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Article

Integrated Role of Row Spacing and Adjuvant to Reduce Herbicide Dose in Maize Under Semi-Arid Conditions

Papel Integrado do Espaçamento Entrelinhas e do Adjuvante na Redução da Dose dos Herbicidas nas Culturas de Milho sob Condições Semiáridas

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ABSTRACT - Crop row spacing adjustment and adjuvants have a significant role in decreasing herbicide cost and environmental damage by reducing herbicide application rate. A field study was conducted to assess the impact of two row spacing values and reduced herbicide rates along with adjuvant on weeds in maize in 2014 and 2015. The experiment consisted of atrazine plus mesotrione plus halosulfuran methyl (pre-mixed herbicide) at label rate (719.2 g a.i. ha^{-1}); reduced rates of 75% (539.4 g a.i. ha^{-1}) and 50% (359.6 g a.i. ha^{-1}) alone and in combination with alkyl ether sulphate at 396.8 mL ha^{-1} as an adjuvant along with weedy check in maize sown at 60 and 75 cm row spacing. Alkyl ether sulphate increased weed control efficacy (13-35%) of the pre-mixed herbicide. Herbicide along with adjuvant provided effective weed control at 60 cm as compared to 75 cm apart sown maize. The most effective control of weeds, and increase in maize grain yield (33-45% as compared to non-treated control) and net income were obtained by the pre-mixed herbicide at 539.4 g a.i. ha^{-1} (75% of recommended rate) with adjuvant and pre-mixed herbicide at 719.2 g a.i. ha^{-1} (recommended dose) without adjuvant. The results revealed that the rate of pre-mixed herbicide can be reduced by up to 25% of the recommended field rate by the addition of alkyl ether sulphate as an adjuvant at 60 cm row spacing of maize to increase maize yield and net income.

Keywords: alkyl ether sulphate, economic analysis, integrated weed management, narrow row maize, reduced herbicide dose, weed control efficiency.

RESUMO - Nas culturas agrícolas, o espaçamento entrelinhas e os adjuvantes desempenham um papel importante para a redução do custo do herbicida e dos danos ambientais através da redução da dose dos herbicidas aplicados. Foi conduzido um estudo de campo para avaliar o impacto de dois espaçamentos entrelinhas e da redução das doses de herbicidas juntamente com o adjuvante em plantas daninhas em cultura de milho em 2014 e 2015. O experimento foi composto de atrazina, mesotriona e halossulfurom-metílico (herbicida pré-misturado) na dose recomendada (719,2 g i.a. ha^{-1}); doses reduzidas de 75% (539,4 g i.a. ha^{-1}) e 50% (359,6 g i.a. ha^{-1}) isoladas e em combinação com alquil éter sulfato a 396,8 mL ha^{-1} como adjuvante, juntamente com capina em milho semeado com espaçamento entrelinhas de 60 e 75 cm. O alquil éter sulfato aumentou a eficácia do controle de plantas daninhas (13-35%) com o herbicida pré-misturado. O herbicida, juntamente com o adjuvante, resultou no controle eficaz de plantas daninhas com uso de espaçamento de 60 cm, em comparação com o milho semeado com espaçamento de 75 cm. O controle mais eficaz das plantas daninhas e o aumento do rendimento de grãos de milho (33-45% em comparação com o controle

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sem tratamento) e da renda líquida foram obtidos pelo herbicida pré-misturado a 539,4 g i.a. ha^{-1} (75% da dose recomendada) com o adjuvante e pelo herbicida pré-misturado a 719,2 g i.a. ha^{-1} (dose recomendada) sem o adjuvante. Os resultados revelaram que a dose de herbicida pré-misturado pode ser reduzida até 25% da taxa de campo recomendada através da adição de alquil éter sulfato como adjuvante com espaçamento de 60 cm para as culturas de milho a fim de aumentar o rendimento do milho e a renda líquida.

Palavras-chave: alquil éter sulfato, análise econômica, manejo integrado de plantas daninhas, cultura de milho com espaçamento entrelinhas estreito, redução da dose de herbicida, eficiência de controle de plantas daninhas.

INTRODUCTION

Herbicide use is the most effective tool for controlling weeds in maize (*Zea mays*) (Khan and Haq, 2004; Juhl, 2004); however, it is being criticized because of issues regarding herbicide use including environmental and health hazards, herbicide hormesis in weeds and evaluation of herbicide resistance (Owen and Zelaya, 2005; Nadeem et al., 2016). Rapid increase in herbicide-resistant weeds worldwide, in developing countries such as Pakistan, has made chemical weed control more difficult (Heap, 2016; Abbas et al., 2016). There is a need to reduce the use of herbicides by reducing herbicide rates or focusing on non-chemical weed control measures to overcome problems relative to herbicide use for sustainable crop production (Pannacci and Covarelli, 2009). Adjuvants increase herbicide efficacy by increasing herbicide retention on the plant surface, more penetration through the cuticle and alteration of the surface tension, pH, thickness and distribution of spray solution (Zadorozhny, 2004). Javaid et al. (2012) reported that alkyl ether sulphate increased the efficacy of post-emergence herbicides and reduced herbicide rates without compensating weed control. However, effective weed control at reduced herbicide rates depends upon the type of herbicides being applied, type of adjuvant and characteristic of target weed species (Bunting et al., 2004).

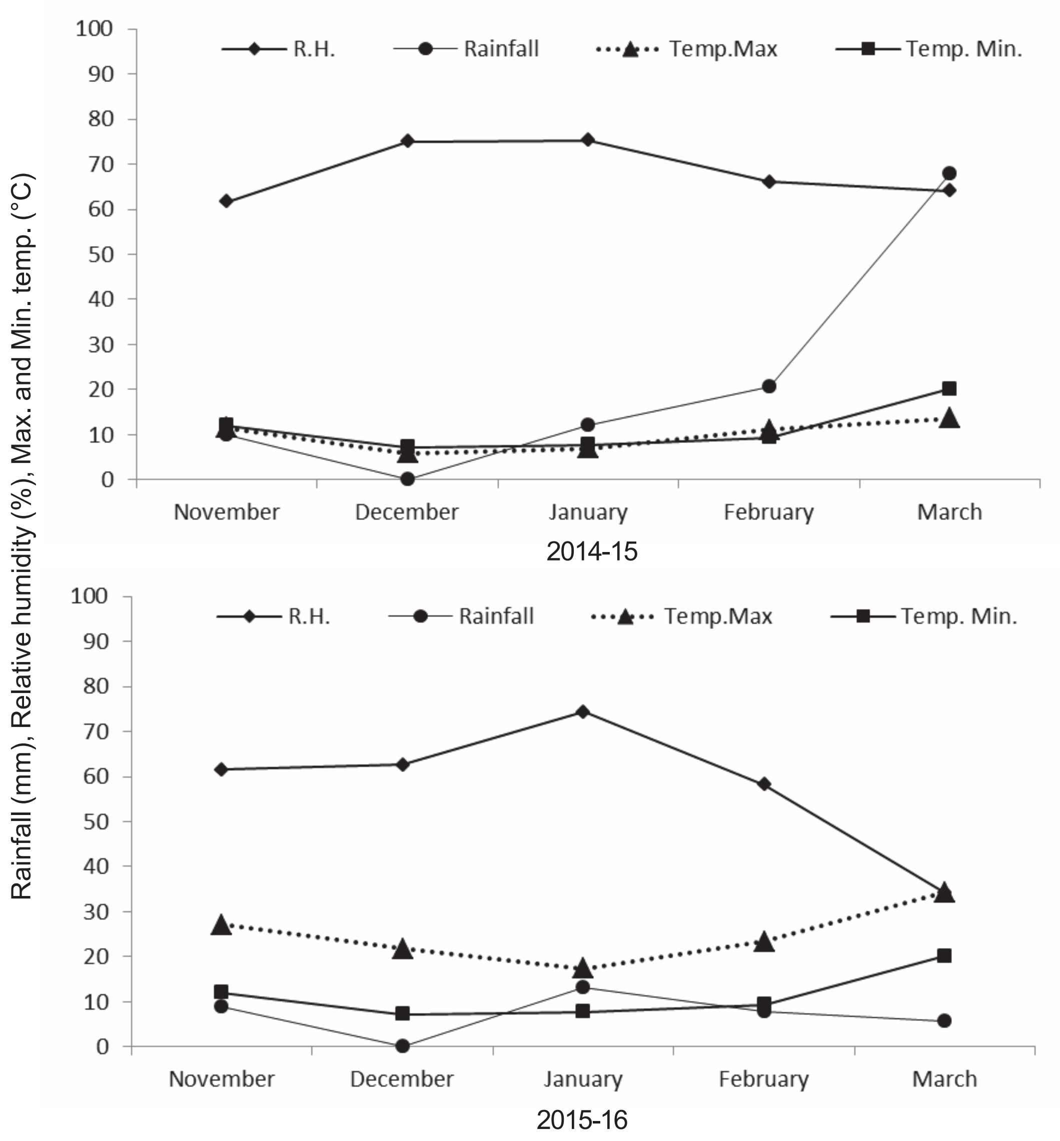
Narrow row spacing of maize negatively influenced weed growth and weed-crop competition by changing the critical period of weed interference with maize, reduced weed growth and more weed-crop competition enhanced the herbicide efficacy (Padilha et al., 2016; Khan et al., 2016). Reducing row spacing accelerates canopy establishment and results in improved radiation interception, growth, and yields of the crop (Andrade et al., 2002) and suppresses weed growth (Alford et al., 2004; Padilha et al., 2016) shifting the advantage in the favor of crops. The suppressed weeds may be controlled efficiently by using the lower doses of the herbicide (Fanadzo et al., 2010).

Adjusting maize row spacing and integrating adjuvant with herbicides may help to reduce the herbicide rate as a result of higher herbicide efficacy and crop competition (Tanveer et al., 2015). Limited literature is available on the integrated use of narrow row spacing and reduced herbicide rates with an adjuvant to control weeds in maize. Furthermore, no research is available on integration of narrow row spacing and reduced rates of pre-mixed herbicide (atrazine plus mesotrione plus halosulfuran methyl) with alkyl ether sulphate as an adjuvant. A two-year field study was, therefore, planned to look at the integrated influence of narrow row spacing and adjuvant on the efficacy of premixed atrazine plus mesotrione plus halosulfuran methyl at both labeled and reduced rates in autumn planted maize. Use of herbicides at a reduced rate will help to minimize environmental safety concerns and herbicide resistance problem lies back behind chemical weed control.

MATERIALS AND METHODS

The field study was conducted at Agronomic Research Area, University of Agriculture Faisalabad, to check the impact of row spacing and reduced herbicide rates along with an adjuvant on weeds in maize in 2014 and 2015. The experiment was laid out in a randomized complete block design with a factorial arrangement. Each treatment was replicated three times and a net plot size of 5 m x 3 m. The experiment consisted of premixed application of atrazine plus mesotrione plus halosulfuran methyl at 539.4 g a.i. ha^{-1} (75% of recommended rate) and atrazine plus mesotrione plus halosulfuran methyl at 359.6 g a.i. ha^{-1} (50% of recommended rate) alone and in combination with alkyl ether sulphate as an adjuvant. The recommended rates of atrazine plus mesotrione plus halosulfuran methyl (719.2 g a.i. ha^{-1}) and weedy check were also included. A knapsack sprayer fitted with flat fan nozzle (800067 nozzle) was used for herbicide application. The amount of water was calibrated before herbicide application and it was used at 250 L ha^{-1} and pressure was 30 psi. The adjuvants were tank mixed at the time of herbicide application. The maize crop was sown at recommended row spacing of 75 cm and narrow row spacing of 60 cm. Fertilizer was applied at 272 (N), 114 (P) and 124 (P) kg ha^{-1}, urea (46% N), diammonium phosphate (46% P and 18% N) and sulphate of potash (50% K) were used as sources of fertilizer. All of P and K and 1/3rd of N were applied at planting and the remaining N was applied as topdressing in two equal splits at 5 and 7 weeks after emergence. Maize stalk borer (*Buseola fusca*) was controlled by applying furadan granules in the maize funnel at 4 weeks after emergence.

In both years, metrological data on temperature and rainfall was collected from AgroMet Observatory, Department of Crop Physiology, UAF (Figure 1). All other field practices relative to crop husbandry were kept standard and uniform. Density and biomass of weeds were recorded from an area of 1 m^2 at random from each plot.



Source: AgroMet Observatory, Department of Crop Physiology, UAF.

Figure 1 - Metrological data during the course of the present study.

Weed control efficiency (WCE) was calculated with the formula (Singh et al., 2013).

$$WCE = \frac{(x-y)}{x} \times 100$$

where, x = weed dry weight in the weedy check and y = weed dry weight in the mixture treated plot.

Grain yield was recoded per plot and was converted to t ha^{-1}.

For comparison of the treatment's means, the data collected were analyzed using Fisher's analysis of variance and the least significant difference test at 5% probability level was used (Steel et al., 1997).

RESULTS AND DISCUSSION

The major weeds present in the maize were *Convolvulus arvensis* (field bindweed), *Trianthema portulacastrum* (desert horsepurslane) and *Coronopus didymus* (lesser swine-cress).

Weed density (m^2) of *C. arvensis*, *T. portulacastrum* and *C. didymus* at harvest

The data on weed density revealed that the interactive effect of herbicide treatments and maize row spacing was significant for both years for *Convolvulus arvensis*, *Trianthema portulacastrum and Coronopus didymus*. Herbicide treatments significantly reduced weed density of all weeds over W_1 (weedy check) in both years of study. Treatment W_5 performed best as compared to other herbicide treatments at S_1 (60 cm row spacing) irrespective of type of weed species, and that was followed by W_5 at S_2 (75 cm row spacing) and W_2 for both years of study. Overall, there was less weed density at narrow row spacing (60 cm) as compared to the recommended row spacing (75 cm) of maize for all herbicide treatments in both years (Table 1).

The addition of adjuvant at 50% and 75% of the recommended rate of the herbicide enhanced its efficacy. Tanveer et al. (2015) reported that adding an adjuvant may improve herbicide efficacy of these weed species and an appropriate adjuvant can decrease the amount of herbicide which lowers the total cost of production for maize. The addition of adjuvant caused a significant reduction in weed density, which increased the efficacy of herbicides. The higher weed control efficacy of herbicide with the addition of adjuvant can be ascribed to greater absorption of herbicide by weeds. These results are supported by Zawierucha and Penner (2001), who stated that an effective adjuvant activator enhances the penetration of the herbicide through major barriers to cell entry. Mortality of *C. arvensis* was different among the various herbicidal treatments because of the difference in their phytotoxic effects. The results of weed control were strongly supported

Table 1 - Density (m^2) of *C. arvensis*, *T. portulacastrum and C. didymus* as influenced by different weed control treatments and reduced row spacing in maize

Treatment	*C. arvensis*				*T. portulacastrum*				*C. didymus*			
	2014		2015		2014		2015		2014		2015	
	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)
W_1	4.33 b	5.67 a	3.66 cd	6.00 a	59.67 b	73.33 a	65.66 b	76.33 a	59.33 b	63.67 a	63.67 a	66.67 a
W_2	1.67 e	2.67 d	2.00 ef	3.34 d	6.67 f	7.33 f	7.00 f	8.66 f	9.67 g	10.67 g	12.00 e	12.00 e
W_3	2.67 d	2.67 d	2.67 e	4.00 c	9.33 f	11.67 ef	16.33 e	19.33 e	10.97 g	11.67 g	27.00 c	28.67 c
W_4	3.67 c	4.67 b	3.33 d	4.67 b	28.67 d	35.66 c	27.66 d	33.67 c	32.33 d	37.67 c	34.00 b	35.33 b
W_5	1.66 e	2.33 d	1.66 g	2.33 e	7.13 f	8.33 f	4.66 f	5.33 f	9.33 g	9.67 g	12.00 e	13.00 e
W_6	2.34 d	2.67 d	3.34 d	3.00 de	11.33 ef	13.33 e	19.66 e	16.34 e	17.67 f	20.67 e	25.67 c	24.67 cd
LSD	0.63		0.65		3.37		1.93		3.1		3.03	

The means having same letter do not differ significantly ($p<0.05$). W_1 = Weedy check, W_2 = Atrazine + mesotrione + halosulfuron methyl at 719.2 g a.i. ha^{-1} (Recommended rate), W_3 = Atrazine + mesotrione + halosulfuron methyl at 539.4 g a.i. ha^{-1} (75% of the recommended rate), W_4 = Atrazine + mesotrione + halosulfuron methyl at 359.6 g a.i. ha^{-1} (50% of the recommended rate), W_5 = W_3 + Alkyl ether sulphate at 396.8 mL ha^{-1} and W_6 = W_4 + Alkyl ether sulphate at 396.8 mL ha^{-1}.

by Vanbiljon et al. (2007). The effect of row spacing was also significant. Decreasing row spacing of maize resulted in significant reduction in weed density (Padilha et al., 2016). This decrease in density can be attributed to the fact that with reduced spacing maize crop established its canopy earlier and ultimately fewer weeds emerged. The results reinforced the findings of Tharp and Kells (2001), Shapiro and Wortmann (2006) and Padilha et al. (2016), who reported that narrow row spacing reduced weed growth by increasing the competitive ability of maize plants with weeds as a result of fast and dense canopy development. These outcomes of this research are supported by Fanadzo et al. (2010), who found that, despite crop density, narrow row offers more weed inhibition than wide rows.

Weed control efficiency of *C. arvensis, T. portulacastrum* and *C. didymus*

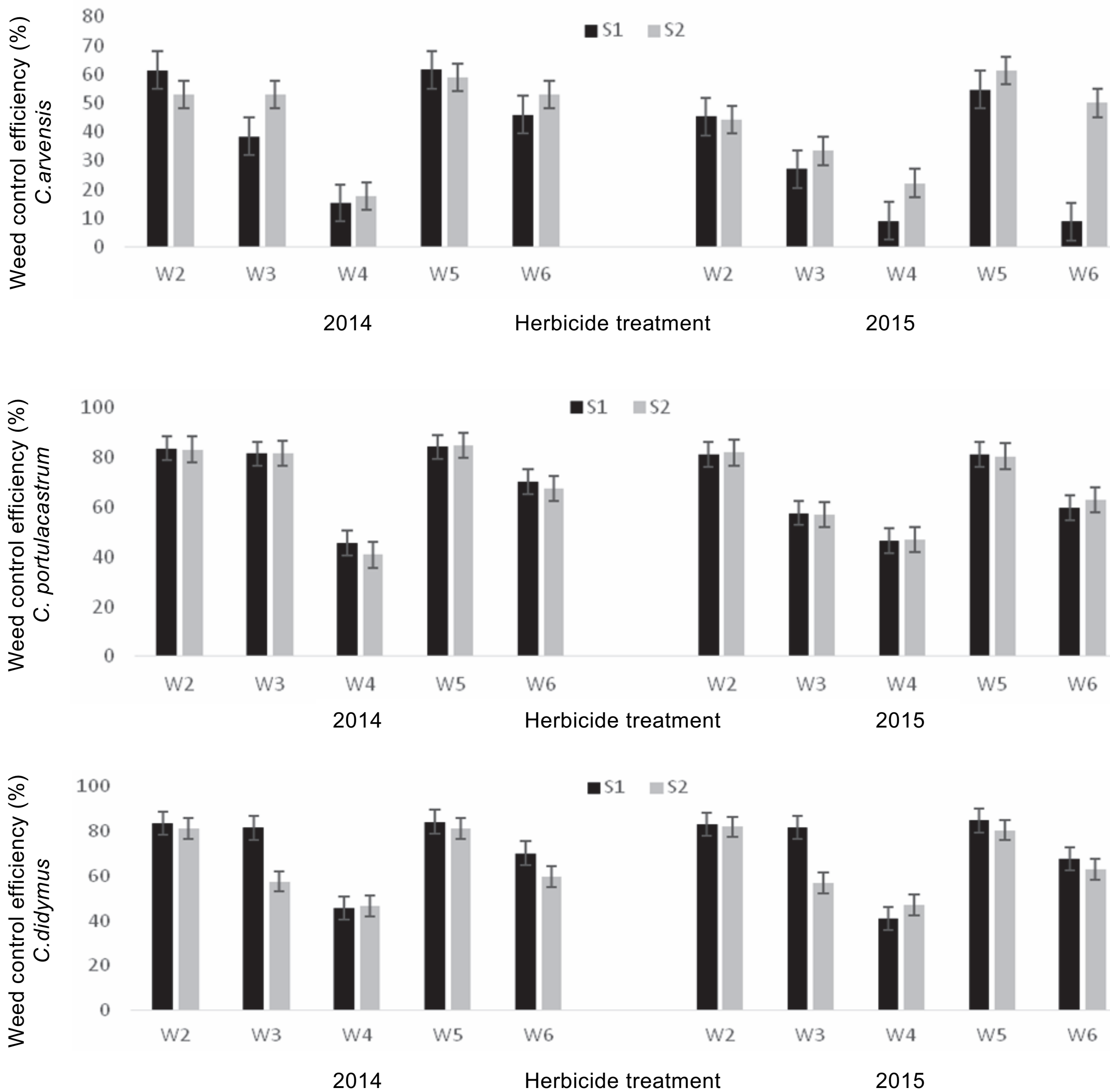
The significant interaction of herbicide treatments and row spacing showed that herbicide treatments with adjuvant showed more weed control efficiency even at lower doses for both row spacing of maize in 2014 and 2015 (Figure 2). Weed control efficiency for W_1 was zero. The maximum weed control efficiency was provided by W_5 (75% of the recommended rate plus adjuvant) irrespective of type of weed; it was followed by W_2 (100% of the recommended rate without an adjuvant). Among the weed control treatments, W_4 provided minimum weed control efficiency in both years. Generally, the effect of row spacing revealed that more weed control efficiency was achieved at narrow row spacing as compared to the recommended row spacing of maize.

The addition of adjuvant caused a significant reduction in weed density to improve weed control efficiency. The higher weed control efficacy with the addition of the adjuvant can be credited to greater absorption of herbicide by weeds. These results are reinforced by Zawierucha and Penner (2001), who stated that an effective adjuvant activator enhances the penetration of the herbicide and increases herbicide efficacy. These results are supported by Shrestha et al. (2001), who found that, despite crop density, narrow row offers more weed inhibition than wide rows. The higher weed control with the addition of adjuvant can be attributed to greater absorption of herbicide by weeds (Tahir et al., 2011; Tanveer et al., 2015). These results are supported by Javaid et al. (2012), who stated that an effective adjuvant activator enhances the penetration of the herbicide and increase weed control efficacy. More weed control efficiency at narrow row spacing might be due to more weed crop competition, which reduced weed growth and weed biomass, ultimately resulting in more weed control efficiency (Padilha et al., 2016). These results are reinforced by Maqbool et al. (2006), who found that, despite crop density, narrow row spacing offers more weed inhibition than wide row spacing.

Grain yield of maize

Interactive effect of herbicide treatments and row spacing revealed that all herbicide treatments positively influenced maize yield as compared to the weedy check at both row spacings for both years (Table 2). Plots treated with W_2 and W_5 showed maximum grain yield than other treatments for both years; these were followed by W_6 at narrow sown maize (60 cm row spacing). Overall results revealed that narrow row spacing (60 cm) produced more grain yield as compared to recommended row spacing (75 cm) of maize for all herbicide treatments. The addition of adjuvant resulted in significantly higher grain yield compared with herbicide alone with the same dose. The use of the adjuvant with 75% of the recommended rate (W_5) resulted in statistically similar grain yield to that of the labeled herbicide rate (W_2). Similarly, the addition of adjuvant with 50% of the labeled rate (W_6) resulted in statistically similar grain yield to that of 75% of the labeled rate without adjuvant (W_3).

The higher grain yield with herbicide treatments over the weedy check can be attributed to less weed crop competition caused by efficient weed control and lower weed density. The efficiency of chemicals with adjuvant and other weed control practices in increasing grain yield had also been demonstrated by Mandhi et al. (2007), Maqbool et al. (2006), and Nadeem et al. (2008), Khan et al. (2016), who reported that the addition of the adjuvant enhanced maize yield by control weed without any phytotoxic effect on the maize crop. In addition, Nadeem et al. (2008) and Tanveer et al. (2015) reported that the addition of adjuvants enabled the reduction in herbicide concentration by 30-60% in maize without affecting its yield.



Vertical bars indicate the standard error of means. W_1 = Weedy check, W_2 = Atrazine + mesotrione + halosulfuron methyl at 719.2 g a.i. ha^{-1} (Recommended rate), W_3 = Atrazine + mesotrione + halosulfuron methyl at 539.4 g a.i. ha^{-1} (75% of the recommended rate), W_4 = Atrazine + mesotrione + halosulfuron methyl at 359.6 g a.i. ha^{-1} (50% of the recommended rate), W_5 = W_3 + Alkyl ether sulphate at 396.8 mL ha^{-1} and W_6 = W_4 + Alkyl ether sulphate at 396.8 mL ha^{-1}.

Figure 2 **-** Weed control efficiency (%) of *C. arvensis*, *T. portulacastrum* and *C. didymus* as influenced by different weed control treatments and reduced row spacing in maize.

Economic analysis

Economic analysis of various herbicide treatments was done using total variabile cost (Table 3) and fixed cost of each treatemnts. It showed that the highest net income was obtained in the W_5S_1 treatment (atrazine + mesotrione + halosulfuron methyl at 539.4 g a.i. ha^{-1} + alkyl ether sulphate at 396.8 mL ha^{-1}), followed by same treatment sown under wider row spacing (W_5S_2). The use of the adjuvant with reduced herbicide rate gave the same yield as with a full rate of herbicide alone; while, the weedy check gave lowest net income because of lower maize grain yield.

Table 2 - Grain yield of maize as influenced by different weed control treatments and reduced row spacing

Treatment	2014		2015	
	S_1 (60 cm)	S_2 (75 cm)	S_1 (60 cm)	S_2 (75 cm)
W_1	5.99 d	5.17 e	5.68 d	5.57 d
W_2	8.85 a	8.07 b	8.07 a	8.00 a
W_3	7.77 bc	7.19 c	7.20 b	7.03 b
W_4	7.00 c	6.21 d	6.47 c	6.28 c
W_5	8.62 a	7.74 bc	8.23 a	8.13 a
W_6	7.96 b	7.01 c	7.10 b	6.79 bc
LSD	0.75		0.54	

The means having same letter are not differed significantly ($p<0.05$). W_1 = Weedy check, W_2 = Atrazine + mesotrione + halosulfuron methyl at 719.2 g a.i. ha^{-1} (Recommended dose), W_3 = Atrazine + mesotrione + halosulfuron methyl at 539.4 g a.i. ha^{-1} (75% of recommended dose), W_4 = Atrazine + mesotrione + halosulfuron methyl at 359.6 g a.i. ha^{-1} (50% of recommended dose), W_5 = W_3 + Alkyl ether sulphate at 396.8 mL ha^{-1} and W_6 = W_4 + Alkyl ether sulphate at 396.8 mL ha^{-1}.

Net income was reduced in all treatments in wider row spacing with 75 cm. Table 4 showed that the highest net income was obtained in W_5S_1 (atrazine + mesotrione + halosulfuron methyl at 539.4 g a.i. ha^{-1} + alkyl ether sulphate at 396.8 mL ha^{-1}) treatment, followed by the same treatment sown under wider row spacing (W_5S_2). Shrestha et al. (2001) reported the effect of narrow row spacing on yield as with narrow row spacing a little increase in yield occur which ultimately increased net return. The results are in close agreement with Tahir et al. (2011). The economic analysis showed that maximum net returns were obtained with a reduced herbicide rate along with an adjuvant (W_5) and minimum net returns were obtained with a weedy check. The enhanced efficiency of the reduced herbicide rate is due to the use of the adjuvant (Kudsk, 2008; Nadeem et al., 2008; Tanveer et al., 2015).

Based on the present results, it can be concluded that narrow row spacing and use of adjuvant are effective strategies to reduce the rate of premixed herbicide (atrazine plus mesotrione plus halosulfuron methyl) to control weeds in maize and to enhance maize yield (up to 54% compared to the non-treated control) and economic return. The results also revealed that the rate of atrazine

Table 3 - Variable cost ($ US) for every treatment per acre

Treatment	Herbicide cost ($ US)	Cost of adjuvant	Rent of sprayer	Application cost	Total variable cost
W_1	-	-	-	-	-
W_2	13.50	-	1.00	5.00	19.50
W_3	10.12	-	1.00	5.00	16.12
W_4	6.72	-	1.00	5.00	12.72
W_5	10.12	4.00	1.00	5.00	20.12
W_6	6.72	4.00	1.00	5.00	16.72

Table 4 - Economic analysis of various herbicide treatments at varied row spacings

Row spacing	Herbicide rates	Grain yield ($t\ h^{-1}$)	Straw yield value	Total income ($ US)	Fixed cost ($ US)	Variable cost ($ US)	Total cost ($ US)	Net benefits ($ US)	Benefit cost ratio
S_1	W_1	5.68	2480	1444.80	1084.77	0	1084.77	360.03	1.33
S_1	W_2	8.07	2480	2042.30	1084.77	48.36	1133.13	909.17	1.80
S_1	W_3	7.20	2480	1824.80	1084.77	39.99	1124.76	700.04	1.62
S_1	W_4	6.47	2480	1642.30	1084.77	31.55	1116.32	525.98	1.47
S_1	W_5	8.23	2480	2082.30	1084.77	49.91	1134.68	947.62	1.84
S_1	W_6	7.10	2480	1799.80	1084.77	41.47	1126.24	673.56	1.59
S_2	W_1	5.57	2480	1417.30	1058.52	0	1058.52	358.78	1.34
S_2	W_2	8.00	2480	2024.80	1058.52	48.36	1106.88	917.92	1.83
S_2	W_3	7.04	2480	1784.80	1058.52	39.99	1098.51	686.29	1.62
S_2	W_4	6.28	2480	1594.80	1058.52	31.55	1090.07	504.73	1.46
S_2	W_5	8.13	2480	2057.30	1058.52	49.91	1108.43	948.87	1.85
S_2	W_6	6.80	2480	1724.80	1058.52	41.47	1099.99	624.81	1.56

plus mesotrione plus halosulfuron methyl can be reduced up to 75% of the recommended rate by the addition of alkyl ether sulphate as an adjuvant and use of 60 cm row spacing.

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