ORIGINAL RESEARCH

Weed control strategies for wheat (*Triticum aestivum* L.) in a cereal-legume cropping system on the Old Brahmaputra Floodplain, Bangladesh

Taslima Zahan [1,2], Md. Moshiur Rahman [2] Mahfuza Begum [2], Md. Abdul Muktadir [1], Md. Zannatul Ferdous[1], Md. Enamul Haque [3] and Richard W. Bell [3]

[1] Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh; [2] Bangladesh Agricultural University, Mymensingh, Bangladesh; [3] Murdoch University, Western Australia, Australia.

Corresponding Author E-mail: taslimazahan_tzp@yahoo.com; taslima@bari.gov.bd

Received: 7 April 2020

Accepted for publication: 10 June 2020

Published: 30 June 2020

Abstract

Strip planting is a promising establishment method for wheat (*Triticum aestivum* L.); however, wheat yields can sharply decline if weeds in the fields are not effectively managed. Therefore, to obtain an adequate and economically-viable weed control strategy for strip-planted wheat, we conducted a study, over two years (2013-14 and 2014-15) with commercially available herbicide. Our study was in Mymensingh, in the Eastern Gangetic Plains (EGP) in Bangladesh. In the study, we used pre-emergence (pendimethalin, pretilachlor and triasulfuron), early post- (ethoxysulfuron and pyrazosulfuron-ethyl) and late post-emergence (carfentrazone-ethyl, carfentrazone-ethyl plus isoproturon and 2,4-D amine) herbicides, following a sequential application approach. Sixteen treatment combinations with these herbicides were tested in wheat, and the trials included one 'weedy check' and one 'weed-free check'. The study field was predominantly infested with three grass weeds [*Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop. and *Echinochloa colona* (L.) Link], one sedge (*Cyperus rotundus* L.) and five broadleaf weeds [*Polygonum lapathifolium* L., *Physalis heterophylla* (L.) Nees, *Lepidium didymum* (L.), *Chenopodium album* L. and *Vicia sativa* L.]. Another broadleaf weed species - ragweed (*Senecio vulgaris* L.) - was also in the field as a minor weed. *Polygonum lapathifolium* was the most dominant weed species in both years. All herbicide treatments fully controlled this species during both years, except the treatments - pretilachlor followed by (fb) hand weeding at 25 days after sowing fb pretilachlor and pretilachlor fb 2,4-D amine.

The herbicide treatments reduced the total weed biomass of strip-planted wheat by 66-95% in the first year and 71-100% in the second year. With regard to the weed control efficacy, six herbicide treatments: (1) pendimethalin followed by (fb) carfentrazone-ethyl plus isoproturon; (2) pendimethalin fb ethoxysulfuron fb carfentrazone-ethyl; (3) pendimethalin fb pyrazosulfuron-ethyl fb 2,4-D amine; (4) pretilachlor fb pyrazosulfuron-ethyl fb 2,4-D amine; (5) pendimethalin fb carfentrazone-ethyl; and (6) pretilachlor fb ethoxysulfuron fb carfentrazone-ethyl were the best performing combinations. These treatments provided more grain yield than the 'weed-free check' by 2-19% with the economic returns increasing by 30 to 164%. Additionally, bioassay testing of the soil in the treated fields indicated that the succeeding mungbean crop was not adversely affected by the residues of herbicides applied in the previous strip-planted wheat. Overall, the study suggests that the sequential application of pendimethalin followed by carfentrazone-ethyl plus isoproturon, pendimethalin/ pretilachlor followed by ethoxysulfuron with 2,4-D amine or pendimethalin/ pretilachlor followed by pyrazosulfuron-ethyl followed by carfentrazone-ethyl would be the most effective combinations for highly effective weed control in strip-planted wheat in the EGP. Given that the wheat fields are usually rotated with rice (*Oryza sativa*) and mungbeans (*Vigna radiata*), we contend that year-wise rotational application of those herbicide treatments in strip-planted wheat might minimize the risk of herbicide resistant weed development in those crop rotations as well as in the cropping pattern.

ORIGINAL RESEARCH

Keywords: Herbicides; Productivity; Strip planted wheat; Weed management, Pendimethalin; Pretilachlor; Triasulfuron; Pyrazosulfuron-ethyl; Ethoxysulfuron; Carfentrazone-ethyl; Carfentrazone-ethyl plus isoproturon; 2,4-D amine

Introduction

In the sub-tropics of South Asia, farmers commonly grow wheat in the winter season after harvest of rainy season rice (Sarker et al., 2014). The rice-wheat-mungbean is one of the popular cropping patterns practiced in the Eastern Gangetic Plains (EGP) in the northern and north-western regions of Bangladesh (Bari and Islam, 2009).

This pattern can contribute to a nutritionally-balanced diet for farming families besides providing high economic returns and improving the soil health (Naresh et al., 2013). The adoption of strip planting of wheat (Hossain et al., 2014), mungbean (Bell et al., 2018) and rice (Haque et al., 2016) in a rotation help to conserve soil resources. However, the residue retention from the previous crop may influence weed population dynamics through various factors (Christoffoleti et al., 2007; Chauhan et al., 2012). Heavy weed infestations in strip-planted wheat causes up to 68% yield loss (Zahan et al., 2016), which demands an effective and affordable weed management strategy.

In Bangladesh, the use of pendimethalin as a pre-emergence (PRE) and carfentrazone-ethyl plus isoproturon as a late post-emergence herbicide (LPOST) is common for weed control in wheat (WRC, 2016). Apart from these, no other herbicide is usually applied in wheat. Generally, the continuous use of any herbicide in the same paddock, or even different herbicides belonging from the same group, may accelerate the development of herbicide resistant weeds (Owen and Powels, 2009). In 67 countries, 478 weed biotypes of 252 weed species are now reported as herbicide-resistant (Vrbničanin et al., 2017). Managing of herbicide resistant weeds is quite difficult, but resistance development could be delayed by selecting and applying herbicides rotationally from different groups or with different modes of action (Norsworthy et al., 2012).

Some weed species can escape the spray of pre-emergence (PRE) herbicide in conservation agriculture systems due to the presence of crop residues (Chauhan and Abugho, 2012). It is one of the reasons why sequential application of PRE and post-emergence (POST) herbicides may ensure effective weed control. On the other hand, despite controlling weeds effectively, persistence of herbicide in soil is a major concern that could adversely affect the subsequently grown crops in a rotation (Hernández-Sevillano et al., 2001).

The primary objective of our study was to investigate how to achieve adequate weed control in wheat with combinations of PRE and POST herbicides, while avoiding undesirable residual effects for a subsequent mungbean crop. At the same time, a second objective was to evaluate the economic returns – whether the herbicide treatments and other inputs and increased weed control would result in increased profits for farmers. In addition, to slow down the development of herbicide resistant weed populations, our aim was to identify a range of efficient and economic herbicides for strip-planted wheat grown in rice-wheat-mungbean cropping pattern in the EGP that can be applied on a rotational basis, year after year, instead of repeated use of the same herbicide(s).

Materials and Methods

The Site and Experimental Design

The study was conducted at the Bangladesh Agricultural University, Mymensingh (24°75' N latitude and 90°50' E longitude), Bangladesh, on a rice-wheat-mungbean cropping system for two consecutively years (2013-14 and 2014-15). The experimental field was well drained medium-high land. The soil was a sandy clay loam in texture; with a pH of 6.8 and low organic matter content (1.74%).

The total amount of rainfall and monthly average of maximum and minimum air temperatures of the experimental site during the studied period are presented in Figure 1.

Cultural Practices

The experimental fields were fertilized with phosphorus (P), potassium (K) and sulphur (S) at 64, 24 and 13 kg ha^{-1} in the form of triple super phosphate, muriate of potash and gypsum, respectively. These fertilizers were broadcast just before the strip planting of wheat (Figure 2).

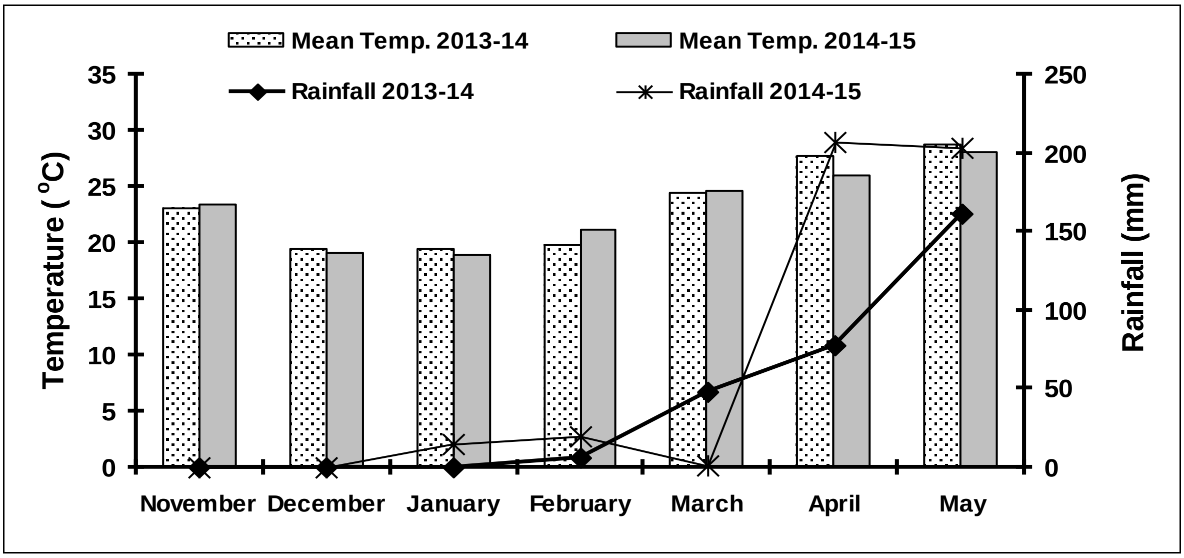

Figure 1. A schemetic presentation of prevailing monthly mean air temperature and monthly total rainfall during the life cycle of wheat and mungbean in 2013-14 and 2014-15 at Mymensingh, Bangladesh. (Source: Weather Yard, Department of Irrigation and Water Management, BAU, Mymensingh).

Cow dung was also added and spread over the field at 3.5 t ha^{-1} three days before the strip planting. Nitrogen (N) was applied at 84 kg ha^{-1} as urea in two split applications at 7 and 35 days after sowing (DAS). The experimental fields were lightly irrigated at 20, 50 and 75 DAS. To avoid insect infestations, chlorpyrifos, at 1 L ha^{-1} was applied at 45 DAS and 65 DAS of wheat.

The first crop, strip-planted non-puddled rainy-season rice, was harvested from the fields retaining behind 20 cm crop residues. To prepare the field for wheat, pre-plant applications of glyphosate were applied twice at 1.54 kg a.i. ha^{-1} to kill the standing weeds before growing wheat.

One week after the second glyphosate application, wheat (*cv*. BARI Gom-26) seeds were sown at 120 kg ha^{-1} on 22 November 2013, and 20 November 2014, within the strips 20 cm apart by a Versatile Multi-crop Planter (VMP) powered by two-wheel tractor (Haque et al., 2017).

The crop was harvested at maturity on 19 March 2014, and in the following year, on 15 March 2015, retaining 20 cm of standing residue. In each year, after the harvest of wheat, the rotational crop - mungbean *cv*. BARI mung-6 was planted in the same field plots. Mungbean was sown at 35 kg of seeds ha^{-1} by strip planting with the VMP on 01 April 2014 and 30 March 2015. Figure 3 shows a strip-planted field in the trials.

Figure 2. Field trial site – planting and fertilizing of wheat with Versatile Multi-crop planter in Mymensingh, Bangladesh

Figure 3. Field trial site – strip-planted wheat field in Mymensingh, Bangladesh

Weed Flora

The strip-planted wheat fields were infested by ten weed species (Table 1). grass weeds [*Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop. and *Echinochloa colona* (L.) Link], one sedge (*Cyperus rotundus* L.) and five broadleaf weeds [*Polygonum lapathifolium* L., *Physalis heterophylla* (L.) Nees, *Lepidium didymum* (L.), *Chenopodium album* L. and *Vicia sativa* L.]. Another broadleaf weed species - ragweed (*Senecio vulgaris* L.) - was also in the field as a minor weed. *Polygonum lapathifolium* was the most dominant weed species in both years (Figure 4).

Figure 4. Field trial site – infestation of *Polygonum lapathifolium* in strip-planted wheat field, Mymensingh, Bangladesh

Herbicide Treatments and Applications

Eight commercially-available herbicides were selected for the study, drawn from different herbicide groups with different modes of action (MOA). Among those herbicides, three were pre-emergence (pendimethalin, pretilachlor and triasulfuron); two were early post- (ethoxysulfuron and pyrazosulfuron-ethyl) and three were late post-emergence (carfentrazone-ethyl, carfentrazone-ethyl plus isoproturon and 2,4-D amine) in action.

These herbicides were evaluated in the two consecutive years in 16 treatment combinations and their performance was tested against one 'weedy check' (unweeded) and one 'weed-free check' (manually weeded at 20, 35, 45 and 55 days after sowing). The experimental design was randomized complete block (RCB) with three replications. In each year, herbicide treatments were differentially randomized and allocated. This ensured that the individual plots (3 m x 4 m) did not receive the same treatment twice during the two-year study period.

The residual effect study of applied wheat herbicides was carried out in the following season on mungbean by using a micro-plot bio-assay technique as described by Hernández-Sevillano et al. (2001).

Pre-emergence (PRE) herbicides were applied three days after sowing wheat (DAS) and early post-emergence (EPOST) and late post-emergence (LPOST) herbicides were applied at 10 DAS and 25 DAS, respectively. Herbicides were applied as treatments only in wheat but not in mungbean; herbicides had also not been previously applied to the rice crops under the rice-wheat-mungbean cropping pattern. Manual weeding was done to control weeds in mungbean, which followed wheat, and, in the previous rice crop, before wheat.

The rates of herbicides (active ingredients, a.i.) applied in wheat in the trials were as follows: pendimethalin (PEND) 1.0 kg ha^{-1}; pretilachlor (PRETI) 0.5 kg ha^{-1}; triasulfuron (TRIA) 0.75 kg ha^{-1}; ethoxysulfuron (ETHOX) 15 g ha^{-1}; pyrazosulfuron-ethyl (PYRAZ) 1.5 g ha^{-1}; carfentrazone-ethyl (CARF) 24.96 g ha^{-1}; carfentrazone-ethyl plus isoproturon (CARF+ISO) 25.51 kg ha^{-1}; and 2,4-D amine (2,4-D) 1.01 kg ha^{-1}.

A hand operated knapsack sprayer (plastic bodied) with a flat-fan nozzle was used to apply the herbicides, delivering a spray volume of 300 L ha^{-1} with 0.3 MPa spray pressure.

Weed Control Evaluation and Measurements

Data on weed densities and biomass were recorded from three randomly selected quadrats of 0.25 m^2 (50 × 50 cm) in each plot at 35 and 50 DAS of wheat. Weeds were counted species-wise per m^2 and then oven dried at 70° C for 72 hours. The weed biomass was expressed as g m^{-2}.

Data on wheat yield contributing characters were taken from 1 m^2 of each plot. Yield data was recorded from the central 3.75 m^2 (1.5×2.5 m) area of each plot and converted into t ha^{-1} at 12% moisture content. Data on emergence, leaf chlorophyll content, shoot and root length and crop biomass at 25 DAS of mungbean were recorded following the procedure of Zahan et al. (2018).

Data were subjected to one-way analysis of variance (ANOVA) and means were compared by Tukey's Honestly Significant Difference (HSD) using the 'R' statistical package program, Version 3.3.3.

To determine the cost-effectiveness of herbicide treatments economic analysis was done according to Parvez et al. (2013) and the results presented in Table 4. Agronomic indices and sum dominance ratio (SDR) were calculated following the formula of Janiya and Moody (1989) and the weed control index (WCI) according to Devasenpathy et al. (2008).

Results

Effect of herbicides on weed species

The dominant weed species of 2013-14 were in the order of *Digitaria sanguinalis* > *Polygonum lapathifolium* > *Cynodon dactylon* > *Vicia sativa* > *Echinochloa colona* > *Cyperus rotundus* > *Physalis heterophylla* > *Lepidium didymum* > *Senecio vulgaris* > *Chenopodium album*, at 35 DAS.

The results of sum dominance ratio (Table 1) showed that grasses were dominant over other weeds at the early crop growth stages; however, subsequently, broadleaf weeds became the more dominant component. In 2014-15, the most dominant weed species were *P. lapathifolium* > *L. didymum* > *Chenopodium album* at 35 DAS and *L. didymum* > *P. lapathifolium* > *P. heterophylla* at 50 DAS. The most suppressed species was *E*. colona at 35 DAS and *S*. *vulgaris* at 50 DAS.

During both years, *Polygonum lapathifolium* was the most extensive weed species. Additionally, the study recorded that *C. album* and *L. didymum*, previously, minor weed species in 2013-14, emerged as major species in the weed community in the 'weedy check' plots during 2014-15.

Table 1. Summed dominance ratio (± standard error) of weeds at 35 and 50 days after sowing (DAS) of wheat in weedy plots during 2013-14 and 2014-15 under strip planting

Weed species	Family	Life cycle	Summed dominance ratio			
			2013-14		2014-15	
			35 DAS	50 DAS	35 DAS	50 DAS
Grass weeds						
Cynodon dactylon	Poaceae	Perennial	18.0±0.6	12.4±0.3	7.3±0.3	8.0±0.7
Digitaria sanguinalis	Poaceae	Annual	25.3±0.1	13.2±0.6	5.5±0.9	3.9±0.6
Echinochloa colona	Poaceae	Annual	10.3±0.5	12.2±0.1	0.8±0.2	3.2±0.2
Sedge weeds						
Cyperus rotundus	Cyperaceae	Perennial	7.8±0.6	7.7±0.5	5.4±0.2	3.5±0.0
Broadleaf weeds						
Polygonum lapathifolium	Polygonaceae	Annual	21.6±0.7	21.0±1.0	26.8±1.9	24.9±1.4
Vicia sativa	Fabaceae	Annual	12.8±0.2	11.6±0.6	10.1±0.8	6.0±0.4
Physalis heterophylla	Solanaceae	Perennial	3.1±0.3	19.5±0.4	4.1±0.7	12.4±1.8
Lepidium didymum	Brassicaceae	Annual/ Biennial	0.5±0.2	2.7±1.8	25.8±1.7	29.5±0.9
Chenopodium album	Amaranthaceae	Annual	0.2±0.2	0.8±0.8	12.7±1.2	7.2±0.3
Senecio vulgaris	Asteraceae	Annual	0.4±0.4	1.2±1.2	1.6±0.8	1.5±0.5

Effect of herbicides on weed species

The highest biomass (g m^{-2}) of all weed species was recorded from 'weedy' plots in all trials. The herbicide treatments reduced the biomass of all weed species both at 35 and 50 DAS of the strip-planted wheat to varying degree compared with the 'weedy check' (Figure 5 and Figure 6; Table 2).

Grass weeds

The herbicide treatments reduced biomass of *C. dactylon*, *D. sanguinalis* and *E. colona* by 17-81%, 82-100% and 39-100 % in 2013-14 and by 29-100%, 50-100% and 100% in 2014-15, respectively, compared to the weedy check (Figure 5). Both *D. sanguinalis* and *E. colona* were fully controlled by PEND followed by (fb) CARF, PEND fb PYRAZ fb

2,4-D and PEND fb CARF+ISO in 2013-14 and by all the treatments with PEND during 2014-15.

Additionally, during both years, the PRETI fb PYRAZ fb 2,4-D treatment provided 100% control of *D. sanguinalis* and *E. colona.* The grasses were also fully controlled by TRIA fb CARF+ISO treatment. In 2014-15, all treatments with PRETI also achieved the full control of *E. colona*.

No herbicide treatment ensured the complete control of *C. dactylon,* except PEND fb ETHOX fb CARF in 2014-15 (Figure 5). Poor control of *C. dactylon* was also observed in PRETI fb CARF and PRETI fb 2,4-D treatments during 2013-14 and PRETI fb CARF+ISO treatment during 2014-15.

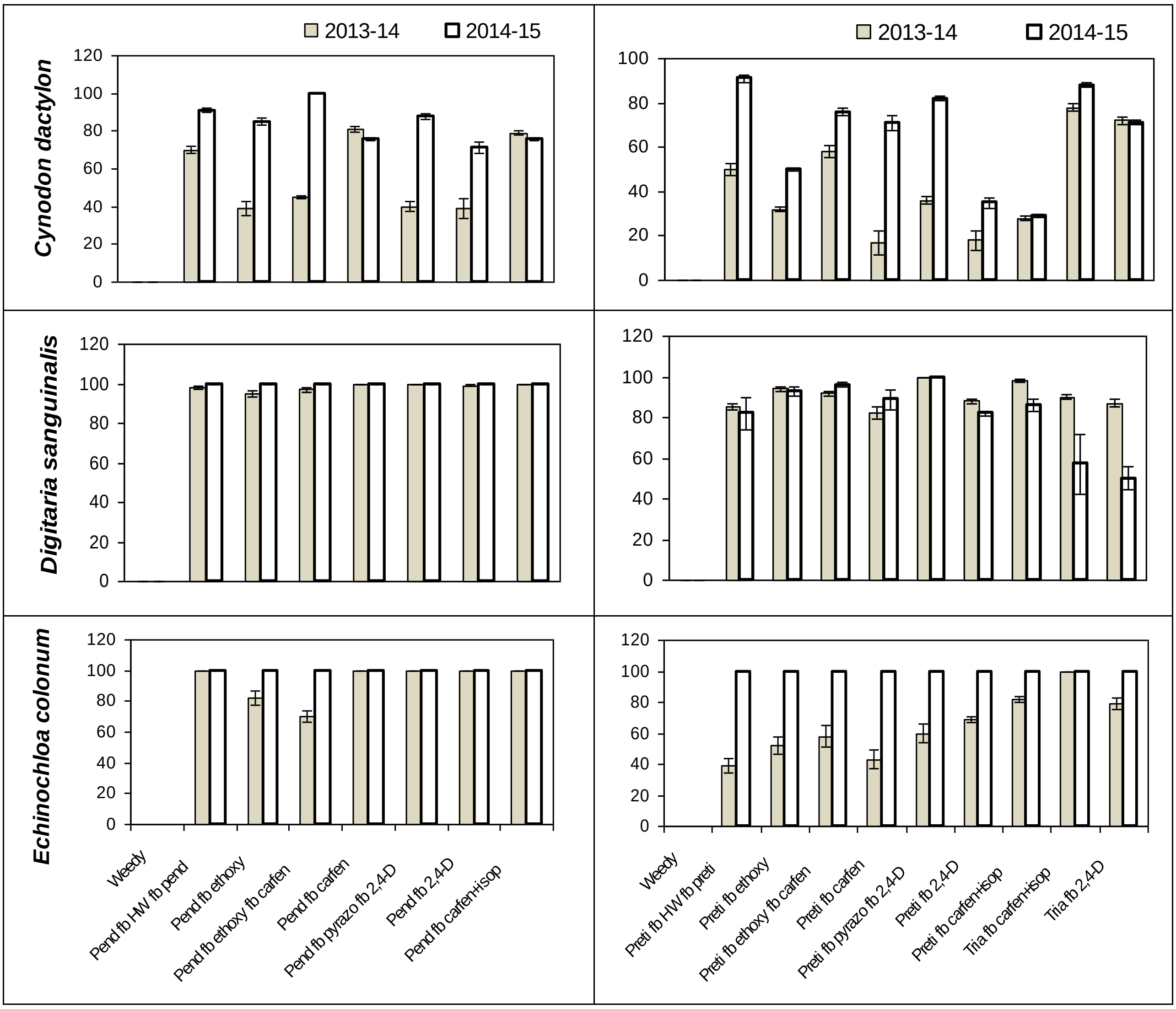

Figure 5. Control (% biomass reduction relative to weedy check) of grasses by herbicide treatments (left - treatments with PEND and other herbicides; right- treatments with PRETI and TRIA and other herbicides) at 35 DAS of wheat during 2013-14 and 2014-15. Vertical bars represent mean±standard errors.

Sedge weeds

The biomass of *C. rotundus* was significantly reduced by some herbicide treatments at 35 DAS compared to the weedy check (Figure 6). Treatments with PEND provided 38-100% biomass suppression of this sedge weed in 2013-14 and 32-100% in 2014-15. Complete control of *C. rotundus* was achieved by PEND fb PYRAZ fb 2,4-D treatment during both the years. PEND fb ETHOX fb CARF also controlled this weed completely during 2014-15.

Among the treatments, applications of PRETI, PRETI fb ETHOX fb CARF offered the most complete control on this sedge by reducing 95% of its biomass in 2013-14, whereas PRETI fb CARF gave the lowest control with only 5% biomass reduction. In 2014-15, applications of PRETI fb ETHOX, PRETI fb ETHOX fb CARF, PRETI fb PYRAZ fb 2,4-D or PRETI fb 2,4-D fully controlled the sedge compared with the weedy plots. Treatments with TRIA reduced the sedge biomass by 38-45% in 2013-14 and 21-29% in 2014-15, which was considered inadequate

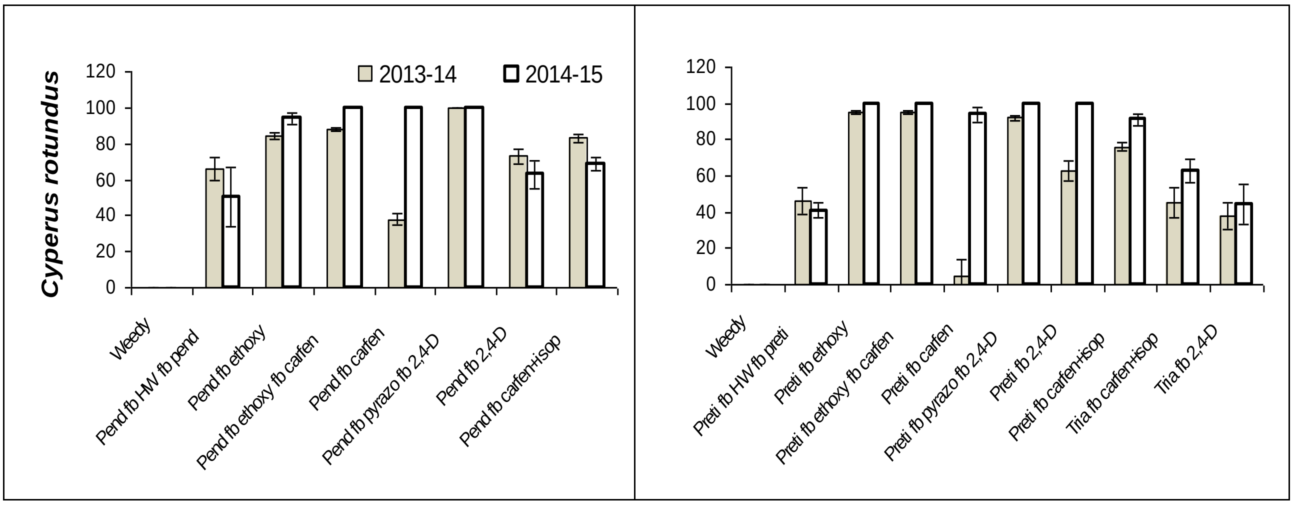

Figure 6. Control (% biomass reduction relative to weedy check) of sedge, *Cyperus rotundus*, by herbicide treatments (left - treatments with PEND and other herbicides; right- treatments with PRETI and TRIA and other herbicides) at 35 DAS of wheat during 2013-14 and 2014-15; Vertical bars represent mean±standard errors.

Broadleaf weeds

The herbicide treatments reduced biomass of *P. lapathifolium*, *V. sativa*, *P. heterophylla* and some other species (*L. didymum*, *C. album* and *S. vulgaris*) by 100%, 98-100%, 82-100% and 100%at 35 DAS, respectively during 2013-14 (Table 2). In 2014-15, biomass reduction of *P. lapathifolium*, *V. sativa*, *C. didymus*, *C. album*, *P. heterophylla* and *S. vulgaris* by herbicide treatments ranged between 72-100%, 33-100%, 99-100%, 60-100%, 55-100% and 100%, respectively (Table 2).

All herbicide treatments except PRETI fb 2,4-D and PRETI fb CARF+ISO ensured complete control of all broadleaf weed species during 2013-14. Moreover, PRETI fb 2,4-D was unable to fully control *P. heterophylla*. In 2014-15, treatments supplying PEND provided complete control of all broadleaf weed species, except *V. sativa*.

This broadleaf weed was fully controlled only by PEND fb ETHOX fb CARF, PEND fb CARF and PRETI fb ETHOX fb CARF. The study also demonstrated that PRETI fb hand weeding fb PRETI gave the lowest control of *P. lapathifolium*, *V. sativa*, *C. album* and *P. heterophylla* (Table 2).

Effect of herbicides on total weed biomass

The highest total weed biomass at 35 DAS was recorded from the weedy check during both years and herbicide treatments offered a significant reduction ($p<0.001$) in total weed biomass compared to that of the weedy check (Figure 7).

During 2013-14, herbicide treated plots had 75-95% lower weed biomass than the weedy plots and PEND fb CARF+ISO treated plots had the lowest amount of total weed biomass at 35 DAS. All herbicide treatments except PRETI fb CARF, PRETI fb 2,4-D and PRETI fb hand weeding fb PRETI ensured a weed control index (WCI) above 80% during 2013-14.

In 2014-15, PEND fb ETHOX fb CARF was the most effective treatment having 100% WCI (Figure 7). Moreover, almost all herbicide treatments had >90% WCI both at 35 and 50 DAS, except for PRETI fb hand weeding fb PRETI and PRETI fb 2,4-D (WCI <90%).

Table 2. Control (% decrease in weed biomass relative to the weedy check) on broadleaf weed species by herbicide treatments in strip-planted wheat at 35 days after sowing in 2013-14 and 2014-15

Treatment	2013-14				2014-15					
	PL	VS	PH	Others	PL	VS	LD	CA	PH	SV
T_1= Weedy check	0 (8.3)	0 (4.7)	0 (1.0)	0 (0.5)	0 (16.9)	0 (5.2)	0 (7.4)	0 (4.7)	0 (1.1)	0 (0.7)
T_3= Pendimethalin fb HW fb pendimethalin	100	100	100	100	100	44	100	100	100	100
T_5= Pendimethalin fb ethoxysul	100	100	100	100	100	96	100	100	100	100
T_7= Pendimethalin fb ethoxysul fb carfentra	100	100	100	100	100	100	100	100	100	100
T_9= Pendimethalin fb carfentra	100	100	100	100	100	100	100	100	100	100
T_{11}= Pendimethalin fb pyrazosul fb 2,4-D	100	100	100	100	100	98	100	100	100	100
T_{13}= Pendimethalin fb 2,4-D	100	100	100	100	100	90	100	100	100	100
T_{15}= Pendimethalin fb carfentra + isoprot	100	100	100	100	100	98	100	100	100	100
T_4= Pretilachlor fb HW fb pretilachlor	100	100	100	100	72	33	100	60	55	100
T_6= Pretilachlor fb ethoxysul	100	100	100	100	100	92	100	100	100	100
T_8= Pretilachlor fb ethoxysul fb carfentra	100	100	100	100	100	100	100	100	100	100
T_{10}= Pretilachlor fb carfentra	100	100	100	100	100	65	100	100	100	100
T_{12}= Pretilachlor fb pyrazosul fb 2,4-D	100	100	100	100	100	98	100	100	100	100
T_{14}= Pretilachlor fb 2,4-D	100	98	82	100	95	88	100	83	100	100
T_{16}= Pretilachlor fb carfentra + isoprot	100	98	100	100	100	90	100	100	100	100
T_{17}= Triasulfuron fb carfentra + isoprot	100	100	100	100	100	98	100	100	100	100
T_{18}= Triasulfuron fb 2,4-D	100	100	100	100	99	92	99	100	100	100

Figures within the parenthesis are the weed dry matter (g m^{-2})

PL = *Polygonum lapathifolium*, VS = *Vicia sativa*, LD = *Lepidium didymum*, CA = *Chenopodium album*, PH = *Physalis heterophylla*, SV = *Senecio vulgaris*

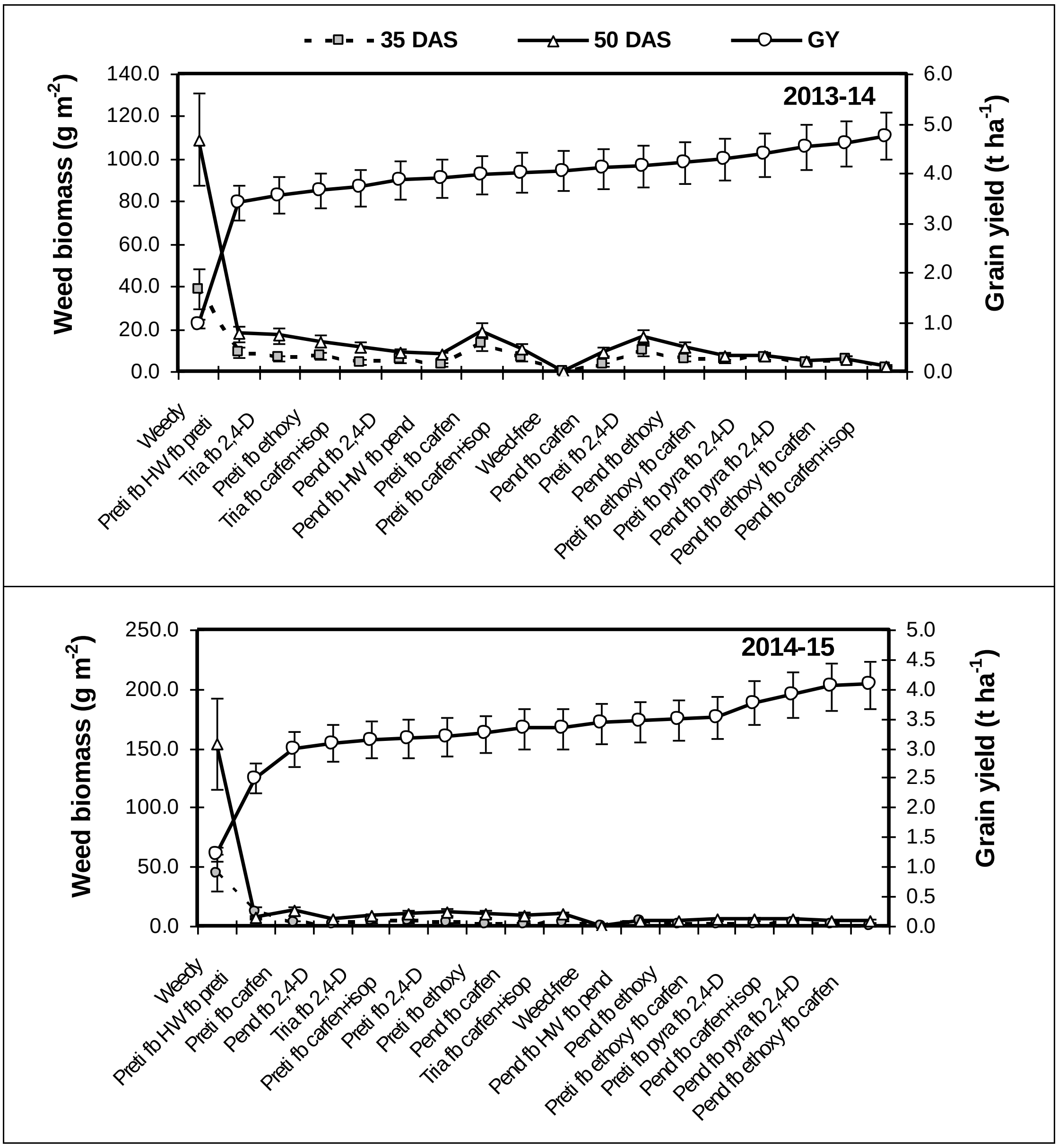

Figure 7. Effect of herbicide treatments on total weed biomass at 35 and 50 days after sowing (DAS) and grain yield (GY) of strip-planted wheat during 2013-14 and 2014-15 [vertical bar represents ±standard errors]

Impact of herbicides on wheat yield

The grain yield of strip-planted wheat varied significantly with herbicide treatments during both years (Figure 7). The lowest wheat grain yields (0.96 and 1.22 t ha^{-1}) were in the 'weedy' check plots and the highest yield was in PEND fb CARF+ISO and PEND fb ETHOX fb CARF treated plots during 2013-14 and 2014-15, respectively. Treatments that produced higher grain yield over the weed-free control in 2013-14 were PEND fb CARF+ISO > PEND fb ETHOX fb CARF > PEND fb PYRAZ fb 2,4-D > PRETI fb PYRAZ fb 2,4-D > PRETI fb ETHOX fb CARF > PEND fb ETHOX > PRETI fb 2,4-D and PEND fb CARF.

During 2014-15, compared to the 'weed-free' check, higher grain yield producing treatments were PEND fb ETHOX fb CARF > PEND fb PYRAZ fb 2,4-D>CARF+ISO > PRETI fb PYRAZ fb 2,4-D > PRETI fb ETHOX fb CARF > PRETI fb ETHOX. Among the herbicide treatments, PRETI fb hand weeding fb PRETI gave the lowest grain yield during both years. The strip-planted wheat yields under 'weed-free' conditions were 4.43-4.67 and 3.55-3.56 t ha^{-1} in 2013-14 and 2014-15, respectively.

As expected, the wheat grain yields were negatively correlated with weed biomass obtained both at 35 and 50 DAS (in 2013-14, R^2 = 0.81 and 0.89 and in 2014-15, R^2 = 0.80 and 0.72) (Table 3). From the regression equation, a 1% increase in weed biomass at 35 DAS decreased grain yield by 5.5-9.2% and at 50 DAS by 1.8-3.3%.

Table 3. Relationships of wheat grain yield (kg ha^{-1}) with weed biomass (kg ha^{-1}) at 35 and 50 DAS

y	x	2013-14		2014-15	
		Regression equation	R^2	Regression equation	R^2
Grain yield	Weed biomass at 35 DAS	y = 4671-9.221x	0.81***	y = 3561-5.469x	0.80***
	Weed biomass at 50 DAS	y = 4431-3.272x	0.89***	y = 3549-1.827x	0.72***

Here, *** means 0.1% level of significance

Economic cost evaluation

The 'weedy' check had the lowest gross return during both years with economic loss of US$258 ha^{-1} in 2013-14 and US $171 ha^{-1} in 2014-15 (Table 4). The highest gross return and net benefit were obtained, not by the weed-free control, but by PEND fb CARF+ISO during 2013-14 and by PEND fb ETHOX fb CARF in 2014-15.

The other treatments which showed higher gross return than the 'weed-free' check were PEND fb ETHOX fb CARF, PEND fb PYRAZ fb 2,4-D, PRETI fb PYRAZ fb 2,4-D, PRETI fb ETHOX fb CARF, PEND fb ETHOX and PEND fb CARF. Additionally, PRETI fb 2,4-D had also higher gross return over 'weed-free' check in 2013-14 and PEND fb hand weeding fb PEND in 2014-15 (Table 4).

Residual effects of herbicides on the succeeding mungbean crop

The results of the residual effects of the herbicide regime used in wheat on the subsequent mungbean crop are presented in Table 5 and Figure 8. The emergence percentages (Figure 8), leaf greenness (SPAD values) (Figure 8), seedlings shoot and root lengths (Table 5) and crop biomass (Table 5) of mungbean at 25 DAS were not significantly different among the treatments during both growing seasons in 2014 and 2015.

However, the emergence percentages were higher in 2014 (85.7-92.0%) than in 2015 (70.7-84.0%), as well as mungbean crop biomasses (1.26-1.59 g plant^{-1} in 2014 and 7.8-9.3 g plant^{-1} in 2015). We attribute this to reduced competition from weeds that have already been controlled well in the previous wheat crop.

Discussion

The sole application of pre-emergence (PRE) herbicide failed to achieve effective control of the perennial weeds with extensive stolons, tubers and rhizome systems (mainly, the grasses and the sedge). As discussed by Zahran et al. (2016), sequential application of herbicides effectively controls a diversity of weeds in wheat under minimum tillage. In the present study, the sequential application of PRE herbicides, followed by late post-emergence (LPOST) herbicides with or without an early post-emergence herbicide (EPOST), provided better control of the weeds, which occurred in our trial plots.

Treatments of PEND/TRIA as PRE, with or without one EPOST (either ETHOX or PYRAZ) and with one LPOSTs (CARF/CARF+ISO/2,4-D), were effective in controlling weeds, especially the grass weeds. Previous studies also reported excellent grass weed control in wheat by PEND (Alshallash, 2014) and by TRIA (Islam et al., 2011) under conventional tillage systems. In the present study, TRIA was less effective than PEND in the strip-planting system and the reason might be related to the absence of loose soil particles in strip-planted field. In conventionally-tilled soil, TRIA can easily be mixed with loose soil particles to enhance weed controlling efficiency through better uptake.

PRE application of PEND provides effective control of *E. colona* in zero-till rice (Mishra and Singh, 2012) and wheat (Singh et al., 2016). PEND and PRETI were very much effective against *C. rotundus* if applied with ETHOX or PYRAZ (an EPOST) followed by CARF or 2,4-D (an LPOST).

Table 4. Economic performance (US \$ ha^{-1}) of herbicide treatments in the trials during 2013-14 and 2014-15

Treatment	2013-14			2014-15		
	WM cost	Gross return	Net benefit	WM cost	Gross return	Net benefit
Weedy check	0	287	-258	0	373	-171
Weed-free check	313	1186	329	313	1019	162
Pend fb HW fb pend	154	1133	434	154	1026	328
Pend fb ethoxy	55	1228	628	55	1028	428
Pend fb ethoxy fb carfen	71	1340	725	71	1201	586
Pend fb carfen	53	1194	597	53	992	395
Pend fb pyrazo fb 2,4-D	75	1324	705	75	1190	571
Pend fb 2,4-D	64	1130	522	64	920	312
Pend fb carfen + isop	80	1381	756	80	1153	528
Preti fb HW fb preti	110	1000	346	110	750	95
Preti fb ethoxy	34	1069	491	34	957	379
Preti fb ethoxy fb carfen	49	1247	654	49	1038	444
Preti fb carfen	31	1156	580	31	893	317
Preti fb pyrazo fb 2,4-D	53	1275	678	53	1111	513
Preti fb 2,4-D	42	1215	629	42	945	358
Preti fb carfen+ isop	54	1168	570	54	942	344
Tria fb carfen+ isop	50	1082	488	50	988	394
Tria fb 2,4-D	34	1039	460	34	933	355

WM cost = weed management cost, fb = followed by, HW = hand weeding at 25 days after sowing, Pend = pendimethalin, Preti = pretilachlor, ethoxy = ethoxysulfuron, carfen = carfentrazone-ethyl, pyrazo = pyrazosulfuron-ethyl, 2,4-D = 2,4-D amine, carfen + isop = carfentrazone-ethyl + isoproturon

Market price of commercial herbicides: Pendimethalin = 31.56 US\$ ha^{-1}, Pretilachlor = 9.88 US\$ ha^{-1}, Triasulfuron = 1.56 US\$ ha^{-1}, Ethoxysulfuron = 11.25 US\$ ha^{-1}, Pyrazosulfuron-ethyl = 5.0 US\$ ha^{-1}, Carfentrazone-ethyl = 8.94 US\$ ha^{-1}, Carfentrazone-ethyl + isoproturon = 36.19 US\$ ha^{-1} and 2,4-D amine = 20.19 US\$ ha^{-1}.

Manual weeding cost: 100 labourers ha^{-1} for 4 weeding events (season-long weed free) @ 3.13 US\$ $labour^{-1}$ day^{-1}, Herbicide application cost: 2 labourers ha^{-1} $round^{-1}$ @ 3.13 US\$ $labour^{-1}$ day^{-1}, Market price of grain: 275 US\$ ton^{-1}, Market price of straw: 15 US\$ ton^{-1}, Gross income = {grain yield (t ha^{-1}) × market price (US\$ t ha^{-1})} + {straw yield (t ha^{-1}) × market price (US\$ t ha^{-1})}, Net benefit = Gross income – Total cost.

Brecke et al. (2005) also reported that sequential application of PRE-, EPOST- and LPOST herbicides effectively controlled shoots and tubers of *C*. *rotundus*. PRE herbicides only provide temporary inhibition of tuber sprouting; however, they have no control on new tuber formation at different growth stages. The application of EPOST (ETHOX or PYRAZ) and LPOST (CARF or CARF+ISO) herbicides after the PRE spray was effective against newly sprouted or emerged *C*. *rotundus* plants.

Shyam and Singh (2015) and Singh et al. (2014) reported ETHOX to be the most effective herbicide on *C. rotundus* in their studies El-Zanaty (2015) evaluating the weed control efficacy of some PRE and POST herbicides on *C*. *rotundus* in sandy and clay soil, found that the efficacy of PRE herbicides significantly varied with soil types, while soil type did not play a significant role in the efficiency of POST herbicides. Their study confirmed that PYRAZ was highly effective against *C*. *rotundus* in sandy soil, and to a lesser extent, in clay soil. On the other hand, Raj et al. (2013) had earlier reported that CARF could achieve the effective control of *C, rotundus* in any type of soil.

The weed control efficacy of PRETI fb hand weeding at 25 DAS fb PRETI and PRETI fb 2,4-D for *P*. *lapathifolium and Vicia sativa* was not satisfactory in the second year. In our study, PRETI was used and tested with an aim to obtaining a substitute of commonly used wheat herbicide, PEND. PRETI is not a registered PRE herbicide for wheat. On the other hand, PEND is the only available PRE herbicide widely used in many crops, such as rice, wheat, potato (*Solanum tuberosum* L.), and onion (*Allium cepa* L.), in Bangladesh.

Therefore, the risk of developing PEND resistant weeds in the country is an issue currently raising considerable concern.

Table 5. Residual effect of herbicides applied in strip-planted wheat on shoot and root length and crop biomass at 25 days after sowing of the succeeding mungbean during 2014 and 2015

Treatment	2014			2015		
	Shoot length (cm)	Root length (cm)	Crop biomass (g plant^{-1})	Shoot length (cm)	Root length (cm)	Crop biomass (g plant^{-1})
T_1= Weedy check	22.6±0.3	5.6±0.2	1.26	19.9±1.8	6.89±0.0	0.78
T_2= Weed-free check	24.1±1.1	5.7±0.3	1.27	21.1±0.9	5.94±0.3	0.86
T_3= Pendimethalin fb HW fb pendimethalin	26.2±1.1	6.0±0.2	1.29	20.4±1.5	6.04±0.2	0.81
T_5= Pendimethalin fb ethoxy	25.4±0.6	5.6±0.1	1.44	21.0±0.4	6.86±0.5	0.88
T_7= Pendimethalin fb ethoxy fb carfentra	27.0±1.1	5.7±0.6	1.29	22.7±1.2	5.96±0.1	0.90
T_9= Pendimethalin fb carfentra	25.6±1.2	5.6±0.2	1.36	24.7±1.4	6.34±0.3	0.84
T_{11}= Pendimethalin fb pyrazosul fb 2,4-D	24.3±0.6	5.6±0.1	1.41	23.2±1.4	6.63±0.2	0.89
T_{13}= Pendimethalin fb 2,4-D	25.4±0.3	5.8±0.1	1.50	24.6±1.1	5.83±0.1	0.87
T_{15}= Pendimethalin fb carfentra + isoprot	24.3±1.2	5.9±0.3	1.50	20.9±1.5	6.08±0.1	0.93
T_4= Pretilachlor fb HW fb pretilachlor	25.3±0.7	5.6±0.1	1.42	23.2±0.5	6.15±0.4	0.96
T_6= Pretilachlor fb ethoxy	23.7±1.2	6.0±0.7	1.35	23.2±0.8	6.22±0.2	0.81
T_8= Pretilachlor fb ethoxy fb carfentra	26.1±1.2	6.0±0.3	1.59	21.0±0.9	6.11±0.1	0.83
T_{10}= Pretilachlor fb carfentra	22.7±1.7	5.6±0.1	1.54	24.3±1.4	6.15±0.2	0.81
T_{12}= Pretilachlor fb pyrazosul fb 2,4-D	26.8±0.6	5.8±0.1	1.32	22.3±0.3	6.46±0.1	0.90
T_{14}= Pretilachlor fb 2,4-D	25.6±1.9	5.9±0.3	1.32	20.7±0.7	6.13±0.3	0.78
T_{16}= Pretilachlor fb carfentra + isoprot	23.5±1.5	5.7±0.2	1.36	19.8±0.6	5.79±0.2	0.84
T_{17}= Triasulfuron fb carfentra + isoprot	22.8±0.7	5.6±0.2	1.27	22.3±1.1	5.97±0.2	0.82
T_{18}= Triasulfuron fb 2,4-D	24.4±1.3	5.6±0.1	1.29	21.7±1.3	6.59±0.5	0.88
Level of significance	ns	ns	ns	ns	ns	ns
CV (%)	7.79	9.01	10.04	8.92	7.32	13.38

For shoot and root length, mean values are presented ± standard errors; fb = followed by, HW = hand weeding at 25 DAS. ethoxy = ethoxysulfuron, carfentra = carfentrazone-ethyl, pyrazosul = pyrazosulfuron-ethyl, 2,4-D = 2,4-D amine, carfentra + isoprot = carfentrazone-ethyl + isoproturon; CV = Co-efficient of variance, ns = non-significant

Our study recorded that two minor weed species (*Chenopodium album* and *Lepidium didymum*) of the first year of strip-planted wheat became major species in the next year. However, all herbicide treatments, except PRETI fb hand weeding at 25 DAS fb PRETI, fully controlled those species. These weeds emerged in several flushes and most of them escaped the hand weeding operations. Similarly, PRETI had no effect on *Chenopodium album* and *Lepidium didymum*.

It is important to note that in our study, treatments - PEND fb CARF+ISO, PEND fb ETHOX fb CARF, PEND fb PYRAZ fb 2,4-D, PRETI fb PYRAZ fb 2,4-D, PRETI fb ETHOX fb CARF and PEND fb ETHOX - produced higher grain yields than the weed-free control plots. One plausible explanation is that in the 'weed-free' control plots, the wheat plants experienced some degree of shock and disturbance, due to the manual hand weeding.

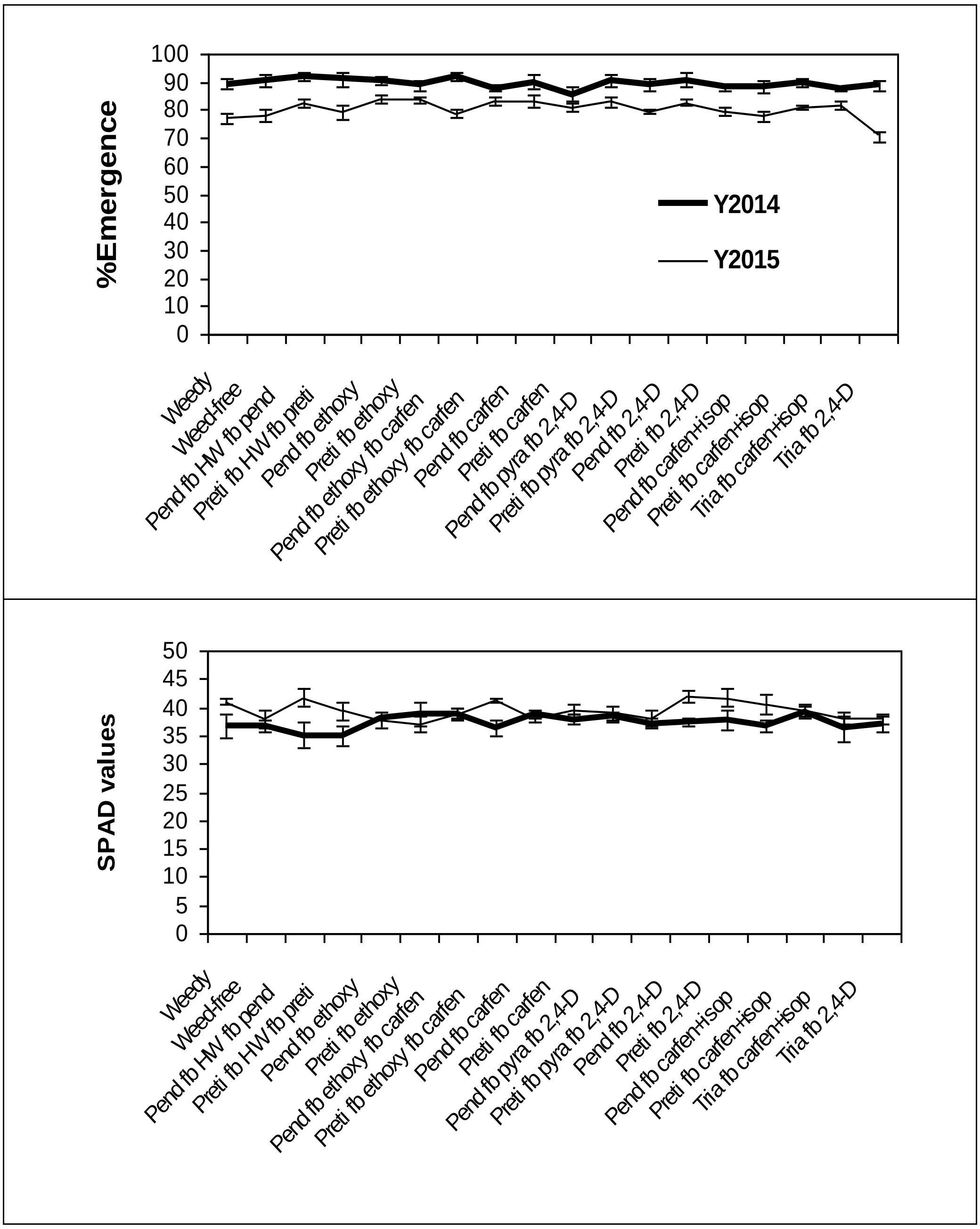

Figure 8. Residual effect of herbicides applied in strip-planted wheat on emergence percentage and leaf chlorophyll content (SPAD value) of the succeeding mungbean during 2014 and 2015

Such an effect may have temporarily caused a set back and slight retardation of the crop growth, while this type of shock was absent in the herbicide-treated plants. Many plant studies have also reported that sequential herbicide application could promote wheat yields (Mukherjee et al., 2011; Khalil et al., 2013; Hamouz et al., 2015) because the control mechanism of an herbicide is target-specific, whereas manual weeding is unable to offer effective control of weeds, which typically emerge as several flushes. Khaliq et al. (2014) also reported significant improvement in wheat growth and grain yield by various herbicidal weed control treatment in comparison to manual weed control.

Our results also show that the wheat grain yield and weed biomass were negatively correlated. The rate of yield reduction with weed biomass accumulation was much higher at 35 DAS than at 50 DAS indicating that weed control early in the growth of the crop is more important than at later the stages. Our results agree with others who have reported that higher weed pressure in the first 30-50 day period of the crop growth cycle causes significant wheat yield reductions (Awan et al., 2015; Fahad et al., 2015).

The economic analysis demonstrated that all herbicide treatments resulted in higher net returns over the weed-free control treatments in both years, except PRETI fb hand weeding fb PRETI. The use of herbicides eliminated the high cost of manual weeding, as has been previously reported in West Bengal by Mukherjee et al. (2011).

Importantly, the herbicides applied in the strip-planted wheat did not show any adverse residual effects on the emergence; shoot and root lengths or crop biomass of the succeeding mungbean as a rotational crop. This result indicates that herbicides applied in wheat might have limited persistence in soil, and any remaining residue (not extracted and/or analyzed), may not adversely affect the next crop. Herbicide persistency depends much on soil type and climatic condition (Curran, 2001).

Usually, in Bangladesh, seasonal rainfall starts after harvest of wheat and this could be a reason why herbicide residues from field applications of this scale may not remain in soil. Moreover, phytotoxic effects from any persistent herbicide residues also depend on the exposed crop species and cultivar and time duration of exposure. However, as our study did not extend to examining herbicide residues extractable from soil in the treated plots, there is scope for further research on this aspect, prior to a broader herbicide recommendation applicable for wheat farmers in the Eastern Gangetic Plains.

Conclusions

The sequential application of PEND or PRETI with or without ETHOX or PYRAZ, followed by CARF+ISO/CARF/2,4-D, would be effective in managing a diversity of weeds in strip-planted wheat, which was grown in trial plots with 20% previously-grown rice residues. Our study indicates that the application of any of these sequential herbicide treatments can increase the wheat yield by 2-16% and can provide an increased revenue for farmers by 21-127% compared to the 'weed-free' check.

Therefore, our study suggests applying the above-mentioned, effective PRE, EPOST or LPOST herbicides in a sequence that can be rotated in an intensive rice-wheat-mungbean cropping pattern in the Eastern Gangetic Plains. Such an approach would not only increase profits from growing wheat, but also slow down the development of herbicide resistance in the weeds encountered in the EGP region. Further research should also be focused on the behaviour and efficacy of the herbicide combinations and regime at higher crop residue levels than used in the present study.

Acknowledgements

We acknowledge the valuable advice and guidance provided by Dr Abul Hashem during this study. The principal author expresses her sincere acknowledgement to ACIAR (Project LWR/2010/080) for funding the research and providing a scholarship.

Authors are grateful to Dr. Nimal Chandrasena, the Editor-in-Chief of the 'Weeds' Journal, for his useful comments and intensive editing. We also would like to thank the anonymous reviewers for their valuable comments and suggestions.

The authors also wish to state that this work was conducted some time back (2013-2015) but it was not published in any other journal.

References

Alshallash, K. S. (2014). Effect of pendimethalin, trifluralin and terbutryn on *Lolium multiflorum* growing with barley during pre-emergence stage. *Annals of Agricultural Science*, 59: 239-242.

Awan, T. H., Cruz, P. C. S. and Chauhan, B. S. (2015). Agronomic indices, growth, yield-contributing traits, and yield of dry-seeded rice under varying herbicides. *Field Crops Research*, 177: 15-25.

Bari, M. N. and Islam, M. R. (2009). Selection of mungbean variety for rice-wheat-fallow cropping system- a participatory research and development approach. *Journal of Agriculture and Rural Development*, 7 (1): 33-40.

Bell, R. W., et al. (2018). Mechanized minimum soil disturbance establishment and yield of diverse crops in paddy fields using a two-wheel tractor-mounted planter suitable for smallholder cropping. *Experimental Agriculture*, 54 (5): 755-773.

Brecke, B. J., Stephenson, I. V., Daniel, O and Bryan, U. J. (2005). Control of purple nutsedge (*Cyperus rotundus*) with herbicides and mowing. *Weed Technology*, 19 (4): 15-21.

Cardina, J., Herms, C. P. and Doohan, D. J. (2002). Crop rotation and tillage system effects on weed seedbank. *Weed Science*, 50 (4): 448-460.

Chauhan, B. S. and Abugho, S. B. (2012). Interaction of rice residue and PRE herbicides on emergence and biomass of four weed species. *Weed Technology*, 26 (4): 627-632.

Chauhan, B. S, Gill, G. and Preston, C. (2006). Tillage system effects on weed ecology, herbicide activity and persistence: a review. *Australian Journal of Experimental Agriculture*, 46 (12): 1557-1570.

Chauhan, B. S., Singh, R. G. and Mahajan, G. (2012). Ecology and management of weeds under conservation agriculture: a review. *Crop Protection*, 38: 57-65.

Christoffoleti, P. J. et al. (2007). Conservation of natural resources in Brazilian agriculture: implications on weed biology and management. *Crop Protection*, 26(3): 383-389.

Curran, W.S. (2001). Persistence of herbicides in soil. Agronomy Facts 36. Penn State College of Agricultural Science, The Pennsylvania State University, Pennsylvania, USA. pp. 1-4.

Devasenpathy, P., Ramesh, T. and Gangwar, B. (2008). Efficiency indices for agricultural management research. Sumit Pal Jain (Ed.), New India Publishing, New Delhi, pp. 160.

Dorji, S., Chauhan, B.S, Baltazar, A.M. and Johnson, D. (2013). Effect of flooding depth and pretilachlor rate on emergence and growth of three rice weeds: jungle rice (*Echinochloa colona*), smallflower umbrella sedge (*Cyperus difformis*), and ludwigia (*Ludwigia hyssopifolia*). *Canadian Journal of Plant Protection*, 1(2): 43-48.

El-Zanaty, T. F. A., El-Deeb, S. T. A., Soliman, F. S. and Ahmed, S. M. (2015). Integrated control of purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*). *Asian Journal of Agriculture and Food Science*, 3 (6): 916-924.

Erenstein, O. and Laxmi, V. (2008). Zero tillage impacts in India's rice-wheat systems: a review. *Soil & Tillage Research*, 100: 1-14.

Fahad, S., et al. (2015). Weed growth and crop yield loss in wheat as influenced by row spacing and weed emergence times. *Crop Protection*, 71: 101-108.

FAOSTAT (2015). Statistical data. Food and Agriculture Organization of the United Nations. Rome. pp. 28-31.

Hamouz, P. Hamouzová, K. and Novotná, K. (2015). Effects of spring herbicide treatments on winter wheat growth and grain yield. *Scientia Agriculturae Bohemica*, 46 (1): 1-6.

Haque, M. E., Bell, R. W., Islam, A. K. M. S., Sayre, K. D. and Hossain, M. M. (2017). An innovative Versatile Multi-crop Planter for crop establishment using two-wheel tractors. *AMA-Agricultural Mechanization in Asia, Africa and Latin America*, 48 (3): 34-39.

Hashem, A., Bowran, D., Piper, T. and Dhammu, H. (2001). Resistance of wild radish (*Raphanus raphanistrum*) to acetolactate synthase-inhibiting herbicides in the Western Australia wheat belt. *Weed Technology*, 15 (1): 68-74.

Hernández-Sevillano , E., Villarroya, M., Alonso-Prados, J. L., Garćia, J. M. B. (2001). Bioassay to detect sulfosulfuron and triasulfuron residue incorporation. *Weed Research*, 15 (3): 447-452.

Islam, M. N., et al. (2011). Herbicidal weed control in wheat. In: Hossain M.A. et al. (Eds.), *Weed management research on different crops 1978-2010*. Agronomy Division, Bangladesh Agricultural Research Institute, Gazipur. pp. 47-50.

Janiy, J. D. and Moody, K. (1989). Weed populations in transplanted wet-seeded rice as affected by weed control method. *Tropical Pest Management*, 35: 8-11.

Khalil, M. F., Hassan, G., Ahmed, G., Anwar, S. and Khan, S. (2013). Comparative efficacy of herbicides on yield and yield components of wheat (*Triticum aestivum* L.). *Journal of Agriculture and Biological Science*, 8 (1): 76-80.

Khaliq, A., et al. (2014). Weed growth, herbicide efficiency indices, crop growth and yield of wheat are modified by herbicide and cultivar interaction. *Pakistan Journal of Weed Science Research*, 20 (1): 91-109.

Misra, J. S. and Singh, V. P. (2012). Tillage and weed control effects on productivity of a dry direct seeded rice-wheat system on a Vertisol in Central India. *Soil & Tillage Research*, 123: 11-20.

Mukherjee, P. K., Bhattacharya, P. M. and Chowdhury, A. K. (2011). Weed control in wheat (*Triticum aestivum* L.) under terai-agroecological region of West Bengal. *Journal of Wheat Research*, 3 (2): 30-35.

Naresh, R. K., Purshottam and Nanher A. H. (2013). Improving income and nutrition by incorporating mungbean in the presence of surface retained residues in rice-wheat cropping system. International *Journal of Life Sciences Biotechnology and Pharma Research*, 2 (2): 158-164.

Norsworthy, J. K., et al. (2012). Reducing the risks of herbicide resistance: best management practices and recommendations. *Weed Science*, 60 (1): 31-62.

Owen, M. J. and Powles, S. B. (2009). Distribution and frequency of herbicide-resistant wild oat (*Avena* spp.) across the Western Australia grain belt. *Crop Pasture Science*, 60 (1): 25-31.

Parvez, M. S., Salam, M. A., Kato-Noguchi, H. and Begum, M. (2013). Effect of cultivar and weeding regime on the performance of transplant aman rice. *International Journal of Agriculture and Crop Science*, 6 (11): 654-666.

Raj, S.K., Jose, N., Mathew, R. and Leenakumary, S. (2013). Chemical management of non-grassy weeds in direct-seeded rice. *Indian Journal of Weed Science*, 45 (3): 159-162.

Sarker, M. A. Z., Alam, M. A., Hossain, A. and Mannaf, M. A. (2014). Agro-economic performance of crop diversification in rice based cropping systems of northwest Bangladesh. *Agriculture, Forestry and Fisheries*, 3 (4): 264-270.

Shyam, R. and Singh, R. (2015). Control of nutsedge and other weeds in sugarcane with ethoxysulfuron. *Indian Journal of Weed Science*, 47 (1): 43-45.

Singh, R., Pratap, T., Singh, V. P., Rekha and Singh, J. (2014). Management of nutsedge in sugarcane by ethoxysulfuron. *Indian Journal of Weed Science*, 46 (4): 342-345.

Singh, V., Jat, M. L., Ganie, Z. A., Chauhan, B. S. and Gupta, R. K. (2016). Herbicide options for effective weed management in dry direct-seeded rice under scented rice-wheat rotation of western Indo-Gangetic Plains. *Crop Protection*, 81: 168-176.

Vrbničanin, S., Pavlović, D. and Božić, D. (2017). Weed resistance to herbicides. In: Herbicide resistance in weeds and crops, Pacanoski Z, IntechOpen, doi: 10.5772/67979. (Available at: **http://www.intechopen.com/books/herbicide-resistance-in-weeds-and-crops/weed-resistance-to-herbicides**).

WRC, (2016). WRC Annual Report 2015-16. Wheat Research Centre, Bangladesh Agricultural Research Institute, Nashipur, Dinajpur, September, 2016. pp. 94.

Zahan, T., Rahman, M. M. and Begum, M. (2016). Weed control efficacy of herbicides in wheat under strip tillage system. *Fundamental and Applied Agriculture*, 1 (2): 92-96.

Zahan, T., Muktadir, M. A., Rahman, M. M. and Ahmed, M. M. (2018). Response of the succeeding crops as affected by the residue of herbicides applied in wheat in Old Brahmaputra Floodplain, Bangladesh. *Annals of Agrarian Science*, 16: 451-457.