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Effect of application timings and tank mixture of herbicides on weed suppression, crop growth and yield of wheat

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ABSTRACT

Herbicides have increasingly become a key component on crop production system because they offer the easiest, cheapest and timely weed management, resulting in higher yield and profit. A single herbicide application in field conditions in most of the cases is not enough to control diverse weed flora. In such situations, tank mixtures of herbicides may provide a prime option to control a broad spectrum of weeds. *Cyperus rotundus* L., a world's most tenacious weed, is becoming a problematic weed in conservation crop production systems. A two-year study (2013/14 and 2014/15) was established in South-West Bangladesh to evaluate the effect of application timings and sole and tank mixtures of 2,4-D and ethoxysulfuron herbicides on weed suppression and performance of wheat. 2,4-D and ethoxysulfuron were applied solely and as tank mixtures at 10, 20, and 30 days after sowing (DAS) and these treatments were compared with completely weedy and weed-free treatments. In controlling weeds, tank mixtures of 2,4-D and ethoxysulfuron performed better than their sole application at any application timing; however, at the earliest time (10 DAS), the combination created toxicity to wheat plants, resulting in 10-22% and 11-32% less wheat plant density and biomass, respectively, compared with their sole application. Tank-mix herbicides reduced *C. rotundus* biomass by 87-91%, 88-100%, and 79-80% when applied at 10, 20, and 30 DAS, respectively, compared with the weedy plots. The plots applied with tank mixtures at 20 and 30 DAS produced wheat grain yield similar to that of weed-free plots, indicating that the tank mixture of 2,4-D plus ethoxysulfuron herbicides is the best option to control weeds without any toxicity to wheat plants.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops, grown extensively throughout the world; the second most important cereals crop after rice in Bangladesh. The area

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and production of wheat in Bangladesh is increasing because of farmers' growing interest in the crop, a shift from *boro* rice (dry season) cultivation, and changes in the food habits (Hossain and Silva, 2013). The lower production cost of wheat compared with irrigation-dependent *boro* rice and less volatile prices compared with rice are encouraging growers to grow wheat crops more on their land. Although *boro* rice is the major crop in dry-season (because of non-availability of labors and their high wages, water scarcity and high pumping cost for underground water), *boro* rice cultivation is becoming less-profitable (Ahmed et al. 2011). In Bangladesh, farmers usually pumping-out huge amounts of groundwater for *boro* rice cultivation, which has led to lowering of groundwater tables and this problem is becoming severe in the Barind tract (north-west) and the High Ganges River Floodplains (south-west) areas (Shamsudduha et al. 2009). Considering the production constraints and importance of cereals, wheat is one of the best options for the replacement of *boro* rice for medium-high to high land in Bangladesh. Wheat crop needs 1-3 irrigations for successful crop growth and yield, depending on soil types, cultivar use, time of sowing, management systems, and weather.

Results from previous studies showed that environmental and management factors adversely affect wheat yield, which is up to 77% of the variation in its yield potential (Joshi et al. 2007; Mahmood et al. 2012; Usman and Khan, 2009). Out of these factors, uncontrolled weeds and diseases have been identified as major biotic factors for low wheat yields especially in South Asia (Waddington et al. 2010). Plant disease is an occasional but weed is a frequent problem in wheat production. Yield reductions in wheat were reported by 48-52% in Pakistan (Khan and Haq, 2002), by 20-40% in India (Mishra, 1997), up to 50% in Nepal (Ranjit, 2002), and by 29-47% in Bangladesh (Mamun and Salim, 1989). However, the extent of yield reduction due to weeds largely depends on cultivar used, weed population density, types of weed species, crop and weed management strategies, etc. (Ahmed et al. 2014). In addition to yield loss, weeds deteriorate the quality and market value of the wheat grain and encourage the development of diseases by providing shelter, as an alternate host, to pests. Hence, weed control in wheat is important to increase its productivity and quality.

Weeds in wheat are usually controlled by physical, mechanical and chemical methods. In developed countries, weed management is pre dominantly herbicide-dependent but in some developing countries in South Asia (Bangladesh, Nepal, and India), traditional manual weeding is still common. Research has shown that if hand weddings are done at optimal times, crop yields of wheat are not reduced by weed competition (Hossain et al. 2009; Safdar et al. 2011). But in reality, crop fields are seldom adequately weeded manually, which is tedious and time-consuming. Laborers are not always available during the critical period of weeding, which is often done late, causing drastic losses in yield. To improve the economic efficacy of weed management, the critical period of weed control (CPWC) concept is important. The CPWC provides an idea into the critical time span when weeding should be done. This could improve the timing of post-emergence herbicide application or mechanical or manual weeding. Several factors such as time of weed emergence (Wilson and Westra, 1991), soil moisture, soil temperature (Mclachlan et al. 1993) and crop-weed composition (Swinton et al. 1994) affect the duration of the critical periods of weed control. Herbicides are considered the most economical and efficient weed control tools and their use in agriculture is increasing dramatically to manage weeds in various crops, including wheat. 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% (Reynolds et al. 2008). In Bangladesh, herbicides are not typically used by farmers to manage weeds in a wheat field; however, one manual hand weeding at 15-25 days after sowing (DAS) is very common. Due to recent trends in farm labor shortage, it is expected that herbicide use will increase in near future to manage weeds in wheat.

Chemical weed control is well established in many wheat growing countries but in Bangladesh, it is still under the research phase. Based on some previous studies, 2,4-D amine and carfentrazone-ethyl are the recommended herbicides in wheat (Hossain et al. 2009; Hossain et al. 2010; Mustari et al. 2014). Both herbicides control broadleaf weeds and usually broadleaf are the predominant weeds in wheat fields noticed in previous studies in Bangladesh (Hossain et al. 2010; Kamrozzaman et al. 2015). In Bangladesh, wheat is mainly cultivated in the *aman* rice (wet-season)-wheat-other crops/fallow sequence. Puddled transplanted rice is the major rice cultivation method in Bangladesh, but due to recent trends in high labor cost and scarcity of fresh water, farmers are becoming more interested in resource conservation rice production technologies. Mechanized dry-seeded rice (DSR) is an emerging resource conservation technology and greatly adopted by the farmers of many parts of South Asia. It is aiming that in near future, farmers of Bangladesh would adopt DSR technologies in large scale.

Cyperus rotundus L. is the most dominant weed in DSR systems (Ahmed and Chauhan, 2014; Chauhan et al. 2015; Singh et al. 2006). Wheat grown in the dry seeded *aman* rice-wheat sequence is found severely infested with this weed (Alam et al. 2017). *C. rotundus* is a persistent and prolific weed and very difficult to control by manual or mechanical weeding. None of the pre-emergence herbicides can control this weed. Therefore, the post-emergence herbicide is the only viable option to manage it (Ahmed and Chauhan, 2014). Post-emergence herbicides such as 2,4-D amine and carfentrazone-ethyl are mostly used in Bangladesh to control weeds in wheat; however, these herbicides are not able to control *C. rotundus.* Ethoxysulfuron, a post-emergence herbicide, has been reported to control *C. rotundus* in DSR when applied at 15-25 DAS (Ahmed and Chauhan, 2014, Ahmed et al. 2015). However, this herbicide was not effective against most of the grass weeds and some of the broadleaf weeds (Ahmed and Chauhan, 2014). We hypothesized that 2,4-D and ethoxysulfuron applied in a tank-mixture would effectively control both broadleaf weeds and the sedge *C. rotundus.* However, no information is available in literature on the compatibility of these two herbicides in wheat and their appropriate application timings. We also hypothesized that a tank-mixture spray at an early stage of wheat growth would control weeds effectively but may cause toxicity to wheat. On the other hand, if sprayed at a later stage, they may not cause toxicity to the crop but less effective against weeds. Therefore, the study was conducted to evaluate the effect of application timings and tank mixture of 2,4-D amine and ethoxysulfuron on weed suppression, crop growth, and yield of mechanized wheat planted in a dry-seeded rice-wheat sequence system.

Materials and Methods

Experimental site

Field trials were established at the research farm of the Regional Agricultural Research Station (RARS) of the Bangladesh Agricultural Research Institute (BARI), Jashore, Bangladesh, during the dry seasons (*rabi*) of 2013/14 and 2014/15. The experimental site was located on the High Ganges River Floodplain, a region of relatively high land and thus not subjected to flooding. The climate of the area is subtropical with highly variable rainfall during the dry season (November to May), ranging from 155-825 mm (mean 355 mm) over the past 30 years (1981-2010). The temperature during the dry season also varies greatly, with minimum daily temperature ranging from 5.4-28.2 ^oC (mean 15 ^oC) during 1981-2010, and maximum temperature ranging from 15.6-42.3 ^oC (mean 30 ^oC). The topsoil (0-15 cm) of the experimental field was a clay loam with a bulk density of 1.56 mg m^{-3}, a pH of 7.6, organic carbon 1%, sand 30%, silt 34%, and clay 36%. Prior to the start of the experiment, the site had been under a rice-fallow-rice cropping system for the last two years and both rice crops were established under mechanized DSR systems.

Experimental design and treatments

A total of 11 weed control treatments were included in the experiment. These were 2,4-D amine applied at 10, 20 and 30 DAS, ethoxysulfuron applied at 10, 20 and 30 DAS, 2,4-D amine plus ethoxysulfuron applied at 10, 20 and 30 DAS, weedy, and weed-free. In each treatment, 2,4-D amine was applied at the rate of 1288 g a.i ha^{-1} and ethoxysulfuron at the rate of 18 g a.i ha^{-1}. The experiment was arranged in a randomized complete block designed with three replications. The size of each plot was 4.5 x 3 m and plots were separated by a 1 m buffer area. Herbicides were applied using a knapsack sprayer attached with three flat-fan nozzles on a boom and the sprayer delivered 450 L water ha^{-1}. Weed-free plots were hand weeded three times at 15, 30, and 60 DAS. In the weedy plots, weeds were allowed to grow season-long.

Crop management

A wheat cultivar BARI gom 26 was used in the experiment as a test crop. 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 and the crop was planted at a sowing depth of 3-5 cm and row spacing of 20 cm. Total elemental fertilizer were applied at the rate of 100, 30, 50, 20, and 2 kg N, P, K, S and B, respectively, as a form of urea, triple super phosphate, muriate of potash, gypsum, and boric acid. Two-thirds of the N and all the P, K, S, and B were applied just before wheat sowing, and the rest of the N was applied before the first irrigation. The wheat was irrigated three times in each season including immediately after sowing, 18-21 DAS, and during the grain filling stage (70-75 DAS).

Observations

To evaluate the performance of herbicides on weeds, weed density and weed biomass were measured at 45 DAS by randomly placing two quadrates, measuring 40 cm by 40 cm, in each plot. Weeds were separated by groups (grass, broadleaf and sedge) and counted. After removing their roots, weeds shoots were placed in paper bags for oven drying the samples at 70 ^{o}C for constant biomass determination (around 72 h). To evaluate the effect of weeds on wheat, wheat biomass was measured from the same quadrates and same time used for measuring weeds data. Grain yield was determined by harvesting a 6.6 m^2 (3 x 2.2 m) area in the centre of each plot. 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. Wheat spike density (numbers m^{-2}) was counted in 5 rows x 1 m from two places in each plot. Twenty spikes were randomly selected from each quadrate for determining the number of filled spikelets. Weed control efficiency (WCE) percentage was calculated using the following formula:

$$WCE = \frac{(\text{weed biomass in weedy plot} - \text{weed biomass in herbicide treated plot})}{(\text{weed biomass in weedy plot})} \times 100$$

Statistical analyses

Analysis of variance (ANOVA) were done to evaluate differences between treatments and the means were separated using least significant difference (LSD) at 5% level of significance (Crop Stat 7.2, International Rice Research Institute, Philippines). Interactions between years and treatments for most of the observed parameters were significant; therefore, the results are presented separately for each year.

Results and Discussion

Effect of herbicide treatments on weed density, weed biomass and weed control efficiency

The common weed species found at the experimental site were *Amaranthus spinosus* L., *Anagalis arvensis* L., *Celosia argentea* L., *Chenopodium album* L., *Cleome rutidosperma* DC., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Digitaria ciliaris* (Retz.) Koel., *Echinochloa colona* (L.) Link, and *Phyllanthus niruri* L. Among the weed species, *C. rotundus and E. colona* were the most dominant. At 45 DAS, the total weed density and biomass were significantly affected by weed control methods (Tables 1 and 2). Application of herbicides had always lower weed density and biomass than without herbicide (weedy plots). The tank mixture application of 2,4-D plus ethoxysulfuron always provided lower weed density and biomass than the sole application. Among herbicide treatments, the plots treated with the tank mixture of 2,4-D plus ethoxysulfuron at 10 DAS had the lowest weed density and biomass and similar results were found for this treatment at 20 DAS. The sole application of 2,4-D and ethoxysulfuron had always similar weed density and biomass across the application timings.

Table 1. Effect of weed control methods on grass, broadleaf, sedge, and total weed density at 45 days after sowing in 2013/14 and 2014/15.

	Weed density (numbers m^{-2})							
	Grass		Broadleaf		Sedge*		Total	
Weed control methods	2013/14	2014/15	2013/14	2014/15	2013/14	2014/15	2013/14	2014/15
2,4-D at 10 DAS	184	91	0	2	95	132	279	225
Ethoxy at 10 DAS	305	128	0	19	15	55	320	202
2,4-D + ethoxy at 10 DAS	117	68	0	0	12	32	129	100
2,4-D at 20 DAS	234	105	0	2	65	118	299	225
Ethoxy at 20 DAS	335	152	0	25	20	75	355	252
2,4-D + ethoxy at 20 DAS	132	73	0	0	5	21	137	94
2,4-D at 30 DAS	273	129	20	17	91	142	384	288
Ethoxy at 30 DAS	445	158	30	36	56	85	531	279
2,4-D + ethoxy at 30 DAS	213	102	9	0	15	36	237	138
Weedy	466	164	116	66	110	186	692	416
Weed free	-	-	-	-	-	-	-	-
$LSD_{0.05}$	129	39	40	15	40	52	115	73

*Only *Cyperus rotundus* species; ethoxy= Ethoxysulfuron; DAS= days after sowing

Similar to the total weed density and biomass, the individual weed group also influenced by the weed control treatments (Tables 1 and 2). At any application time, the sole application of 2,4-D and the tank mixture of 2,4-D plus ethoxysulfuron had similar grass weed density and biomass; however, tank mixtures had always lower grass weed density and biomass than the sole application of ethoxysulfuron, which were similar to the weedy treatment. When herbicide application timings delayed from 10 to 30 DAS, the efficacy of the sole application of 2,4-D and the tank mixture application of 2,4-D plus ethoxysulfuron on grass weed control decreased.

Table 2. Effect of weed control methods on grass, broadleaf, sedge, and total weed biomass at 45 days after sowing in 2013/14 and 2014/15.

Weed control methods	Weed biomass (g m^{-2})							
	Grass		Broadleaf		Sedge*		Total	
	2013/14	2014/15	2013/14	2014/15	2013/14	2014/15	2013/14	2014/15
2,4-D at 10 DAS	28	12	0	0	8	17	36	29
Ethoxy at 10 DAS	46	16	0	2	1	7	47	25
2,4-D + ethoxy at 10 DAS	12	7	0	0	2	3	14	10
2,4-D at 20 DAS	33	14	0	0	12	20	45	34
Ethoxy at 20 DAS	49	15	0	5	1	12	50	32
2,4-D + ethoxy at 30 DAS	17	10	0	1	0	4	17	15
2,4-D at 30 DAS	48	15	2	2	15	24	65	41
Ethoxy at 30 DAS	58	21	5	9	9	15	72	45
2,4-D + ethoxy at 30 DAS	23	12	1	0	3	7	27	19
Weedy	62	17	16	9	15	33	93	59
Weed Free	-	-	-	-	-	-	-	-
LSD $_{0.05}$	18	7	4	2	8	14	19	10

*Only *Cyperus rotundus* species; ethoxy= Ethoxysulfuron; DAS= days after sowing

Across application timings, the tank mixture application of 2,4-D plus ethoxysulfuron had almost complete control of broadleaf weeds. The sole application of 2,4-D also controlled broadleaf weeds completely when applied at 10 and 20 DAS; however, the efficacy slightly decreased when applied at 30 DAS. The sole application of ethoxysulfuron had similar broadleaf weed control efficacy to the sole application of 2,4-D and the tank mixture application of 2,4-D plus ethoxysulfuron when applied at 10 and 20 DAS; however, the efficacy decreased when applied at 30 DAS. *C. rotundus* were significantly affected by the weed control methods. The sole application of ethoxysulfuron and the tank mixture of 2,4-D plus ethoxysulfuron reduced sedge density and biomass significantly at all the spraying times compared with the weedy plots. The efficacy of ethoxysulfuron slightly decreased when spraying was delayed from 10 DAS to 30 DAS. The sole application of 2,4-D was not effective against sedges and failed to reduce their density and biomass.

The weed control efficiency (WCE) was significantly affected by weed control methods (Table 3). The tank mixtures of 2,4-D plus ethoxysulfuron had always higher WCE than the sole application of ethoxysulfuron (in both seasons) and 2,4-D (in 2014/15 but not in 2013/14). The WCE of herbicide treatments decreased when the application time delayed from 10 to 30 DAS; however, this decreasing rate was higher for the sole application of ethoxysulfuron.

Table 3. Effect of weed control methods on wheat plant density and biomass, and weed control efficiency (WCE) at 45 days after sowing in 2013/14 and 2014/15.

Weed control methods	Plant density (numbers m^{-2})		Plant biomass (g m^{-2})		WCE (%)	
	2013/14	2014/15	2013/14	2014/15	2013/14	2014/15
2,4-D at 10 DAS	343	355	94	151	61	50
Ethoxy at 10 DAS	370	371	112	182	50	58
2,4-D + ethoxy at 10 DAS	290	314	84	123	85	83
2,4-D at 20 DAS	363	370	119	169	52	42
Ethoxy at 20 DAS	344	359	106	172	46	45
2,4-D + ethoxy at 20 DAS	325	352	111	171	82	75
2,4-D at 30 DAS	345	366	114	161	30	31
Ethoxy at 30 DAS	333	350	106	154	23	24
2,4-D + ethoxy at 30 DAS	346	371	119	176	71	68
Weedy	254	294	80	110	-	-
Weed-free	396	422	128	190	-	-
$LSD_{0.05}$	48	65	22	44	30	17

WCE= weed control efficiency; ethoxy= Ethoxysulfuron; DAS= days after sowing

Effect of weed control methods on wheat plant density and biomass

Plant density and biomass of wheat were significantly affected by weed control methods at 45 DAS in both seasons (Table 3). The lowest plant density and biomass were recorded from the season long weedy plots and all the herbicide-treated plots, except the tank mixtures of 2,4-D plus ethoxysulfuron applied at 10 DAS, had significantly higher plant density and biomass than the weedy plots. Among herbicide treatments, ethoxysulfuron applied at 10 DAS, 2,4-D at 20 DAS, and the tank mixtures of 2,4-D plus ethoxysulfuron applied at 30 DAS had similar plant density and biomass to the weed-free treatment.

Yield and yield components

Spike density (number m^{-2}), grains (number $spike^{-1}$), and grain yield (t ha^{-1}) were significantly affected by weed control treatments. The highest spike density was recorded from the weed-free plots. The plots treated with 2,4-D plus ethoxysulfuron at 10 DAS in both seasons had significantly lower spike density compared with other herbicide treatments but similar to the weedy treatment (Figure 1). The tank mixtures of 2,4-D plus ethoxysulfuron at 20 and 30 DAS had similar spike density to the weed-free treatment. Grain numbers $spike^{-1}$ did not vary among the herbicide treatments and had similar numbers to the weed-free treatment (Figure 2). The weed-free treatment had always the highest grain yield (4.0- 4.2 t ha^{-1}). Although slightly lower, the herbicide treatment 2,4-D plus ethoxysulfuron applied at 20 and 30 DAS had similar yields (3.7-3.9 t ha^{-1}) to the weed-free treatment (Figure 3). The lowest grain yield (1.3-2.2 t ha^{-1}) was recorded from the season-long weedy plots. All herbicide treated plots had always higher grain yield than the weedy treatment in both years. Among the herbicide treatments, the lowest grain yield (2.5-2.7 t ha^{-1}) was recorded from the plots treated with 2,4-D plus ethoxysulfuron at 10 DAS.

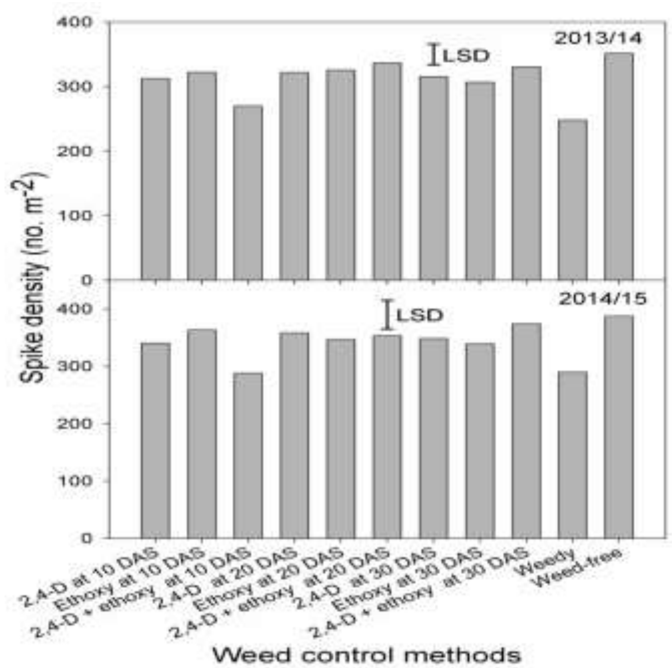

Figure 1. Effect of weed control methods on wheat spike density at physiological maturity in 2013/14 and 2014/15.

The tank mixture of 2,4-D plus ethoxysulfuron performed well in terms of controlling weeds and achieving higher grain yield compared with the sole application across the application timings. The use of mixtures of two or more herbicides may significantly modify the behavior of every single herbicide in the mixture and these interactions often result in a decrease or an increase in the activity of the mixed herbicides compared with activities when each one of them is applied alone (Maity and Mukherjee, 2008). At the field level, weed flora normally consists of many species with varying levels of herbicide sensitivity; therefore, it is often needed to apply more than one herbicide for effective control (Chauhan et al. 2015; Mahajan and Chauhan, 2015). Weed flora in the previous crop, DSR, was very complex and diverse in the same field (Ahmed et al. 2014) and wheat cultivation in the sequence with DSR also recorded a diverse weed infestation. Therefore, a combination of herbicides (sequential application or tank mixture) or a broad-spectrum herbicide is needed to effectively control diverse weed flora (Mahajan et al. 2009).

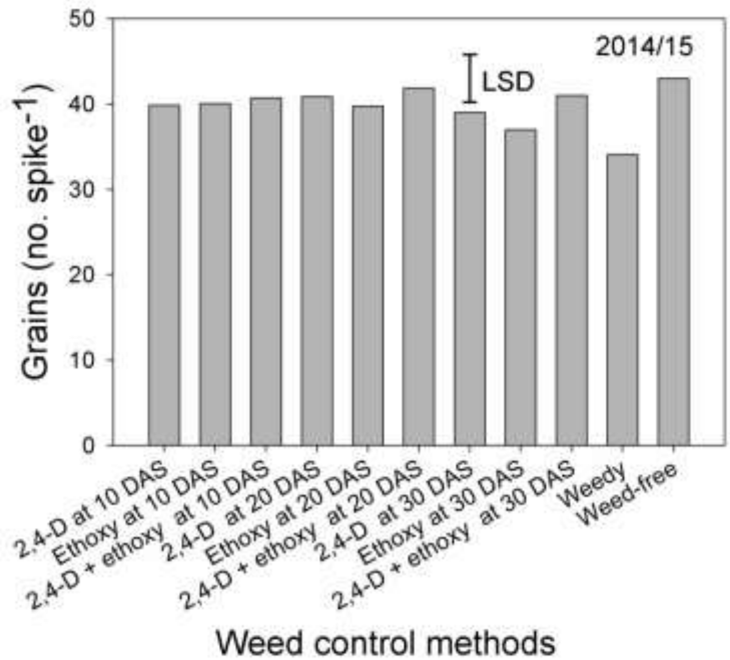

Figure 2. Effect of weed control methods on wheat grain at physiological maturity in 2014/15.

Several previous studies reported that the tank mixing of herbicides improved the weed control spectrum and the efficacy of combined herbicides (Damalas, 2004; Jhala et al. 2013). For example, the application of pretilachlor plus safener followed by (fb) propanil/thiobencarb reduced weed density by 60% compared with the weedy treatment, and this reduction was further increased to 75% with the application of pretilachlor plus safener fb propanil/thiobencarb fb bentazon/MCPA (Anwar et al. 2013). A tank mixture is also important to reduce herbicide resistance development in weed populations as well as a shift in weed flora and contributes to sustainable weed management (Diggle et al. 2003; Friesen et al. 2000; Green and Owen, 2011). Shaw and Arnold (2002) also reported a tank mixer of herbicides with different modes of action is one of the methods used to reduce herbicide rates while maintaining weed control at acceptable levels. We found that the efficacy of ethoxysulfuron decreased when applied at 20 and 30 DAS; even the efficacy of its tank mixture with 2,4-D also decreased slightly when applied at 30 DAS. This response may be due to large plants as growth stages of weed species affect herbicide efficacy by influencing uptake and metabolism of herbicides (Chauhan and Abugho, 2012). Bispyribac-sodium, for example, was more effective on *Echinochloa crus-galli*, *Echinochloa colona*, and *Digitaria ciliaris* when applied at the two-leaf stage than at the four and eight-leaf stage (Chauhan and Abugho, 2012). On the other hand, trifloxysulfuron was more effective on *Cyperus esculentus* L. when applied at later stages (Singh and Singh, 2004). Generally, the herbicide efficacy is lower when applied on larger weeds. The herbicide degradation rate may be faster in larger plants; thus, herbicide rates may need to be increased to achieve the same level of control (Singh and Singh, 2004).

The sole application of 2,4-D and the tank mixtures of 2,4-D plus ethoxysulfuron were slightly effective against grass weeds; however, the sole application of ethoxysulfuron was not able to control any grass weed, which is evident from the similar grass density and biomass to the weedy treatment (Tables 1 and 2). Ethoxysulfuron has been reported to be an effective herbicide in controlling a wide range of broadleaf weeds as well as perennial sedges; however, it was not able to control any grass weeds (Ahmed and Chauhan, 2014; Shyam and Singh, 2015).

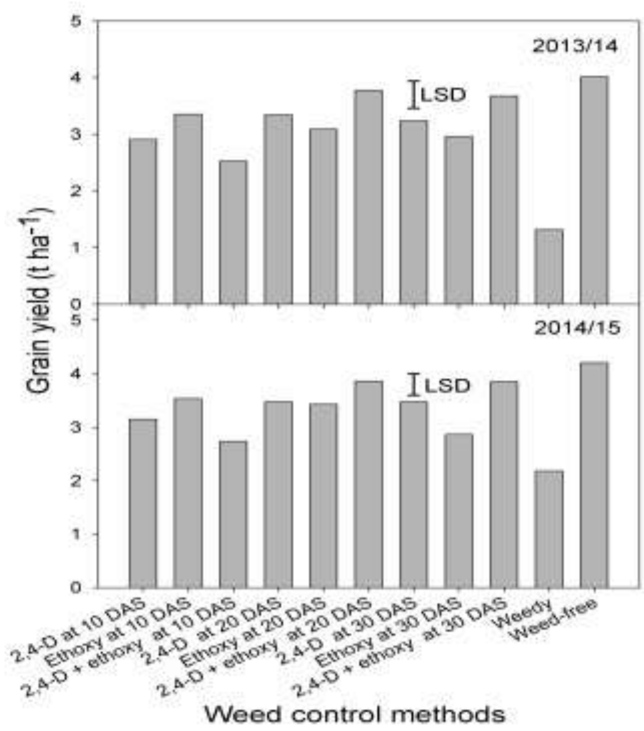

Figure 3. Effect of weed control methods on wheat grain yield in 2013/14 and 2014/15.

In the current study, ethoxysulfuron was mostly effective against broadleaf and sedge weeds when applied at 10 DAS but the efficacy decreased when applied at 20 and 30 DAS. In previous studies also, ethoxysulfuron performed better against broadleaf weeds and sedges at the early growth stage of weeds (Ahmed and Chauhan, 2014; Costa et al. 2015). These results suggest that ethoxysulfuron should be applied at an early weed growth stage to control broadleaf and sedge weeds. On the other hand, 2,4-D alone effectively controlled broadleaf weeds up to 30 DAS. These results suggest that farmers can apply this herbicide alone if their wheat fields are infested by only broadleaf weeds. In the field, broadleaf weeds usually emerge later than grass and sedge weeds (Ahmed et al. 2015; Chauhan et al. 2015); therefore, to effective controlling broad leaf weeds in wheat, 2,4-D may be applied at 25 to 30 DAS to keep fields free from broad leaf weeds during critical crop-weed competitive periods, which range from 15-45 DAS. 2,4-D is very effective against broadleaf weeds, but not sedges as reported by Miller and Norsworthy (2015) and Schulz and Segobye (2016). Although higher WCE was recorded from the tank mixture of 2,4-D plus ethoxysulfuron at all application timings compared with other treatments in this study, this treatment caused toxicity when applied at 10 DAS. This treatment resulted in 10-22% and 11-32% less wheat plant density and biomass, respectively, compared with the sole herbicide application treatments. This toxicity effects had a great influence on grain yield. For example, the tank mixture of 2,4-D plus ethoxysulfuron at 10 DAS had 24-35% higher WCE than the sole application; however, the grain yield of the tank-mix herbicide applied plots at 10 DAS was lower than the sole application. The tank mix application of 2,4-D plus ethoxysulfuron had relatively higher WCE and no phytotoxicity at 20 and 30 DAS resulted in similar yield and yield components to the weed-free treatment.

Conclusion

The sole application of 2,4-D or ethoxysulfuron was never enough to control weeds effectively and resulted in higher weed infestation and suboptimum yields of wheat. The tank mixture of 2,4-D plus ethoxysulfuron greatly improved the WCE, resulting in similar grain yields to the weed-free treatment when applied at 20 and 30 DAS; however, the tank mixture caused toxicity to the wheat plants when applied at 10 DAS. Therefore, even after good weed control by the tank mixture of 2,4-D plus ethoxysulfuron at 10 DAS, the yield performance of wheat was poor. Our study thus demonstrated that if farmers do not like to practice any manual weeding to save on weeding costs, the tank mixture of 2,4-D plus ethoxysulfuron between 20 to 30 DAS is a good option to control broadleaf and sedge weeds. Post-emergence herbicides for controlling grass weeds in wheat are not available in Bangladesh and usually, they are not required due to less grass weed problems in wheat, which is mostly cultivated after transplanted *aman* rice. However, in our study, grass weeds were also a great problem in wheat cultivated in the sequence of *aman* DSR. Therefore, considering the limitation of selective post-emergence herbicides, further studies need to be emphasized on the evaluation of pre-emergence herbicides in wheat in Bangladesh.

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Conflicts of Interest

No conflicts of interest have been declared**.**

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