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Herbicidal weed control in drill sown spring wheat under Bangladesh condition

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ABSTRACT

Weeds are considered as one of the major factors responsible for current low wheat yield in Bangladesh. Although chemical weed control is well established in many wheat growing countries, in Bangladesh, the herbicides are typically not used by farmers to manage weeds in wheat. Hence, to evaluate the efficacy of pre- and post-emergence herbicides in mechanized drilled sown wheat, a two-year field study was conducted in southwest Bangladesh. The study evaluated the performance of four pre-emergence herbicides (oxadiargyl 80 g, pendimethalin 850 g, pyrazosulfuron 15 g, and mefenacet + bensulfuran methyl 550 g active ingredient ha^{-1}) applied at 2 days after sowing (DAS) and four post-emergence herbicides (2,4-D 1400 g, ethoxysulfuron 18 g, penoxsulam 22.5 g, and fenoxaprop 56 g active ingredient ha^{-1}) applied at 20 DAS, on weed control efficacy. A season long weed-free and a season long weedy plots were also maintained to compare the results. The weed control option using a single pre- or post-emergence herbicide was not adequate to control weed effectively when weed infestation was relatively higher. The best yield provided by pre-emergence (pendimethalin and oxadiargyl) and post-emergence (2,4-D and ethoxysulfuron) herbicide treatments were respectively 13-15% and 12-17% lower than the yield (4.1-4.2 t ha^{-1}) of weed-free treatment. Post-emergence herbicides fenoxaprop was the best in controlling weeds; however, due to phytotoxic effects on wheat plants, the plots applied with fenoxaprop produced very low yield (2.6-2.8 t ha^{-1}). Similarly, even after good weed control by the post-emergence application of penoxsulam, phytotoxicity on wheat resulting in low yield. The study suggested that the best weed control option for wheat is to use a pre-emergence (pendimethalin or oxadiargyl) followed by (fb) a post-emergence (2,4-D or ethoxysulfuron) herbicides depending upon weed species which would benefit the farmers by providing high weed control efficacy at lower cost compared to manual weeding.

Keywords: Weed shift, weed control efficiency, herbicide toxicity, yield gap, wheat

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1 Introduction

There is a big gap (up to 2.0 t ha^{-1}) in yield of wheat at research stations and farmers' fields of South Asia (Chatrath et al., 2007). Results from previous studies showed that environmental and management factors are keys which adversely affect the wheat yield (Joshi et al., 2007; Mahmood et al., 2012; Usman and Khan, 2009). In Bangladesh, about 17-69% yield gaps in farmers' wheat production were reported by Kashem et al. (2013) which was mainly due to management factors (sowing time, seed rate, quality seeds, land preparation, fertilizers, irrigation, pest management, etc.) and environmental variations (temperatures, mist, winds etc.). Weeds and diseases are the major pests of wheat, although disease is occasional but weed is the frequent and regular problem for wheat and caused yield reduction by 29-47% in Bangladesh (Hossain et al., 2010; Kabir et al., 2015; Riya et al., 2017; Shabi et al., 2018). However, the extent of yield reduction due to weeds largely depends on cultivar used, tillage practices, seeding rate, seeding methods, weed population density, types of weed species; weed management strategies etc. (Ahmed et al., 2014; Khan et al., 2017). Weeds not only reduce the wheat yields but also deteriorate the quality and market values. In addition, weeds may encourage the development of diseases by providing shelter as an alternate host for pests.

Although weed management in developed countries is almost herbicide dependent but some developing countries of South Asia (Bangladesh, Nepal, and India), traditional manual weeding is still common in wheat crop (Chatrath et al., 2007; Hossain et al., 2009). Research has shown that, if an adequate hand weeding is done at the optimal times, crop yields of wheat are not reduced by weed competition (Safdar et al., 2011). But in reality, those crop fields are seldom adequately weeded manually which is expensive, tedious, and time-consuming. In addition, laborers are not always available in the peak period of weeding and often done late, causing drastic losses in yield.

Herbicides are considered the most economic and efficient weed control tool and their use in agriculture is increasing dramatically to manage weeds in various crops including wheat (Rashid et al., 2007; Anwar et al., 2012; Islam et al., 2017, 2018). In India, herbicides are used on 57% of the wheat area (Sharma and Singh, 2010), in Pakistan about 63% (Fahad et al., 2013), and in Nepal 5-10% (Bhatta et al., 2008). Although, the use of herbicides in Bangladesh has 37-fold increase in the last three decades (Islam et al., 2018), they are not typically used in the wheat fields. Generally, farmers perform at least one hand weeding to manage the weeds. Due to shift of labors from agriculture to industry, farmers have no other way but applying herbicides in wheat fields. The broadleaf is the predominance weeds in wheat and most of the research conducted in Bangladesh mostly focused on broadleaf weeds and their control measure (Hossain et al., 2010; Mahmood et al., 2012; Mustari et al., 2016). Based on many previous studies (Hossain et al., 2010; Kamrozzaman et al., 2016) 2,4-D and carfentrazone-ethyl are the recommended herbicides to manage broadleaf weeds in wheat.

In Bangladesh, wheat is mainly cultivated after the harvest of puddled transplanted aman rice, which is a major rice ecotype of Bangladesh. As puddled transplanted rice require more irrigation water and labour (Alam et al., 2018), farmers are becoming more interested in resources conservation rice production technologies such as direct-seeded rice (Ahmed et al., 2015, 2016), reduced or zero tillage non-puddled rice (Haque et al., 2016) and strip tillage with surface residue retention in rice based cropping system (Alam et al., 2017). Furthermore, wheat cultivation method has also undergone tremendous changes in the last decade. Earlier, the wheat seeds were manually broadcast in the well-pulverized soil, but now-a-days, reduced, zero and strip tillage in wheat sowing is becoming popular among farmers because of availability of conservation machinery. Those machinery help reduce the land preparation cost by doing tillage and sowing operations together and comparatively less soil disturbance which is one of the principles of conservation agriculture (CA). In a CA practice, weed infestation is relatively high and use of herbicide provides the best efficient and economical weed control.

Several studies have reported that changes from a conventional to reduced tillage system alters the disturbance regime, which can lead to shifts in weed species composition and weed density (Kumar et al., 2013; Rao et al., 2007; Singh et al., 2005). In reduced or zero tillage systems, due to low soil disturbance, it is likely to leave a large proportion of the weed seed bank on or near the soil surface after crop sowing, resulting in greater emergence of grasses and sedges such as *Echnochloa colona*, *Digitaria ciliaris*, *Eleusine indica*, *Leptochloa chinenesis*, *Cynodon dactylon* and *Cyperus rotundus* (Ahmed and Chauhan, 2014). Considering the changing tillage systems in wheat, there are chances for diverse weed species to infest the wheat field which may not be controlled manually and cause a severe yield reduction in wheat crop of Bangladesh.

Therefore, current study was designed to evaluate the efficacy of different pre- and post-emergence herbicide options for economic weed control to enhance productivity of mechanized drill sown wheat.

2 Materials and Methods

2.1 Experimental site

Field trials were established at the research farm of the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institute (BARI), Jessore, during the dry seasons (rabi) of 2013–14 and 2014–15. The climate of the area is subtropical with highly variable rainfall during the dry season (November to May) ranging from 156-830 mm (mean 356 mm) over the past 30 years (1981–2010). The temperature during the dry season also varies greatly, with minimum daily temperature ranging from 5.4 to 28.2 °C (mean 15 °C) during 1981–2010, and maximum temperature ranging from 15.6 to 42.3 °C (mean 30 °C). December and January are the coolest months, with an average minimum temperature of <12 °C. The topsoil (0-15 cm) of the experimental field was a clay loam (sand 28%, silt 36% and clay 36%) soil with a bulk density of 1.54-1.57 mg m^{-3}, a pH of 7.6 (1:2 soil:water) and organic carbon content <1%. Prior to the establishment of the experiment, the site had been under a rice-fallow-rice cropping system for the last two years.

2.2 Treatments and design

A total of ten treatments were examined. The treatments included four pre-emergence herbicides (oxadiargyl 80 g, pendimethalin 850 g, pyrazosulfuron 15 g, and mefenacet + bensulfuranmethy l550 g active ingredient (ai) ha^{-1}) applied at 2 d after sowing (DAS), four post-emergence herbicides (2,4-D amine 1400 g, ethoxysulfuron 18 g, penoxsulam 22.5 g, and fenoxaprop-p-ethyl 56 g active ingredient ha^{-1}) applied at 20 DAS. A season long weed-free and a season long weedy plots were also maintained to compare the results. In the weedy treatment, weeds were allowed to grow season-long and in the weed-free treatment; plots were kept completely weed-free by 3 times manual weeding (15, 30, 45 DAS). The experiment was arranged in a randomized complete block designed with three replications. The size of each plot was 5 m × 3 m and plots were separated by a 1 m buffer area. Herbicide was applied using a knapsack sprayer attached with three flat-fan nozzles on a boom, and the sprayer delivering 400 L solution ha^{-1}.

2.3 Plant material

A wheat cultivar BARI Gom-26, developed by the Wheat Research Centre (WRC), Bangladesh Agricultural Research Institute (BARI) was used in the experiment as the test crop. The cultivar is a high yielding and heat resistant one with tolerance to leaf spot and rust diseases. The average plant height of this cultivar ranged 90-100 cm. The leaf blades are wide and dark green and the flag leaf is droopy in nature. The spike is large and contains 45-50 grains $spike^{-1}$. The weight of 1000 grains is 48-52 g. The field duration is 104-110 d and yield potential is 3.5-4.5 t ha^{-1} (BARI, 2011).

2.4 Crop management

The crop was sown using a power tiller operated seed-drill fitted with a fluted-type seed metering device. A seed rate of 120 kg ha^{-1} was used with a sowing depth of 3-5 cm and row spacing of 20 cm. In both the years crop was sown in the last week of November. The fertilizers were applied at the rate of 100, 30, 50, 20 and 1 kg ha^{-1} N, P, K, S and B, respectively in the form of urea, triple superphosphate, muriate of potash, gypsum and boric acid. Two-thirds of N and full amount of P, K, S and B were broadcast just before wheat sowing and the rest of the N was top dressed just after second irrigation. The wheat was irrigated three times each season – immediate after sowing, at crown root initiation (15-20 DAS), and at grain filling (75-80 DAS) in both the seasons.

2.5 Observations

To evaluate the performance of weed control treatments on weeds, weed density and weed biomass were measured at 45 DAS by randomly placing two quadrats, measuring 40 cm×40 cm, in each plot. Weeds were separated by group, counted, and their biomasses were measured after oven drying the samples at 70 °C for constant biomass determination. To evaluate the effect of weeds on wheat, weed and wheat biomass were measured from two 40 cm × 40 cm quadrats at 45 DAS. Grain yield was determined by harvesting a 6 m^2 (3 m × 2 m) area in the center of each plot. The grains were mechanically threshed and fresh grain weight was determined. Grain moisture content was determined using a grain moisture meter (Model: GMK-303RS) at the time of weighing. Fresh grain yield was converted to grain yield (t ha^{-1}) at 12% moisture content. The spike density (number m^{-2}) were counted in 5 rows × 1 m in two places in each plot, and was calculated from the average of the two locations. Twenty five spikes were randomly selected from each quadrat for determining the number of filled florets $spike^{-1}$.

2.6 Statistical analysis

The analysis of variance (ANOVA) were done to evaluate differences between treatments, and the means were separated using least significant difference (LSD) at the 5% level of significance (Crop Stat 7.2, International Rice Research Institute, Philippines).

3 Results and Discussion

3.1 Weed density and biomass

The grass weeds were dominant in both seasons of study followed by sedges and then broadleaf weed (Table 1). The dominant grass weed species were *Cynodon dactylon* (L.) Pers., *Digitaria ciliaris* (Retz.) Koel., and *Echinochloa colona* (L.) Link. The broadleaf weed species were *Amaranthus spinosus* L., *Anagalis arvensis* L., *Celosia argentea* L., *Chenopodium album* L., *Cleome rutidosperma* DC., and *Phyllanthus niruri*, and the sedge was *Cyperus rotundus* L.

The total weed density and biomass at 45 DAS were significantly affected by the weed control treatments, and the higher weed density and biomass recorded during 2013–14 than the year of 2014–15 (Table 1). Application of herbicides had always lower weed density and biomass than the weedy plots. Among the herbicide treatments, the pre-emergence application of pendimethalin and post-emergence applications of fenoxaprop-p-ethyl were the most effective against the grass weeds and reduce the maximum density and biomass. The pre-emergence application of oxadiargyl and mefenacet + bensulfuranmethyl, and post-emergence application of penoxsulam also reduced grass weed density and biomass significantly, compared to the weedy plot; however, they were relatively less effective than the pendimethalin and fenoxaprop in controlling grass weed. The herbicide pyrazosulfuron used as a pre-emergence and 2,4-D amine and ethoxysulfuron used as a post-emergence were not effective against the grass weeds.

Post-emergence herbicides were superior in controlling broadleaf weeds than the pre-emergence herbicide. All post-emergence herbicide except the fenoxaprop controlled broadleaf weeds significantly. Among the pre-emergence herbicide, the oxadiargyl and pyrazosulfuron reduced broadleaf weed density and biomass significantly compared to the weedy treatment; however, the pendimethalin and the mefenacet + bensulfuranmethyl were not effective against the broadleaf weeds. Pre-emergence application of the pyrazosulfuron and post-emergence application of the ethoxysulfuron and penoxsulam had significantly reduced the density and biomass of sedge (only *Cyperus rotundus*) weeds. Other pre- and post-emergence herbicides were not effective against the *Cyperus rotundus*. Among the herbicide treated plots, the lowest total weed density and biomass were recorded from the plots applied with fenoxaprop as a post-emergence.

3.2 Wheat plant density and biomass

Wheat plant density and biomass were significantly affected by weed control treatments at 45 DAS in both seasons (Table 2). The highest plant density and biomass were recorded from the weed-free plots. All the pre-emergence herbicide treatments had always higher plant density and biomass than the weedy treatment. The post-emergence herbicides fenoxaprop and penoxsulam in both seasons had similar plant density and biomass than the weedy treatment. The post emergence herbicide ethoxysulfuron in 2013–14, and the ethoxysulfuron and 2,4-D amine in 2014–15 had similar plant density to the weed-free treatment. Among the herbicide treatments, the lowest plant density and biomass were recorded from the fenoxaprop applied plots that had plant density and biomass similar to the weedy treatment and it was due to phytotoxic effect on the wheat plant. Similarly, penoxsulam had also phytotoxic effect on wheat plant, resulting in similar plant density and biomass to the fenoxaprop treatment and fenoxaprop was relatively more phytotoxic than the penoxsulam. Wheat plant growth was retarded due to the phytotoxic effect of herbicide as reported by Chhokar et al. (2008) in wheat, Ahmed and Chauhan (2015), Awan et al. (2006) in rice, and Nemat Alla et al. (2008) in maize. In a previous study, Yaacoby et al. (1991) reported that foliar sole application of fenoxaprop-p-ethyl reduced wheat dry biomass by 30%, however, no biomass reduction occurred when fenoxaprop-p-ethyl was applied after mixing with safener.

3.3 Yield and yield components

Wheat grain yield was significantly affected by the weed control treatments and the highest grain yield (4.1-4.2 t ha^{-1}) was recorded from the weed-free treatment (Fig. 1a). In 2013–14, all herbicide treatments had lower yield than the weed-free treatment; however, in 2014–15, the pre-emergence application of oxadiargyl and pendimethalin, and post emergence application of 2,4-D had similar grain yield to the weed-free treatment. Among the pre-emergence herbicides, oxadiargyl and pendimethalin performed similarly and resulted higher grain yield than the others two pre-emergence herbicides. Compared with the weed-free treatment, the pre-emergence applications of oxadiargyl, pendimethalin, pyrazosulfuron, and mefenacet + bensulfuranmethyl had 15, 13, 21 and 23% lower yield in 2013–14, and 5, 10, 19, and 16% lower yield in 2014–15, respectively.

Among the post emergence herbicides, the fenoxaprop and penoxsulam treatments had the lowest grain yield which was similar to the yield (2.2-2.5 t ha^{-1}) of weedy treatment. The lower grain yield was not due to higher weed completion but it was due to the toxicity effects of both herbicides on wheat plants. The post-emergence herbicide ethoxysulfuron and 2,4-D performed similarly, although ethoxysulfuron performed slightly better than 2,4-D in 2013–14 whereas, it was vice-versa in 2014–15. In 2013–14, the sedge weed *Cyperus rotundus* density was higher

Table 1. Effect of weed control treatments on weed density and weed biomass at 45 days after sowing

	Grass		Broadleaf		Sedge		Total	
	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15	2013–14	2014–15
Weed density (no. m^{-2})								
Oxadiargyl	153	29	15	18	192	121	360	168
Pendimethalin	28	5	37	25	325	146	390	176
Pyrazosulfuron	345	111	29	11	122	72	496	194
Mefenacet+ bensulf. †	207	30	61	24	179	135	447	189
2,4-D amine	291	92	9	5	175	90	475	187
Ethoxysulfuron	330	126	20	13	65	35	415	174
Penoxsulam	215	88	10	8	139	66	364	162
Fenoxaprop	13	8	56	26	182	100	251	134
Weedy	379	145	73	39	297	143	749	327
$LSD_{0.05}$	141	29	40	16	113	65	133	62
Weed biomass (g m^{-2})								
Oxadiargyl	11	5	5	3	26	13	42	21
Pendimethalin	2	1	4	4	41	17	47	22
Pyrazosulfuron	30	19	2	1	14	6	46	26
Mefenacet + bensulf. †	19	5	6	3	28	13	53	21
2,4-D amine	29	15	1	1	22	10	52	26
Ethoxysulfuron	36	19	2	2	6	4	44	25
Penoxsulam	17	9	2	1	14	6	33	16
Fenoxaprop	2	1	4	1	12	10	18	12
Weedy	43	24	7	5	32	18	82	47
$LSD_{0.05}$	24	7	3	2	16	9	22	10

† bensulf. = bensulfuranmethyl

Table 2. Effect of weed control treatments on wheat plant density and wheat biomass at 45 days after sowing

	Wheat plant density (no. m^{-2})		Wheat plant biomass (g m^{-2})	
	2013–14	2014–15	2013–14	2014–15
Oxadiargyl	411	458	154	165
Pendimethalin	388	444	137	159
Pyrazosulfuron	406	440	125	145
Mefenacet + bensulfuranmethyl	407	433	131	155
2,4-D amine	370	474	128	165
Ethoxysulfuron	375	464	144	153
Penoxsulam	319	354	113	120
Fenoxaprop	297	325	95	107
Weed-free	445	509	162	181
Weedy	296	319	91	102
$LSD_{0.05}$	72	83	30	35

than in 2014–15 and ethoxysulfuron performed better than 2,4-D in controlling this weed species. On the other hand, 2,4-D was better than the ethoxysulfuron in controlling grass and broadleaf weeds, that's why less *Cyperus rotundus* would provided an advantage to 2,4-D for better weed control efficiency than the ethoxysulfuron in 2014–15.

The spike density was always higher for the weed-free treatment and lower for the weedy treatment (Fig. 1b). All the herbicide treatments, except fenoxaprop and penoxsulam, had significantly similar spike density to the weed-free treatment. The herbicide treatment fenoxaprop and penoxsulam had similar spike density to the weedy treatment. In weedy plots, spike density was lower due to crop-weed completion resulted in less tiller production and more unproductive tiller. In addition, the lower spike density in fenoxaprop and penoxsulam was not the reason for crop-weed completion. It was due to the effect of toxicity which stunted the growth, ob-

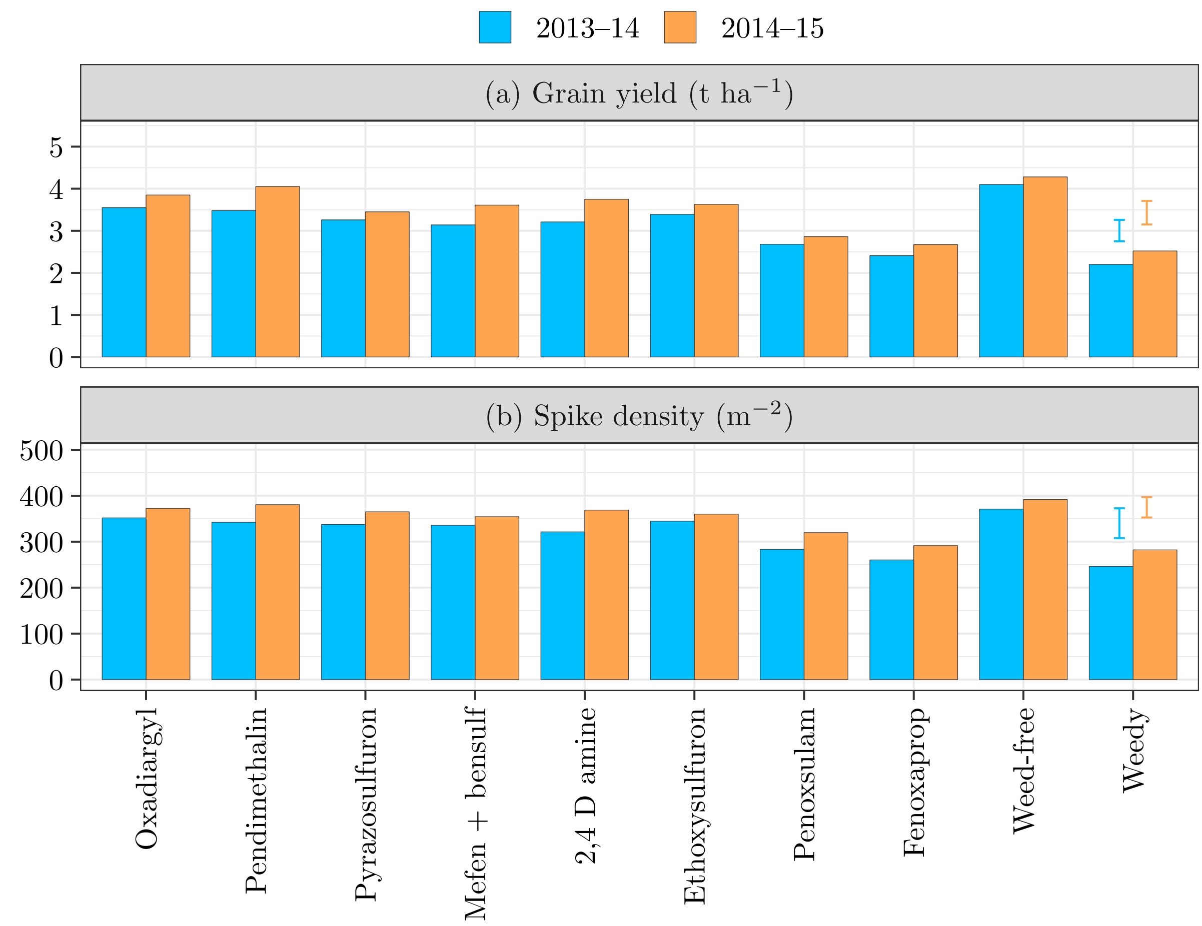

Figure 1. Effect of weed control treatments on (a) wheat grain yield and (b) spike density at physiological maturity in 2013–14 and 2014–15. Vertical lines represent least significant differences (LSD) at P=0.05. Mefen + bensulf = Mefenacet + bensulfuranmethyl

structed tiller production, and caused plant mortality. The florets spike^{-1} maintained the similar trends to the spike density (Fig. 2). The florets spike^{-1} is a genetic trait and when a wheat plant having optimum growth and development it can produce the maximum genetically potential florets; however, due to management practice it differs largely. When weed had a more competitive effect on wheat or wheat plant had an injury due to the phytotoxic effect of herbicide, plant growth was retarded and number of florets spike^{-1} was reduced compared to lower weed competition.

In wheat field intra crop competition(due to the higher plant density than the required plants) or inter competition with the weeds, greatly affected the plant growth as well as yield components such as lower florets spike^{-1}, lower average spike weight, and more unfilled florets. In the current study, yield was strongly influenced by the weed control treatments and it was mostly because of varying weed control treatments had different levels of weed control percentage and phytotoxicity to the wheat crop. Among the pre-emergence herbicides, pendimethalin and oxadiargyl were best in controlling weeds and as well as providing higher grain yield. Both of the herbicide treatments provided wheat yield similar to the yield of weed-free treatment in 2014–15 but not in 2013–14. The reason for the lower yield by pendimethalin and oxadiargyl in 2013–14 was due to both of the herbicides were not effective against *Cyperus rotundus* which severely infested the crop in 2014–15. In 2014–15, infestation of this weed was comparably lower than in 2013–14. Both of the herbicides were very much effective against grass weeds but not against sedge weeds. In 2013–14, due to higher sedge weed infestation in the field, even after effective grass weeds control by these two herbicides, uncontrolled sedge hindered the yield. Similar results were reported in Philippines where bispyribac sodium provided the highest cost benefit ratio in one season when rice crop was not infested by *Leptochloa chinensis* and in 2nd season when crop was infested by *Leptochloa chinensis*, same herbicide provided the lowest cost to benefit ratio (Awan et al., 2015).

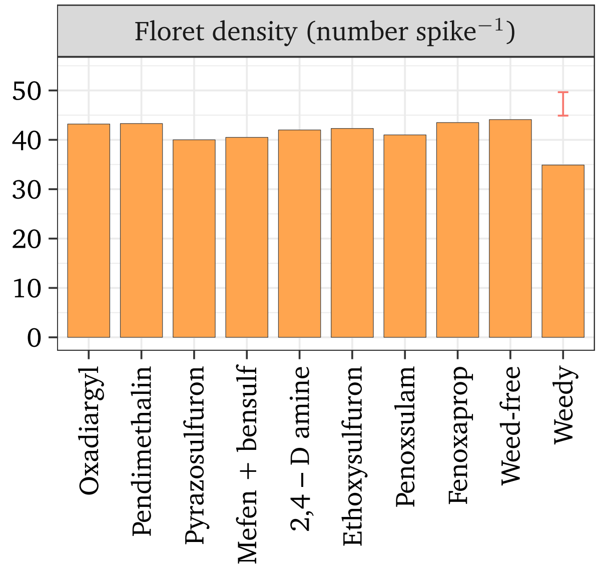

Figure 2. Effect of weed control treatment on florets per spike at physiological maturity in 2014–15. Vertical line represents least significant difference (LSD) at P=0.05. Mefen + bensulf = Mefenacet + bensulfuranmethyl.

The pre-emergence herbicides pendimethalin and oxadiargyl effectively controlled grass weed and less effective against sedges especially *Cyperus rotundus* was reported by many previous studies (Ahmed and Chauhan, 2014, 2015; Ahmed et al., 2016; Bhowmick and Ghosh, 2002; EFSA, 2013; Awan et al., 2016). The herbicide mefenacet + bensulfuranmethyl was not sufficient enough to control weeds in the current study, resulting in always lower yield, compared to the weed-free treatment. Our result supports the earlier results of Ahmed and Chauhan (2014) and Rahman et al. (2012), where they reported that this herbicide was not adequate to control sufficient weeds under aerobic rice condition, similar soil condition of wheat field. However, Bhuiyan and Ahmed (2010) found this herbicide was very much effective in transplanted rice systems in Bangladesh. The contradictory results may be due to the different soil environment which was mostly wet in puddled rice and dry in aerobic rice. These results are an indication of this herbicide may not be effective under aerobic condition. The treatment, application of pyrazosulfuron was slightly effective against broadleaf and sedge weeds but not able to control any of the grass weeds resulting in poor weed control efficiency and these results are supported by the study of Ahmed et al. (2014) and Mahajan and Chauhan (2015).

Post emergence application of the herbicide fenoxaprop was very much effective against grass weed and reduced grass density by 94-97%. This herbicide was also partially effective against broadleaf and sedges weeds and, therefore, provided the best weed control efficiency among all the herbicide treatments of the current study. The fenoxaprop is a selective herbicide and excellent control of grass weeds reported by Jordan (1995), Awan et al. (2006, 2015) and Zhang et al. (2005). In Bangladesh, the fenoxaprop is a post-emergence herbicide registered mostly for the weed control of jute and onions.

The herbicide penoxsulam was mostly effective against the broadleaf weed and partially effective against grass and sedge weeds resulting in reduced weed biomass by 60-66%. This herbicide was originally designed for use in rice fields and is capable of killing a range of broadleaf weeds, and a few grasses and sedges that prefer wet environments (Mahajan and Chauhan, 2008; Khaliq et al., 2012). The herbicide 2,4-D effectively controlled broadleaf weeds, slightly effective in controlling grass weeds but was not able to control any sedge weeds supports the earlier results of Norsworthy et al. (2012); Schulz and Segobye (2016). Zand et al. (2007) reported that 2,4-D is the most effective herbicide against broadleaf weed in wheat field. Ethoxysulfuron was reported to be an effective herbicide in controlling a wide range of broadleaf weeds as well as perennial sedges, however, was not able to control any grass weed as reported from many previous studies (Awan et al., 2006; Ahmed and Chauhan, 2014; Shyam and Singh, 2015).

Although post emergence application of herbicide fenoxaprop and penoxsulam had always higher weed control efficiency than 2,4-D and ethoxysulfuron but yield was always lower.It was due to phytotoxicity of these two herbicides in wheat. Similar results were reported by Singh et al. (2006) and Awan et al. (2006) in rice, where the herbicide triclopyr 1500 g ha^{-1} was effective in reducing weed density and biomass; however, due to phytotoxicity, it resulted in a reduced yield in rice.

4 Conclusions

Present study confirms that the best weed control option is to use a pre-emergence herbicide (pendimethalin or oxadiargyl) followed by (fb) a post-emergence herbicide (2,4-D or ethoxysulfuron). Weed control by a pre-emergence fb a post-mergence herbicide application would be beneficial to farmers, as this is more cost effective and less laborious than manual weeding. If the field has more chance to an infestation of grass and sedge (*Cyperus rotundus*) weeds, farmers may choose pre-emergence herbicide pendimethalin fb post-emergence ethoxysulfuron. If more chance to an infestation of grass and broadleaf weeds, oxadiargyl fb 2,4-D are the best option. The study suggested that the best weed control option for wheat crop is to use a pre-emergence (pendimethalin or oxadiargyl) fb an appropriate post-emergence herbicide depending upon weed species.

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Conflict of Interest

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

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