practices (BDT ha^{-1}) in *boro* rice (BRRI dhan29).

Treatments	Vc	Hc	Lc	TC	BRRI dhan 29		
					GI	NI	BCR
No weeding	90400	0	0	90400	102690	12290	1.14
Pre-emergence	90400	629	1800	92829	116270	23441	1.25
Post-emergence	90400	400	1800	92600	111870	19270	1.21
Pre-emergence fb HW at 40 DAT	90400	629	10800	101829	193400	91571	1.90
Post-emergence fb HW at 40 DAT	90400	400	10800	101600	162200	60600	1.60
Pre- fb post-emergence	90400	1029	2700	94129	178340	84211	1.89
Two HW at 20 and 40 DAT	90400	0	18000	108400	168200	59800	1.55

Vc = variable cost (all material cost from seedbed preparation to post harvest operation except herbicide cost, labor cost needed for herbicide application and hand weeding), Hc = herbicide cost, Lc = labour cost, TC = total cost, GI = gross income, NI = net income, BCR = benefit-cost ratio; One man-day labor was valued at 450 Tk ; Talon 52WP = 629 Tk @ 85 Tk 100 g^{-1} , Clean master 18WP = 400 Tk @ 80 Tk 100g^{-1}

Discussion

Weeds belonging to different species of grass, sedge and broadleaf were identified to be present in the rice-ecosystem. According to the current investigation, 34 weeds were documented from the *boro* rice field comprising eight grasses, seven sedges and 19 broadleaves. Whereas, Monira *et al.* (2020) identified 19 weeds including six grasses, five sedges and eight broadleaves in *boro* rice fields. In our study, *Monochoria vaginalis*, *Fimbristylis miliacea*, *Echinochloa crus-galli*, *Cyperus rotundus*, and *Alternanthera sessilis* were recognized to be the most prevalent and abundant weed species. But, Monira *et al.* (2020) stated that *Echinochloa crusgalli*, *Panicum repens*, *Leersia hexandra*, *Fimbristylis miliacea* and *Scirpus juncoides* were the most dominant weed species in *boro* rice fields. The two dominant weeds such as, *Echinochloa crus-galli* and *Fimbristylis miliacea* are similar with my findings. Besides, Begum *et al.* (1999) found that Cyperaceae family ranked first contributing the highest number of weeds in *boro* rice, while Poaceae was enlisted to be the largest family in the current study. Generally, the presence, composition, abundance, importance and ranking of weed vegetation fluctuate over time and mostly rely upon agro-climatic conditions, crop management and local weed seedbank status (Anwar *et al.*, 2013). The periodic changes in land and irrigation management may be to blame for the switch of weed flora from perennials to annuals and vice versa which is supported by De Datta (1988). Broadleaves were more abundant than grasses and sedges, while this result differed from Huda *et al.* (2017). In their study, sedges were more abundant (RA value: 103.4) than the broadleaves (RA value: 101.9) and grasses (RA value: 94.8). The continual puddling approach employed across the farmlands would make a significant contribution to the present findings, which is further corroborated by Moody (1982).

The quick growing weeds having increased adaptability to the altered environments and prolific seed production capability render an strong competition to crops (Swanton *et al*., 2015) and mostly, such competition during early growth stage (15-45 DAS) exerted an substantial impact on rice yield (Moody, 1993; Ladu and Singh, 2006; Sangeetha *et al*., 2009). Recently, shortage of manpower at peak period along with their high wages urges rice growers for implementing herbicide-based farming practices to manage weeds compared to 2-3 hand weedings (Ahmed *et al*., 2001) to lessen crop-weed competition and economic damage from delayed weeding (Hasanuzzaman *et al*., 2009; Rashid *et al*., 2012). Due to narrow time window of pre-emergence weedicide, application of post-emergence herbicide (Mahajan and Chauhan, 2013) or HW (Dhakal *et al*., 2019) in later growth stage is crucial for controlling late flushes effectively with maximum WCE.

The results also indicated that the least number of weeds and dry weight, and the greatest WCE were documented from Pre-emergence fb HW at 40 DAT. Whereas, Pre-emergence fb post-emergence herbicide ranked second followed by two HW, and post-emergence fb HW at 40 DAT. This result is in accordance with the findings of Tasmin *et al*. (2019) and Dash *et al*. (2016b) and they found that among the weed control practices, application of pre-emergence fb hand weeding at 40 DAT gave the lowest weed density and dry weight, but highest weed control efficiency. While others reported the minimum weed pressure and the maximum WCE under two HW treatment (Kumar *et al*., 2017; Rekha *et al*., 2002; Singh and Deo, 2004). The possible cause was that pre-emergence weedicide (Pretilachlor + Triasulfuron) suppressed the growth of all types of weeds at the initial phases (Banerjee *et al*., 2008b) but the post-emergence weedicide (Acetachlor + Bensulfuron) performed better against the grassy weeds (Sharif and Chauhan, 2014). Besides, weed flora treated with post-emergence herbicide fb HW, or two HW get enough time to emerge and flourish vigorously that increases their ability to resist herbicides and ultimately reduces WCE. No weeding yielded the largest number of weeds and dry mass, and the least WCE due to endless competition of weeds to crops.

The highest yield was observed in pre-emergence herbicide fb HW at 40 DAT treatment compared to other treatments. The probable cause is that weeds were successfully managed under this treatment to lessen their fight for the growth limiting resources and this promotes in producing the largest quantity of yield contributing attributes. This result collaborates the findings of Reddy and Bandyopadhyay (2015) and Islam *et al*. (2016). They documented the highest no. of filled grains panicle^{-1}, 1000-grain weight and seed yields from pre-emergence herbicide fb HW at 40 DAT. Furthermore, higher leaf production would promote photosynthesis rate due to minimum crop-weed competition and that subsequently increases rice productivity. The result is in corroborated with Dhakal *et al*. (2019). According to the economic study, pre-emergence herbicide fb HW at 40 DAT treatment yielded the maximum financial profits and B:C ratio. Besides, treatments like pre-emergence fb post-emergence herbicide, and post-emergence fb HW at 40 DAT produced more profit than two HW treatment. It happens because of less labor cost involvement in comparison to two HW. Sathyamoorthy *et al*. (2004) and Parvez *et al*. (2013) supported this result.

Conclusion

In my study, Poaceae family contributed the highest number of weed plants. Broadleaf weeds were more abundant than grass and sedge weeds. Among the five abundant weed species, *Monochoria vaginalis* was the highest abundant weed flora identified from the experimental area. The results of the recent investigation also showed that the treatments such as pre-emergence fb HW at 40 DAT, pre-emergence fb post-emergence herbicide, and post-emergence herbicide fb HW at 40 DAT were more profitable than two HW at 20 and 40 DAT. Farmers can adopt any of the aforesaid approaches based on available facilities such as manpower. But, following the latest research, pre-emergence herbicide fb HW at 40 DAT revealed as the best viable method to manage weeds and produce yield with the maximum economic returns in *boro* rice (BRRI dhan29). However, the consequences of long-term, recurrent herbicide usage on soil health have been recognized as a pressing problem due to considerable rise in herbicide use in Bangladesh and it requires attention for more inquiry before reaching at any specific decision.

Conflict of interests

The authors have declared that there is no conflict of interests regarding the publication of this paper.

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