EFFICIENT WEED MANAGEMENT OF WHEAT UNDER CONSERVATION AGRICULTURE SYSTEMS WITH THE BEST POST-EMERGENCE HERBICIDE AND AT THE RIGHT APPLICATION RATE

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ABSTRACT

Planting wheat in a strip-tilled field is a challenge for controlling weeds at the early crop growth stage and ultimately yield has to sacrifice. Therefore, a study was done to select suitable herbicides and their appropriate application rate for getting effective weed control and optimum yield of strip-planted wheat under the conservation agriculture (CA) system. A two-year study (July 2017 to March 2019) was done that started with untreated non-puddled transplanted rainy season rice (following general weed management by applying pyrazosulfuron-ethyl: 10 g a.i ha^{-1} as pre-emergence control and bispyribac-sodium: 20 g a.i ha^{-1} as post-emergence control) and ended with strip-planted wheat. Rice was harvested retaining 20 cm standing residue and the subsequently planted wheat crop received post-emergence (POST) herbicides as treatments. Three POST herbicides named ethoxysulfuron (Sunrise; early post-emergence: 150 g a.i ha^{-1}), carfentrazone-ethyl plus isoproturon (Affinity; late post-emergence: 50.75 g a.i ha^{-1}) and carfentrazone-ethyl (Hammar; late post emergence: 24 ml a.i ha^{-1}) were applied at their label rate and double of the label rate and compared with a non-treated control (manually weeded at 20 and 40 days after wheat sowing). Pendimethalin was commonly applied in wheat to control pre-emergence weeds. The study identified 17 weed species in the strip-planted wheat field during 2017-18 and 09 species during 2018-19. Application of carfentrazone-ethyl plus isoproturon both at the label rate and double of the label rate controlled all weeds most effectively; however, the study suggests label rate application of carfentrazone-ethyl plus isoproturon in strip-planted wheat for attaining optimum yield and economic profit.

Keywords: Agronomy, herbicide, strip tillage, weed, wheat

INTRODUCTION

Weeds cause severe yield loss in wheat and uncontrolled weeds can cause wheat yield reduction of up to 72% (Flessner *et al*., 2021; Zahan *et al*., 2020; Fahad *et al*., 2015; Amare, 2014). Moreover, the outbreak of weed emergence is considered as a major problem for a field that is transforming from conventional tillage to a reduced tillage system (Baker *et al*., 2018; Scopel *et al*., 1991). In such cases, weed management is more difficult and challenging that can cause more yield loss than conventional cultivation systems (Buhler, 1995) due to complex weed shift, composition and growth (Baker *et al*., 2018; Shrestha *et al*., 2002; Swanton *et al*., 1999). Conservation agriculture (CA) is a holistic approach to sustainable intensification of crop cultivation (FAO, 2010) which is now at the adoption level in Bangladesh (Bell *et al*., 2019). However, weed is considered the major hindrance to the adoption of CA. During the earlier period of transformation of CA systems, a field becomes highly infested by weeds due to the absence of heavy pulverization of soil. Later on, the infestation of weeds decreases due to the less amount of available weed seeds on the soil surface and also for not coming up the weed seeds from the weed seed bank. Weeds can be manually controlled, but it is very costly and laborious. Currently, the labour crisis and high wages of labour discourage the farmers to go with manual weeding. On the other hand, the dependency on herbicides is high in CA for controlling weeds. The use of herbicides is time-consuming, cost-effective, and less laborious. The selection of post-emergence herbicide on weed is most important for wheat. Because wheat is mostly infested by broadleaf weeds and post-emergence herbicide plays an important role in broadleaf weed management.

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Therefore, a study has been designed and conducted to get the best post-emergence herbicide and its suitable rate of application for managing weeds in strip-planted wheat under CA systems.

MATERIALS AND METHODS

Study period and area

A study was carried out at the on-station field of the On-farm Research Division, Bangladesh Agricultural Research Institute, Gazipur (locates in central Bangladesh) from July 2017 to March 2019. The experimental land was medium high land with sandy loam textured soil with low organic matter (0.87%) and a soil pH of 5.04.

Weather condition

The study was started during the rainy season (July) of 2017 with transplanted rainy season rice (T. *aman* rice) and the study area received the highest amount of rainfall during July 2017 (520 mm), in May 2018 (414 mm) and in July 2019 (590 mm) (Fig. 1). It indicates that rainy season rice received ample rainwater. However, in wheat, the weather was almost rainless.

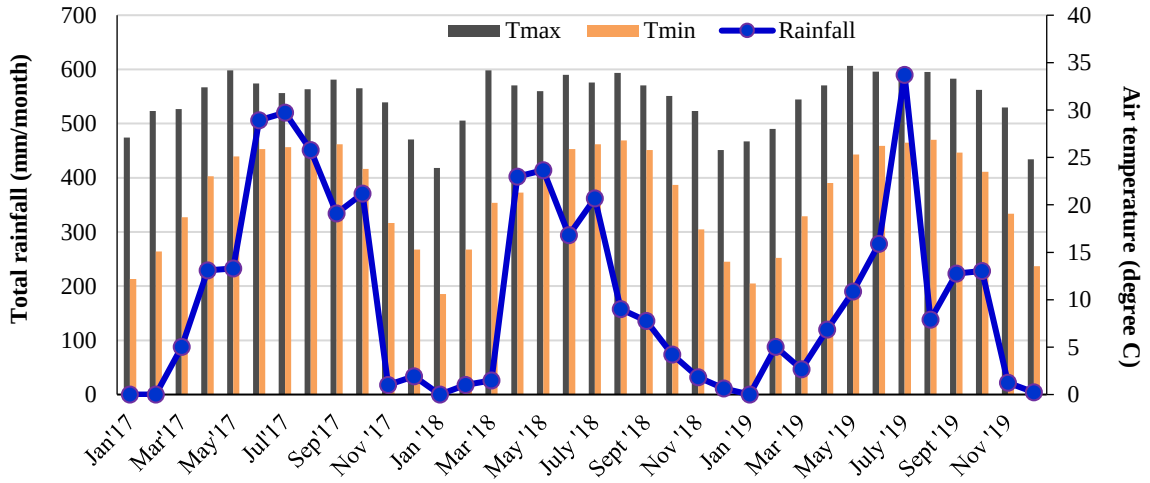


Fig. 1. Monthly total rainfall and the monthly average of maximum (Tmax) and minimum (Tmin) air temperature of the study area from January 2017 to December 2019 at Gazipur, Bangladesh (source: Agromet Division, Bangladesh Meteorological Department, Joydebpur, Gazipur, Bangladesh)

Experimental treatments, design, and other details

The study was initiated with general T. *aman* (rainy season) rice cultivation on 07 July 2017 and continued for two years (2017-2019) with the T. *aman* rice-wheat-mungbean cropping pattern. No weed management treatment was imposed in T. *aman* rice and mungbean, however; weeds in rice were controlled by applying pyrazosulfuron-ethyl @ 10 g a.i ha^{-1} as pre-emergence and bispyribac-sodium @ 20 g a.i ha^{-1} as a post-emergence herbicide. Unfortunately, mungbean was not harvested for both the years due to severe damage by heavy rainfall at its vegetative stage. Information regarding planting date, variety, fertilizer dose, and harvesting date are given in Table 1.

Table 1. Variety name, planting time, fertilizer dose, and harvesting date of crops in T. *aman* (rainy season) rice-wheat-mungbean cropping pattern

Crop	Variety	Planting date	Fertilizer dose (N-P-K-S-Zn-B kg ha^{-1})	Harvesting date
T. *aman* rice	BRRI dhan71	07 July 2017 17 July 2018	70-24-35-10-3.5-0	19 October 2017 04 November 2018
Wheat	BARI Gom-30	November 2017 17 November 2018	92-70-25-18-0-0	20 March 2018 26 March 2019
Mungbean	BARI mung-6	28 March 2018 18 April 2019	45-90-40-50-0-10 21-43-20-8-0-1.5	Damaged

The performance of three post-emergence herbicides (ethoxysulfuron, carfentrazone-ethyl plus isoproturon, and carfentrazone-ethyl) was evaluated at two rates in seven (07) treatment combinations *viz.*, T_1= control (manual weeding for two times at 20 and 40 days after sowing), T_2= ethoxysulfuron @ label rate (×1), T_3= ethoxysulfuron @ double of label rate (×2), T_4= carfentrazone-ethyl plus isoproturon (×1), T_5= carfentrazone-ethyl plus isoproturon (×2), T_6= carfentrazone-ethyl (×1) and T_7= carfentrazone-ethyl (×2). The details of herbicides along with their product name, label rate, the active ingredient, company name, type, and time of application are given in Table 2.

Table 2. The name of the product, their label rate, the active ingredient, company name, type, and time of application of the tested herbicides

Herbicide	Name of product	Label rate (ha^{-1})	Active ingredient (kg ha^{-1})	Company name	Type	Time of application
Ethoxysulfuron	Sunrice	15.0 L	150	Bayer Crop Science Ltd.	Early post-emergence	12 days after sowing
Carfentrazone-ethyl plus isoproturon	Affinity	25.5 L	50.75	Auto Crop Care Ltd.	Late post-emergence	22 days after sowing
Carfentrazone-ethyl	Hammer	24.9 kg	24	Auto Crop Care Ltd.	Late post-emergence	22 days after sowing

Rice was harvested retaining 20 cm standing residue in the field. Before seeding wheat, no pre-planting herbicide was applied as the field was free from weeds. Wheat seeds were planted by a two-wheel tractor-driven strip planter within the strips apart by 20 cm maintaining 150 kg seeds per hectare. All the fertilizers except N fertilizer were broadcasted before striping the land in the forms of urea, triple superphosphate, muriate of potash, gypsum, zinc sulphate, and boric acid. N fertilizer was applied in two equal splits 15 days after sowing (DAS) and at the panicle initiation stage. Shallow irrigation was provided four times to ensure proper germination and growth of wheat. Herbicides were applied by a manually operated knapsack hand sprayer. Crop protection measures were also taken as and when necessary.

Data collection, process, and analysis

The species of weeds were identified and populations of each species were counted from unbiased pre-selected 1 m^2 of area. The data on total weed density and biomass were collected at 35 DAS from randomly selected two spots of 50 cm × 50 cm sized quadrat. The biomass of wheat was also collected from the same spots at the same time. Yield and yield contributing data were recorded from the central 2 m × 3 m area of each plot and converted into t ha^{-1}. The collected data were processed for statistical analysis and the analysis

was done with the statistical package program 'R' (version 3.3.3). Some efficiency indices like Herbicide efficiency index (HEI), Weed control efficiency (WCE), Weed control index (WCI), Weed persistence index (WPI), Weed index (WI), Herbicide efficiency index (HEI), and Yield increase over control (YOC) were calculated the methods described by Misra and Misra (1997) and Devasenpathy *et al*. (2008). Economic analysis was also been carried out to determine the cost-effectiveness of the treatments following the producers by Parvez *et al*. (2013). Labours required for one manual weeding and one round of herbicide spraying per hectare area were 25 and 2, respectively. The cost required for one labour was 250 Bangladeshi Taka (Tk.) day^{-1}. Herbicide requirement was calculated by the amount of commercial product ha^{-1} and the cost of each herbicide was calculated based on their local market price. The price of grain and straw was estimated as per the government fixed rate. The net benefit per hectare for each treatment was calculated by deducting the total cost (fixed cost + weed management cost) from the gross return.

RESULTS AND DISCUSSION

Infested weeds

The strip-tilled wheat field was infested by grass, sedge, and broadleaf weed species (Table 3). There were four (04) grass weeds identified in 2017-18 named *Cynodon dactylon*, *Digitaria sanguinalis*, *Echinochloa colona* and *Elusina indica*. In the next year, besides these four grass weeds, *Oryza rufipogon* was also found. In the case of sedge weed, *Cyperus rotundus* was the only species found in 2017-18; but did not exist in the next year. A wide range of broadleaf weeds (11 species in 2017-18 and 4 species in 2018-19) was identified in both years; however, most species were not common in both years (Table 3).

Table 3. Weed species of strip-tilled wheat fields in Gazipur during 2017-18 and 2018-19

Weed	Weed species		English name along with nature
	2017-18	2018-19	
Grass	*Cynodon dactylon* (L.) Pers.	*Cynodon dactylon* (L.) Pers.	Bermuda grass; Perennial
	Digitaria sanguinalis (L.) Scop.	*Digitaria sanguinalis* (L.) Scop.	Crab grass; Annual
	Echinochloa colona (L.) Link	*Echinochloa colona* (L.) Link	Jungle rice; Annual
	Elusina indica (L.) Gaertn.	*Elusina indica* (L.) Gaertn.	Indian goosegrass; Perennial
	-	*Oryza rufipogon*	Wild rice; Annual
Sedge	*Cyperus rotundus* L.	-	Nutsedge; Perennial
Broadleaf	*Polygonum lapathifolium* (L.) Delarbre	-	Pale smartweed; Annual
	Chenopodium album L.	-	White goosefoot; Annual
	Gnaphalium affine (D.Don) Anderb.	-	Pseudognaphalium affine; Biennial
	Portulaca oleracea L.	-	Common purslane; Annual
	Enhydra fluctuans Lour.	*Enhydra fluctuans*	Water spinach; Perennial
	Amaranthus viridis L.	-	Slender amaranth; Perennial
	Vicia sativa L.	-	Common vetch; Perennial
	Eclipta prostrata (L.) L.	-	False daisy; Perennial
	Physalis heterophylla Nees	-	Clammy groundcherry; Perennial
	Nicotiana plumbaginifolia Viv.	-	Tex-Mex tobacco; Perennial
	Alternanthera sessilis (L.) R Br. ex DC.	-	Dwarf copperleaf; Perennial
	-	*Blumea lacera* (Burm.f.) DC.	Kakronda lettuce-leaf; Annual
	-	*Marsilea quadrifolia* L.	Four leaf clover; Perennial
	-	*Brassica kaber* var. *schkuhriana* (Rchb.) L.C.Wheeler	Wild mustard; Perennial

The number of grass, sedge, and broadleaf weeds varied with treatments (Table 4). The highest numbers of grasses, sedges, and broadleaf weeds were counted from control plots. Application of Ethoxysulfuron at double the label rate offered the highest reduction in numbers of grasses and broadleaf weeds than the other treatments during 2017-18. During 2018-19, the number of grasses was reduced to the maximum by application of Carfentrazone-ethyl plus isoproturon at double the label rate. The less control of ethoxysulfuron on wild rice might be the reason for becoming less efficient than carfentrazone-ethyl plus isoproturon in the second year of study. The emergence of wild rice in the strip-tilled wheat field is related to the minimum tillage. Heavy conventional tillage helps to bury the seeds of wild rice in the sub-surface layer of soil. However; in strip tillage, seeds of wild rice remain on the surface of the soil and germinate when received optimal environment.

Table 4. Total population of grass, sedge and broadleaf weeds in strip-planted wheat field at Gazipur, Bangladesh during 2017-18 and 2018-19

Treatment	Grass		Sedge		Broadleaf	
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Control	165	334	5	-	56	12
Ethoxy×1	48 (71%)	129 (61%)	0 (100%)	-	5 (91%)	3 (78%)
Ethoxy×2	39 (77%)	94 (72%)	0 (100%)	-	2 (96%)	1 (89%)
Carf+iso×1	78 (53%)	91 (73%)	0 (100%)	-	9 (84%)	11 (11%)
Carf+iso×2	74 (55%)	88 (74%)	0 (100%)	-	3 (94%)	5 (56%)
Carfen×1	77 (53%)	135 (60%)	0 (100%)	-	7 (88%)	0 (100%)
Carfen×2	66 (60%)	112 (67%)	0 (100%)	-	2 (96%)	0 (100%)

Here, 'Ethoxy' stands for 'Ethoxysulfuron', Carf+iso' stands for 'Carfentrazone-ethyl plus isoproturon', 'Carfen' stands for 'Carfentrazone-ethyl'Within the first bracket (), the percentage of reduction in numbers of weeds compared to control treatment.

The highest reduction in the number of broadleaf weeds was in the plots having carfentrazone-ethyl at the label rate and double the label rate. This herbicide offered good control of broadleaf weeds at the early stage.

Weed density and biomass

The total weed density and biomass significantly varied with the treatments (Table 5). The highest weed densities and biomasses were in the control plots during both years. Application of ethoxysulfuron at double the label rate offered the highest reduction in weed density by 82% in 2017-18 and 73% in 2018-19 compared to control plots because of providing good control on both grass and broadleaf weeds. In the case of weed biomass, the highest reduction was obtained from the application of carfentrazone-ethyl plus isoproturon at double the label rate in 2017-18 and the label rate in 2018-19 (Table 5). Carfentrazone-ethyl plus isoproturon is a ready-mix herbicide having the inhibition potentiality of both protoporphyrinogen oxidase (Protox) and acetolactate synthase that directly injured leaf tissues and caused leaf necrosis of weeds. The highest mean of WCE (78%) was provided by ethoxysulfuron at double the label rate (Table 6). The highest mean of WCI (70%) was get from carfentrazone-ethyl plus isoproturon at the label rate and the double the label rate also gave a similar WCI (69%). However; in the case of WPI, the lowest value (0.75 in 2017-18 and 1.08 in 2018-19) was obtained from carfentrazone-ethyl plus isoproturon at the label rate (Table 6), and a close WPI value was also found from the double the label rate application of carfentrazone-ethyl plus isoproturon. These results indicate that carfentrazone-ethyl plus isoproturon effectively controlled weeds of strip-planted wheat. In several previous studies, this herbicide performed very well in controlling weeds of wheat (Dixit and Singh, 2008; Shehzad *et al*., 2012).

Table 5. Total Weed density and biomass in strip-planted wheat at Gazipur, Bangladesh during 2017-18 and 2018-19

Treatment	Weed density (no. m^{-2})		Weed biomass (g m^{-2})	
	2017-18	2018-19	2017-18	2018-19
Control	226 a	346 a	12.54 a	47.60 a
Ethoxy×1	53 d (77)	132 b (62)	5.03 b (60)	27.27 b (43)
Ethoxy×2	41 e (82)	95 b (73)	5.47 b (56)	24.53 bc (48)
Carf+iso×1	87 b (62)	102 b (71)	3.63 b (71)	15.20 c (68)
Carf+iso×2	78 bc (66)	93 b (72)	3.44 b (73)	16.93 c (64)
Carfen×1	84 b (63)	135 b (61)	4.68 b (63)	28.00 b (41)
Carfen×2	68 c (70)	111 b (68)	3.96 b (68)	31.73 b (33)
Level of sig.	***	***	***	***
CV (%)	6.26	18.43	13.51	19.87

Here, 'Ethoxy' stands for 'Ethoxysulfuron', Carf+iso' stands for 'Carfentrazone-ethyl plus isoproturon', 'Carfen' stands for 'Carfentrazone-ethyl' Within the first bracket (), the percentage of reduction compared to the control treatment.

Table 6. Weed control efficacy, weed control index, and weed persistence index of herbicide treated plots in strip-planted wheat at Gazipur, Bangladesh during 2017-18 and 2018-19

Treatment	WCE (%) (Mean)	WCI (%) (Mean)	Weed persistence index (WPI; %)	
			2017-18	2018-19
Control	-	-	-	-
Ethoxy×1	70	52	1.71	1.50
Ethoxy×2	78	52	2.40	1.88
Carf+iso×1	67	70	0.75	1.08
Carf+iso×2	70	69	0.79	1.32
Carfen×1	62	52	1.00	1.51
Carfen×2	69	51	1.05	2.08

Here, 'Ethoxy' stands for 'Ethoxysulfuron', Carf+iso' stands for 'Carfentrazone-ethyl plus isoproturon', 'Carfen' stands for 'Carfentrazone-ethyl', WCE = Weed Control Efficacy, WCI = Weed Control Index.

Weed biomass and wheat biomass

The weed and wheat biomasses at 35 DAS were recorded and it was observed that control plots had the highest weed biomass and the lowest wheat biomass (Fig. 2). The highest wheat biomass was measured in the plots with carfentrazone-ethyl plus isoproturon at the label rate in 2017-18 and a double, the label rate in 2018-19; however; the lowest weed biomass was recorded from double the label rate application. It indicates that good growth of wheat can be ensured by providing a less weed-competitive environment.

Grain yield

The control plots had the lowest grain yields during both years (Table 7). The plots having the label rate application of carfentrazone-ethyl plus isoproturon had the highest grain yields. The highest HEI was also calculated from the same treatment. This result expresses that effective weed control can improve wheat yield significantly. Plots with double the label rate application of carfentrazone-ethyl plus isoproturon also provided close yield and HEI with the label rate. Several earlier studies also suggested the application of carfentrazone-ethyl plus isoproturon to get effective weed control and the best yield (Zahan *et al*., 2020, Shehzad *et al*., 2012, Dixit and Singh, 2008). The lowest HEI was in the plots with double the label rate of carfentrazone-ethyl. This herbicide injures the leaf tissue of both weeds and crops; however, the degree of injury depends on the amount of protoporphyrin IX (Proto IX) present in the treated tissues (Dayan *et al*., 1999). That's why; besides weeds, wheat plants may also be affected by this herbicide and didn't produce the expected yield.

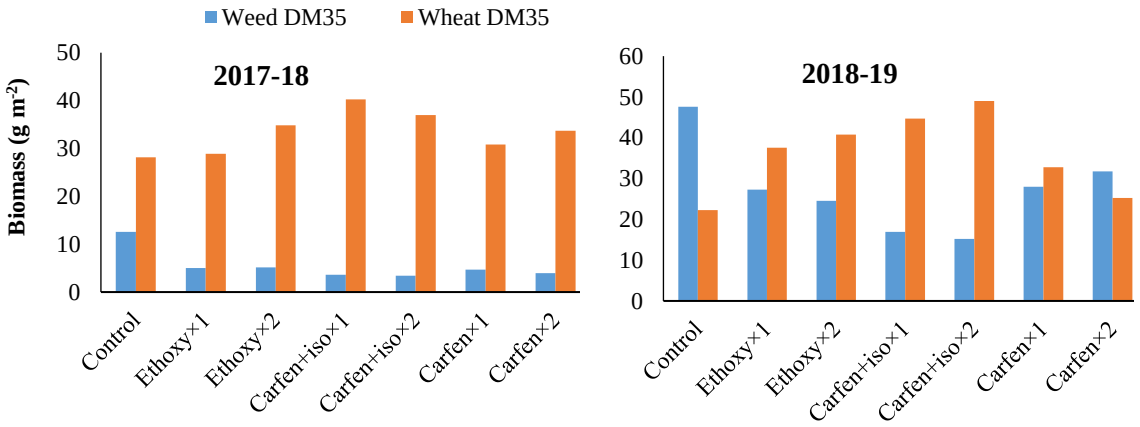


Fig. 2. Weed and wheat biomasses at 35 days after sowing of strip-planted wheat at Gazipur, Bangladesh, during 2017-18 and 2018-19

Table 7. Effect of treatment on grain yield, yield increase over control, and herbicide efficiency index in strip-planted wheat at Gazipur, Bangladesh during 2017-18 and 2018-19

Treatment	Grain yield (t ha^{-1}) with YOC (%)		HEI (%)	
	2017-18	2018-19	2017-18	2018-19
Control	3.86 c	2.63 e	-	-
Ethoxy×1	3.89 c (0.8)	3.10 de (17.9)	2.46	30.94
Ethoxy×2	4.04 bc (4.7)	3.67 bc (39.5)	11.83	76.14
Carf+iso×1	4.82 a (24.9)	4.37 a (66.2)	85.93	185.03
Carf+iso×2	4.56 ab (18.1)	4.13 ab (57.0)	66.25	178.38
Carfen×1	4.22 bc (9.3)	3.20 cd (21.7)	25.02	36.58
Carfen×2	3.81 c (-1.3)	3.13 cde (19.0)	-3.56	28.48
Level of sig.	*	***	-	-
CV (%)	8.08	8.79	-	-

Here, 'Ethoxy' stands for 'Ethoxysulfuron', Carf+iso' stands for 'Carfentrazone-ethyl plus isoproturon', 'Carfen' stands for 'Carfentrazone-ethyl', 'YOC' stands for 'yield increase over control', 'HEI' stands for 'Herbicide efficiency index'.

CONCLUSION

The CA transformed field always faces a severe infestation of weeds. To control heavily infested weeds of wheat under CA systems and also to attain the maximum yield, label rate application of carfentrazone-ethyl plus isoproturon is the best option.

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