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Article

Increased Foliar Activity of Isoproturon+Tribenuron and Pyroxsulam Against Little Seed Canary Grass and Field Bindweed by Proper Adjuvant Selection in Wheat

Aumento da Atividade Foliar de Isoproturon+Tribenuron e Pyroxsulam em Erva-Cabecinha e Corriola por Meio de Seleção Adequada de Adjuvantes no Trigo

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ABSTRACT - Using an adjuvant to optimize and increase the foliar activity of post emergence herbicides is an acceptable way to reduce their side effects. Field researches were conducted to detect a suitable adjuvant for two post-herbicides namely, isoproturon+tribenuron and pyroxsulam against little seed canary grass (*Phalaris minor*) and field bindweed (*Convolvulus arvensis*). Treatments were, isoproturon+tribenuron at 1,025 g a.i. ha^{-1} (recommended dose) and pyroxsulam at 140.6 g a.i. ha^{-1} (recommended dose) alone or their reduced dose (75% of the recommended dose) isoproturon+tribenuron at 769 and pyroxsulam at 105.5 g a.i. ha^{-1}, tank mixed with three different adjuvants viz. alkylethersulphate sodium salt at 400, fatty alcohol ethoxylate at 200 and sunflower oil at 1,000 mL ha^{-1}. These treatments were applied at the two to three leaf stages of weeds. All the adjuvants enhanced the efficacy of herbicides; however, maximum herbicide efficacy against *P. minor* (93.50-97.66%) and *C. arvensis* (82-100%) was achieved with the application of isoproturon+tribenuron plus alkylethersulphate sodium salt, showing the lowest total weed dry weight (1.48, 0.88 g m^{-2}). The maximum NPK-uptake was associated to the untreated control. Nutrient saving (55-95% N, 43-92% P, 55-95% K) was enhanced by the addition of all adjuvants to herbicides, with better weed control. The maximum yield (41 - 43% increase over weedy check) and yield attributes were recorded with reduced rates of isoproturon+tribenuron plus alkylethersulphate sodium salt, followed by the recommended rate of the same herbicide applied alone. In contrast, sunflower oil with pyroxsulam exerted greater control of little seed canary grass and field bindweed with more yield and yield related traits than alkylethersulphate sodium salt and fatty alcohol ethoxylate with pyroxsulam. These results demonstrated the improvement in the performance of reduced rates of isoproturon+tribenuron with the inclusion of alkylethersulphate sodium salt, with a dose higher than or equal to the recommended dose of the same herbicide, and this is the most cost-effective combination.

Keywords: herbicides, alkylethersulphate sodium, fatty alcohol ethoxylate, sunflower oil.

RESUMO - O uso de adjuvantes para otimizar e aumentar a atividade foliar de herbicidas pós-emergência é uma forma aceitável de reduzir seus efeitos colaterais. Pesquisas de campo foram conduzidas para detectar um adjuvante adequado para dois herbicidas, nomeadamente isoproturon + tribenuron e pyroxsulam, em

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*erva-cabecinha (**Phalaris minor**) e corriola (**Convolvulus arvensis**). Os tratamentos foram: isoproturon + tribenuron at 1,025 g i.a. ha^{-1} (dose recomendada) e pyroxsulam at 140,6 g i.a. ha^{-1} (dose recomendada) isolado ou a sua dose reduzida (75% da dose recomendada), isoproturon + tribenuron at 769 g i.a. ha^{-1} e pyroxsulam at 105,5 g i.a. ha^{-1}, misturados com três adjuvantes diferentes: alquiletilsulfato de sódio at 400, álcool gordo etoxilado at 200 e óleo de girassol at 1.000 mL ha^{-1}. Os tratamentos foram aplicados nas fases de duas a três folhas das plantas daninhas. Todos os adjuvantes melhoraram a eficácia dos herbicidas; no entanto, a eficácia máxima do herbicida em **P. minor** (93,50-97,66%) e **C. arvensis** (82-100%) foi obtida com a aplicação de isoproturon + tribenuron mais alquietilsulfato de sódio, mostrando a menor massa seca total das plantas daninhas (1,48 e 0,88 g m^{-2}). A absorção máxima de NPK foi associada ao controle não tratado. A assimilação de nutrientes (55-95% N, 43-92% P e 55-95% K) foi aumentada pela adição de todos os adjuvantes aos herbicidas, com melhor controle de plantas daninhas. O rendimento máximo (aumento de 41 a 43% em relação ao controle de plantas daninhas) e as características de produção foram registrados com taxas reduzidas de isoproturon + tribenuron mais alquietilsulfato de sódio, seguidos da taxa recomendada do mesmo herbicida aplicado isoladamente. No entanto, o óleo de girassol com pyroxsulam exerceu maior controle em erva-cabecinha e corriola, com maior rendimento e características de rendimento que o alquiletilsulfato de sódio e álcool gordo etoxilado com pyroxsulam. Os resultados demonstraram melhor desempenho de taxas reduzidas de isoproturon + tribenuron com a inclusão de alquiletilsulfato de sódio, com uma dose maior ou igual à dose recomendada do mesmo herbicida, sendo esta a combinação mais eficiente.*

Palavras-chave: herbicidas, alquiletilsulfato de sódio, álcool gordo etoxilado, óleo de girassol.

INTRODUCTION

Wheat is an essential crop in the world. Being a semi-dwarf plant, wheat usually has a slow initial growth behavior, which provides a favorable environment for weed incidence. Severe weed infestations are one of the major yield limiting factors, causing 25-55% losses (Verma et al., 2008; Singh, 2009). The use of herbicides has become highly prevalent in modern agriculture, in order to facilitate the conservation of agriculture; it potentially reduces weed density, species diversity and species richness, depletes soil seed banks over a long period of time and ensure higher yield (Muoni et al., 2014; Sharma and Singh, 2014). Using herbicides is considered a quick and efficient weed control method, with less cost and time involvement (Chhokar et al., 2013). The main goal of using herbicides is to stunt or kill weeds, allowing wheat to place on a competitive advantage over weeds, in order to ensure the maximum utilization of resources that contribute to grain yield (Prakash et al., 2013). Dynamic weed infestation losses and the use of herbicides at advertised rates are being voiced as a major current problem in the present agro-production system.

It is a need of the time to develop newer techniques that will lead towards the reduction of the herbicide load in the agricultural crop production through decreasing herbicide doses and spray volumes. This may be possible by optimizing the efficacy of herbicides at reduced rate by adding an adjuvant (Devendra et al., 2004). Adjuvants improve the efficacy of post-emergence herbicides at reduced doses and give efficient weed control (Green and Foy, 2000; Johnson et al., 2002). Herbicide use can be reduced by 75% through the integration with adjuvants without compromising yield and net benefits for the cost-effective and eco-friendly management of weeds (Frihauf et al., 2005). Herbicides are now trending towards more active and concentrated formulations used at reduced doses. Adjuvant schemes fit well for an effective application of herbicides to minimize the margin of application losses (Basu et al., 2002).

In recent years, there has been a growing interest on the mixed application of herbicide. Benefits associated with mixed application are controlling diverse weed flora with a single application, reducing the number of passes over a field, timely application at critical stages, lower operating expenses, energy, resources, time saving and reduced soil compaction in using heavy machinery (Ramachandra et al., 2014). Pyroxsulam is a newly used broad spectrum herbicide belonging to the sulfonamide group, which controls broad leaf weeds as well as narrow leaf weeds in wheat by inhibiting the enzyme acetolactatesynthase (ALS) necessary for branched-chain amino acids (Singh et al., 2009). Tribenuron is an herbicide from the sulfonylurea group which causes the death of weeds by inhibiting ALS activity. Isoproturon belongs to the phenyl urea group of herbicides and causes damages in the PSII by blocking the electron transport chain between PSII and PSI (Dayan and Watson, 2011).

The hypothesis of this study was that herbicide application at recommended and reduced doses in combination with a proper adjuvant will demolish weed species and their density over time. From the farmer's point of view, it is more useful to determine the efficacy of herbicides with adjuvants. This study was designed to specify the compatibility of chemical adjuvants and vegetable oil to enhance post emergence herbicides activity against *P. minor* and *C. arvensis* in wheat.

MATERIALS AND METHODS

Site and soil description

This two-year study was conducted at the Agronomic Research Area of the University of Agriculture, Faisalabad (31.25^o N latitude, 73.09^o E longitude, and 184.4 m above the sea level), Pakistan during 2013-14 and 2014-15. The experimental soil belongs to the Layallpur soil series (Haplicyermosols in FAO and aridisol-fine-silty, mixed, HaplargidhypertermicUstalfic in the USDA classification scheme).

Experimental details

Wheat variety "Punjab 2011" was sown on November 12th, 2013 and November 15th, 2014 in 25 cm apart rows with a locally designed single row hand drill, using a seed rate of 125 kg ha^{-1}. Each plot was 6 m x 1.5 m. Fertilizers were applied at 120-85-60-N-P-K kg ha^{-1} using urea (46% N), diammonium phosphate (18% N, 46% P_2O_5) and sulphate of potash (50% K_2O) as source of NPK. Half of the N and whole of P_2O_5 and K_2O was broadcasted and incorporated in soil during sowing time and the remaining half of the N was applied before the first irrigation by broadcast method. Wheat was supplied with a total of four irrigations (each 3 acre inch) in addition to soaking irrigation (4 acre inch) throughout the growing season. The crop was planted in a field that had heavy weed infestations in previous years.

The experiment consisted in nine treatments viz. untreated control (weedy check), isoproturon + tribenuron (pre mixed formulation) at 1,025 g a.i. ha^{-1} (recommended dose), isoproturon + tribenuron at 769 g a.i. ha^{-1} (75% of recommended dose) plus alkylethersulphate sodium salt at 400 mL ha^{-1}, isoproturon + tribenuron at 769 g a.i. ha^{-1} plus fatty alcohol ethoxylate at 200 mL ha^{-1}, isoproturon + tribenuron at 769 g a.i. ha^{-1} plus sunflower oil at 1,000 mL ha^{-1}; pyroxsulam at 140.6 g a.i. ha^{-1} (recommended dose), pyroxsulam at 105.5 g a.i. ha^{-1} (75% of the recommended dose) plus alkylethersulphate sodium salt at 400 mL ha^{-1}, pyroxsulam at 105.5 g a.i. ha^{-1} plus fatty alcohol ethoxylate at 200 mL ha^{-1} and pyroxsulam at 105.5 g a.i. ha^{-1} plus sunflower oil at 1,000 mL ha^{-1}. Spray solutions were prepared by adding herbicides in a plastic bottle containing tap water. All herbicide treatments were applied with backpack knapsack sprayers equipped with Tee jet flat-fan 8002 nozzles calibrated to deliver 250 L ha^{-1} at a speed of 3.2 km h^{-1}.

The density of weeds 3 and 4 WAT (weeks after treatment) from a unit area of one square meter was recorded by counting all weeds from one randomly selected area in each experimental unit. At the crop harvesting stage, weeds were slashed at ground level from one square meter area at random from each plot and fresh weight was recorded. Dry weight was taken after drying weeds at 70 ^{o}C for 72 hours.

Spike bearing tillers were counted at maturity from a randomly selected area of one square meter. Ten spike samples were selected randomly from each plot, in order to determine the number of grains per spike. Finally, the whole plot was harvested to record 1,000 grain weight grain yield.

Nitrogen, P and K nutrient contents were estimated in wheat weeds at harvesting stage. Collected weed samples were air dried for 5 days and placed in an oven at 70 ^{o}C for 72 hours, and then grinded. Nitrogen, P and K were determined by the Wolf (1982) method. The generated values were later converted to per hectare values.

Statistical analysis

Data recorded with all their dependent variables were subjected to analysis of variance (ANOVA) by using the computer software Statistix 8.1 (Statistix, 2006) for each experiment, and significance was tested by variance ratio (i.e. F value) at 5% level. Individual comparisons of treatment means were made by using Tukey's HSD test at 5% level of probability (Steel et al., 1997). Preplanned orthogonal contrasts were used to compare herbicides with and without adjuvants.

RESULTS AND DISCUSSION

Effect of herbicides with or without adjuvants on weed density, dry weight and nutrient uptake by weeds in wheat

Two weed species accompanied the wheat crop in this research: little seed canary grass (*Phalaris minor*) and field bindweed (*Convolvulus arvensis*). Weed density 3 and 4 WAT (weeks after treatment) was significantly affected by herbicides with or with adjuvants (Table 1). The highest efficiency (>92%) in decreasing *P. minor* and *C. arvensis* density was obtained with the tank-mix application of isoproturon+tribenuron at 769 g a.i. ha^{-1} (reduced rate) plus alkylethersulphate sodium salt at 400 mL ha^{-1}, compared to other treatments during both years. It was followed by the treatment where the recommended dose of isoproturon+tribenuron was applied without any adjuvant.

The contrast analysis on *P. minor* density indicated that herbicides plus chemical adjuvants had a lower performance in controlling *P. minor* (20.37 m^{-2}) than herbicides plus sunflower oil during 2014-15. On the other hand, in 2013-14, *P. minor* control was similar with herbicides plus chemical adjuvants and herbicides plus sunflower oil. Herbicides plus alkylethersulphate sodium salt gave efficient *P. minor* control, resulting in a lower weed density (19.75, 17.37 m^{-2}) than with herbicides plus fatty alcohol ethoxylate (35.37, 23.37 m^{-2}) during both years. Contrasts analysis of herbicides with alkylethersulphate sodium salt to herbicides with sunflower oil were non-significant during 2014-15. Similarly, herbicides plus fatty alcohol ethoxylate resulted in a lower control of *P. minor* than herbicides with sunflower oil during both years. A similar trend was observed as for *P. minor* density at 4 WAT.

Herbicides plus chemical adjuvants had a lower performance in controlling *C. arvensis* (9.68, 7.18 m^{-2}) than herbicides with sunflower oil (6.75, 5.87 m^{-2}). Herbicides with alkylethersulphate sodium salt had a better performance in controlling *C. arvensis* (5.87 m^{2}) than herbicides with fatty alcohol ethoxylate (8.5 m^{-2}) during both years. Herbicides plus sunflower oil resulted in efficient control by giving lower weed density (6.75 m^{-2}) than alkylethersulphate sodium salt (10.25 m^{-2}) during 2013-14; however, during 2014-15, the contrast was non-significant. Likewise, herbicides with sunflower oil controlled *C. arvensis* more (6.75, 5.87 m^{-2}) than fatty alcohol ethoxylate (8.5, 9.125 m^{-2}) during both years.

Weed control treatment caused significant reduction in the total weed dry weight (Table 2). The tank mixture of isoproturon+tribenuron at 769 g a.i. ha^{-1} plus alkylethersulphate sodium salt at 400 mL ha^{-1} proved more effective in reducing *P. minor* and *C. arvensis* dry weight. It was followed by the labeled dose of isoproturon+tribenuron. On the other hand, sunflower oil as an adjuvant improved the efficacy of the isoproturon+tribenuronat reduced dose, and resulted in less dry weight; it was also statistically similar with the recommended dose of pyroxsulam during both years. The tank- mix application of fatty alcohol ethoxylate with pyroxsulam caused the least reduction in the dry weight of weeds during both years.

The contrast comparison of the recommended herbicide dose without adjuvants vs the reduced herbicide dose with 3 different adjuvants was non-significant during 2013-14, while during 2014-15 herbicides without adjuvants resulted in a lower dry weight (2.91) than herbicides with adjuvants. However, the comparison between herbicide with chemical adjuvant vs herbicide with sunflower

Table 1 **-** Effect of herbicides with or without adjuvant on weed density, 3 and 4 weeks after treatment (WAT)

Herbicide	Weeds density (m^{-2}) 3 WAT				Weeds density (m^{-2}) 4 WAT			
	P. minor		*C. arvensis*		*P. minor*		*C. arvensis*	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Untreated control (weedy check)	115.5 a	57.25 a	51.25 a	52.00 a	136.00 a	85.50 a	29.50 a	48.25 a
Isoproturon + tribenuron at 1,025 g a.i. ha^{-1} (recommended dose)	16.00 e (86.16)	8.75 f (84.71)	7.50 de (85.36)	3.50 de (93.26)	11.06 fg (91.91)	5.00 f (94.15)	8.00 ef (72.88)	2.00 ef (95.85)
Isoproturon + tribenuron at 769 g a.i. ha^{-1} + alkylether sulphate Na salt at 400 mL ha^{-1}	7.50 f (93.50)	4.00 g (93.01)	4.00 e (92.1)	1.25 e (97.59)	5.25 g (96.13)	2.00 g (97.66)	5.25 f (82.20)	0.00 f (100)
Isoproturon + tribenuron at 769 g a.i. ha^{-1} + fatty alcohol ethoxylate at 200 mL ha^{-1}	25.25 d (78.13)	12.25 e (77.60)	10.75 bd (79.02)	5.75 cd (88.94)	17.50 ef (87.13)	7.75 ef (90.93)	10.50 de (64.40)	3.50 e (92.7)
Isoproturon + tribenuron at 769 g a.i. ha^{-1} + sunflower oil at 1,000 mL ha^{-1}	20.50 de (82.25)	11.50 ef (79.91)	9.50 cd (81.46)	4.25 d (91.82)	10.00g (92.64)	9.00 e (89.47)	5.75 c (80.50)	4.25 e (91.19)
Pyroxsulam at 140.6 g a.i. ha^{-1} (recommended dose)	38.05 c (67.05)	25.75 d (55.02)	8.25 d (83.90)	7.75 c (85.09)	27.00 cd (80.14)	13.50 cd (84.21)	11.00 de (62.71)	7.50 cd (84.45)
Pyroxsulam at 105.5 g a.i. ha^{-1} + alkylethersulphate Na salt at 400 mL ha^{-1}	33.00 c (71.42)	30.75 c (46.28)	13.00 bc (74.63)	10.50 b (79.80)	31.50 c (76.83)	17.75 b (79.29)	13.50 cd (54.23)	10.00 c (79.27)
Pyroxsulam at 105.5 g a.i. ha^{-1} + fatty alcohol ethoxylate at 200 mL ha^{-1}	45.50 b (60.60)	34.50 b (39.73)	14.50 b (71.70)	11.25 b (78.36)	39.00 b (71.32)	16.00 bc (80.99)	22.50 b (23.72)	15.50 b (67.35)
Pyroxsulam at 105.5 g a.i. ha^{-1} + sunflower oil at 1,000 mL ha^{-1}	34.00 c (70.56)	24.50 d (57.2)	7.50 de (85.36)	7.50 c (85.57)	21.00 de (84.55)	12.50 d (85.38)	16.75 c (43.22)	7.00 d (85.49)
HSD	5.342	3.187	3.763	4.086	6.634	2.806	3.777	2.562
Contrasts								
Weedy Check vs All treatments	115.5 vs 26.05**	57.25 vs 17.5**	51.25 vs 9.4**	52 vs 6.02**	136 vs 18.3**	85.5 vs 10.175*	29.5 vs 13.47**	48.25 vs 5.85**
Herbicides without adjuvant vs herbicides with adjuvants	27.37 vs 27.45^{NS}	17.25 vs 19.58**	11.37 vs 8.70*	5.62 vs 6.75*	19 vs 20.7^{NS}	9.25 vs 10.875*	9.5 vs 14.04**	4.75 vs 6.75**
Herbicides with chemical adjuvant vs herbicides with sunflower oil	27.56 vs 27.25^{NS}	20.37 vs 18**	9.68 vs 6.75**	7.18 vs 5.875**	23.3 vs 15.5**	10.93 vs 10.75^{NS}	12.93 vs 16.25*	7.31 vs 5.62**
Herbicides with alkylethersulphate Na salt vs herbicides with fatty alcohol ethoxylate	19.75 vs 35.37**	17.37 vs 23.37**	10.25 vs 9.12**	5.87 vs 8.5**	18.4 vs 28.25**	9.87 vs 12*	9.37 vs 16.5**	5 vs 9.62**
Herbicides with alkylethersulphate Na salt vs herbicides with sunflower oil	19.75 vs 27.25**	17.37 vs 18^{NS}	10.25 vs 6.75**	5.87 vs 5.87^{NS}	18.3 vs 15.5^{NS}	9.87 vs 10.75^{NS}	9.37 vs 16.25**	5 vs 5.62^{NS}
Herbicides with fatty alcohol ethoxylate vs herbicides with sunflower oil	35.375 vs 27.25*	23.37 vs 18**	9.12 vs 6.75**	8.5 vs 5.87**	28.3 vs 15.5**	12 vs 10.75*	16.5 vs 16.25^{NS}	9.62 vs 5.62**

Columns sharing the same case letter, for a parameter, in a year did not differ significantly at $p = 0.05$; Data given in parenthesis show the decrease (%) with the application of that treatment with respect to untreated control.

oil was non-significant during 2014-15, while during 2013-14 herbicides with chemical adjuvants resulted in a lower dry weight (7.06 g) than herbicides with sunflower oil (7.84 g). Herbicides with alkylethersulphate sodium salt gave efficient weed control, resulting in a lower dry weight (5.09, 3.99) than herbicides with fatty alcohol ethoxylate (9.03, 5.40), during both years. The addition of alkylethersulphate sodium salt to herbicides caused more reduction in dry weight than with herbicides plus sunflower oil during both years. Similarly, herbicides with fatty alcohol ethoxylate caused less reduction in the dry weight of weeds (9.03, 5.40) than herbicides plus sunflower oil (7.84, 4.03) during both years.

The highest NPK-uptake was recorded in the untreated control during both years (Table 2). Maximum savings in N (95%), P (91-92%) and K (94-95%) were observed with reduced doses of isoproturon+tribenuron plus alkylethersulphate sodium salt. Contrast comparisons show that all herbicides treatments reduced the NPK-uptake by weeds compared to the weedy check.

Table 2 - Effect of herbicides with or without adjuvants on dry weight and nutrient uptake by weeds in wheat

Herbicide (g a.i. ha^{-1})	Weeds dry weight (g m^{-2})		N-uptake (kg ha^{-1})		P-uptake (kg ha^{-1})		K-uptake (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Untreated control (weedy check)	32.13 a	24.10 a	4.66 a	2.94 a	2.36 a	2.07 a	3.96 a	3.04 a
Isoproturon + tribenuron at 1025 (recommended dose)	6.58 e	2.36 e	1.05 e (77.35)	0.41 d (85.96)	0.39 e (83.55)	0.18 f (91.29)	0.98 d (75.16)	0.35 d (88.47)
Isoproturon + tribenuron at 769 + alkylethersulphate Na salt at 400 mL ha^{-1}	1.48 f	0.88 f	0.25 f (94.56)	0.15 e (94.63)	0.21 e (91.05)	0.16 f (92.40)	0.24 e (93.91)	0.14 e (95.34)
Isoproturon + tribenuron at 769 + fatty alcohol ethoxylate at 200 mL ha^{-1}	6.85 de	3.15 de	1.17 de (74.92)	0.53 cd (81.94)	0.87 d (62.97)	0.43 e (79.36)	1.20 cd (69.60)	0.51 cd (83.30)
Isoproturon + tribenuron at 769 + sunflower oil at 1,000 mL ha^{-1}	7.41 cde	3.88 cd	1.24 cde (73.43)	0.67 c (77.12)	1.07 cd (54.73)	0.58 cd (71.73)	1.18 cd (70.17)	0.56 c (81.41)
Pyroxsulam at 140.6 (recommended dose)	8.61 c	3.46 cd	1.51 c (67.51)	0.58 cd (80.15)	1.20 bc (49.05)	0.51 de (75.48)	1.20 cd (69.66)	0.52 c (82.94)
Pyroxsulam at 105.5 + alkylethersulphate Na salt at 400 mL ha^{-1}	8.70 c	7.11 b	1.49 c (68.07)	1.24 b (57.64)	1.11 c (53.06)	0.95 b (54.12)	1.22 cd (69.09)	0.96 b (68.48)
Pyroxsulam at 105.5 + fatty alcohol ethoxylate at 200 mL ha^{-1}	11.21 b	7.66 b	2.00 b (57.07)	1.33 b (54.76)	1.32 b (43,88)	0.93 b (55.09)	1.76 b (55.47)	1.00 b (67.10)
Pyroxsulam at 105.5+ sunflower oil at 1,000 mL ha^{-1}	8.28 cd	4.17 c	1.41 cd (69.74)	0.71 c (75.89)	1.22 bc (48.23)	0.64 c (69.07)	1.43 bc (63.78)	0.60 c (80.19)
HSD	1.53	0.959	0.289	0.242	0.207	0.127	0.365	0.160
Contrasts								
Weedy Check vs All treatments	32.13 vs 7.39**	24.10 vs 4.04**	4.66 vs 1.26**	2.94 vs 0.69**	2.36 vs 0.95**	2.07 vs 0.55**	3.96 vs 1.16**	3.04 vs 0.57**
Herbicides without adjuvant vs herbicides with adjuvants	7.60 vs 7.32^{NS}	2.91 vs 4.47**	1.28 vs 1.25^{NS}	4.98 vs 0.77**	0.79 vs 0.96**	0.34 vs 0.61**	1.09 vs 1.17^{NS}	0.43 vs 0.62**
Herbicides with chemical adjuvant vs herbicides with sunflower oil	7.06 vs 7.84*	4.70 vs 4.03^{NS}	1.22 vs 1.32**	0.81 vs 0.69**	0.88 vs 1.14**	0.61 vs 0.61^{NS}	1.10 vs 1.30**	0.65 vs 0.58**
Herbicides with alkylethersulphate Na salt vs herbicides with fatty alcohol ethoxylate	5.09 vs 9.03**	3.99 vs 5.40**	0.87 vs 1.58**	0.70 vs 0.93**	0.66 vs 1.10**	0.55 vs 0.67**	0.73 vs 1.48**	0.55 vs 0.75**
Herbicides with alkylethersulphate Na salt vs herbicides with sunflower oil	5.09 vs 7.84**	3.99 vs 4.03**	0.87 vs 1.32**	0.70 vs 0.69^{NS}	0.66 vs 1.14**	0.55 vs 0.61^{NS}	0.73 vs 1.30**	0.55 vs 0.58^{NS}
Herbicides with fatty alcohol ethoxylate vs herbicides with sunflower oil	9.03 vs 7.84**	5.40 vs 4.03*	1.58 vs 1.32**	0.93 vs 0.69**	1.10 vs 1.14^{NS}	0.67 vs 0.61^{NS}	1.48 vs 1.30^{NS}	0.75 vs 0.58**

Means sharing the same case letter, for a parameter, in a year did not differ significantly at p = 0.05; Data given in parenthesis show the nutrient saving (%) with the application of that treatment with respect to untreated control.

Herbicides with or without adjuvants significantly affected the weed density of little seed canary grass and field bindweed at 3 and 4 WAT, and better weed control was recorded with isoproturon+tribenuron plus alkylethersulfate sodium salt (Table 1). This could be attributed to a susceptibility to the herbicidal activity in the inhibition of the acetolactatesynthase (ALS) enzyme activity (which is necessary for branched-chain amino acids) and damage in PSII due to disrusption of electron transport chain between PSII and PSI (Dayan and Watson, 2011). Moreover, the addition of adjuvants to herbicides decreased the surface tension of the herbicide solution producing smaller droplets with a low level of energy, increased the activity by enhancing spreading, wetting, absorption, retention and penetration of herbicides through plant cuticles and ultimately increased weed mortality and reduced weed density (Bunting et al., 2004; Kaczmarek et al., 2009; Mohassel et al., 2010). The same conclusion was mentioned by Baghestani et al. (2008). They indicated that the *P. minor* population decreased by 43% when fenoxaprop-p-ethyl was applied alone, but when tank-mixed with adjuvants, it decreased the weed population up to 85% in wheat. Also, Brecke and Stephenson (2006) argued that the addition of non-ionic adjuvants resulted in the efficient control of *Melochiacorchorifolia* (redweed), *Sennaobrusifolia* (sicklepod) and *Desmodiumtortuosum* (florida beggar) weeds compared to trifloxysulfuron-sodium without adjuvants.

Adding adjuvants substantially enhanced herbicide efficacy by resulting in >95% *C. arvensis* control (Table 1), due to the synergistic effect of adjuvants on herbicide activity. These results are also in agreement with those by Aliverdi et al. (2009). They reported that the tank-mix application of tribenuron-methyl and adjuvants have a synergistic effect to control weeds in wheat. Comparatively, maximum *C. arvensis* control efficiency >90% was observed in herbicides with adjuvants. The addition of oil adjuvants or nonionic surfactants improves the effectiveness of herbicides and application characteristics by decreasing the surface tension, delaying the crystallization of herbicides, beading and bouncing off droplets and providing a better coverage of plant (Green and Foy, 2000; Johnson et al., 2002).

The lowest weed dry mass was noted with isoproturon+tribenuron at recommended and reduced doses plus adjuvants (Table 3). Our results are in line with those of Kieloch and Domaradzki (2008). They indicated that fluroxypyr+MCPA with an adjuvant (Atpolan-80 EC) significantly reduced the weeds dry weight, compared to the weedy check. All herbicides, alone and in combination with different adjuvants, resulted in a significantly lower NPK-uptake by weeds than the untreated control (Table 3), mainly because of lower dry matter accumulations by weeds, which enabled them to absorb fewer nutrients in these treatments. These results also showed similarity with those of Marzouk (2013) and Singh et al. (2014), who characterized clodinafop-propargyl activity against *Melilotusindica, Eragrostisciliagensis* and *Loliummultiforum* with less biomass and nutrient uptake flexibility. Tanveer et al. (2017) found that the maximum nutrient uptake was associated with the weedy check, compared to herbicide application in wheat field.

Yield and yield attributes of wheat

Herbicide applications along with different adjuvants positively affected the yield related parameters of wheat in both years (Table 3). Number of spike bearing tillers, grains per spike and 1,000 grain weight was substantially higher when a reduced dose of isoproturon+tribenuron was applied with alkylethersulphate sodium salt, and it was statistically at par with recommended dose of same herbicide during both seasons (Table 3). Similarly, the tank-mix application of sunflower oil as an adjuvant with a reduced dose of pyroxsulam increased its phytotoxicity against weeds, and resulted in a significantly higher number of spike bearing tillers, grains per spike and 1,000 grain weight during both years, and it was statistically similar to those of recommended doses of pyroxsulam alone.

Contrasts showed that all herbicide treatments produced higher numbers of spike bearing tillers, grains per spike and 1,000 grain weight than the weedy check. However, herbicides without adjuvants resulted in higher numbers of grains per spike and 1,000 grain weight than herbicides with adjuvants. Herbicides with alkylethersulphate Na salt resulted in higher numbers of spike bearing tillers, number of grains per spike and 1,000 grain weight, compared to herbicides with fatty alcohol ethoxylate and herbicides with sunflower oil. Herbicides with sunflower oil resulted in higher numbers of spike bearing tillers, grains per spike and 1000 grain weight than herbicides with fatty alcohol ethoxylate .

All the herbicides along with adjuvants showed superiority in enhancing the performance of the tested herbicides as for grain yield. The maximum grain yield (5291.0 and 5471.3 kg ha^{-1}) was recorded with the tank-mix application of reduced doses of isoproturon+tribenuron plusalkylethersulphate sodium salt and was statistically similar to its recommended dose of 1,025 g a.i. ha^{-1} during both years. The performance of reduced doses of pyroxsulam plus sunflower oil as an adjuvant equals the performance of recommended doses of pyroxsulam alone as for grain yield. The addition of fatty alcohol ethoxylate and sunflower oil to either of isoproturon+tribenuron or pyroxsulam had a lower performance in enhancing grain yield.

Contrasts showed that herbicides with adjuvants statistically resulted in a lower grain yield (4564.21 kg ha^{-1}) than that of herbicides without adjuvants (6725.75 kg ha^{-1}) during 2013-14, whereas during 2014-15, contrasts between herbicides with adjuvants vs without adjuvants

Table 3 **-** Effect of herbicide with or without adjuvants on yield and yield related traits of wheat

Herbicide (g a.i. ha^{-1})	Spike bearing tillers (m^{-2})		Grains per spike (No.)		1,000 grain weight (g)		Grain yield (kg ha^{-1})	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
Untreated control (weedy check)	283.50 f	288.00 f	34.55 f	36.07 f	32.38 g	33.55 g	3106.3 f	3439.5 f
Isoproturon + tribenuron at 1025 (recommended dose)	356.75 ab	363.50 ab	45.77 b	49.45 ab	45.92 b	46.88 ab	5025.0 ab (38.18)	5230.8 ab (40.61)
Isoproturon + tribenuron at 769 + alkylethersulphate Na salt at 400 mL ha^{-1}	367.25 a	377.00 a	48.70 a	51.65 a	49.17 a	50.98 a	5291.0 a (41.29)	5471.3 a (43.22)
Isoproturon + tribenuron at 769 + fatty alcohol ethoxylate at 200 mL ha^{-1}	350.25 bc	349.50 bc	43.12 c	46.87 bc	41.22 cd	45.92 bc	4785.0 bc (35.08)	5076.8 bc (38.81)
Isoproturon + tribenuron at 769 + sunflower oil at 1,000 mL ha^{-1}	343.50 cd	347.25 c	42.87 c	46.85 bc	41.65 c	42.11 de	4628.3 cd (32.88)	4979.5 cd (37.61)
Pyroxsulam at 140.6 (recommended dose)	332.25 d	338.25 cd	38.80 de	44.77 cd	37.67 ef	43.50 cd	4443.5 d (30.09)	4729.3 de (34.31)
Pyroxsulam at 105.5 + alkylethersulphate Na salt at 400 mL ha^{-1}	319.50 e	324.50 de	37.17 e	40.10 e	35.45 f	36.00 fg	4105.5 e (24.33)	4565.3 e (31.98)
Pyroxsulam at 105.5 + fatty alcohol ethoxylate at 200 mL ha^{-1}	316.50 e	321.50 e	37.95 e	38.75 e	35.62 f	36.92 f	4080.5 e (23.87)	4532.8 e (31.47)
Pyroxsulam at 105.5+ sunflower oil at 1,000 mL ha^{-1}	337.50 d	341.00 c	40.75 cd	43.75 d	38.68 de	40.15 e	4495.0 d (30.89)	4912.5 cd (36.76)
HSD	11.125	14.560	2.502	2.315	2.610	3.0286	268.06	250.34
Contrasts								
Weedy Check vs All treatments	283.5 vs 340.85**	288.0 vs 346.44**	34.55 vs 42.09**	36.075 vs 45.56**	32.38 vs 40.83**	33.55 vs 42.64**	3106.3 vs 4609.34**	3439.5 vs 4903.98**
Herbicides without adjuvant vs herbicides with adjuvants	344.5 vs 339.08NS	350.8 vs 344.3 NS	42.28 vs 41.76**	46.96 vs 44.66**	41.8 vs 40.37**	45.25 vs 42.03**	4725.75 vs 4564.21**	4980.05 vs 4853.4NS
Herbicides with chemical adjuvant vs herbicides with sunflower oil	338.35 vs 340.5*	343.6 vs 347.2 NS	41.73 vs 41.81 NS	44.343 vs 45.3**	40.37 vs 40.19NS	42.45 vs 41.15**	4565.5 vs 4561.65**	4911.5 vs 4737.25**
Herbicides with alkylethersulphate Na salt vs herbicides with fatty alcohol ethoxylate	343.3 vs 333.37*	351.75 vs 335.5**	42.93 vs 40.53**	45.87 vs 42.81**	42.35 vs 38.45**	43.5 vs 41.45*	4698.25 vs 4432.75**	5018.3 vs 4804.8**
Herbicides with alkylethersulphate Na salt vs herbicides with sunflower oil	343.3 vs 340.5 NS	351.75 vs 347.25*	42.93 vs 41.81 NS	45.875 vs 45.3 NS	42.35 vs 40.19**	43.4 vs 41.15**	4698.25 vs 4561.65NS	5018.3 vs 4737.25NS
Herbicides with fatty alcohol ethoxylate vs herbicides with sunflower oil	333.37 vs 340.5*	335.50 vs 347.25*	40.53 vs 41.81 NS	42.81 vs 45.3**	38.45 vs 40.19**	41.5 vs 41.15 NS	4432.75 vs 4561.65NS	4804.8 vs 4737.25NS

Means sharing the same case letter, for a parameter, in a year did not differ significantly at p = 0.05; Data given in parenthesis show the nutrient saving (%) with the application of that treatment with respect to untreated control.

were non-significant. However, herbicides with natural oil produced more wheat grain yield than herbicides with chemical adjuvants during both years. Similarly, herbicides with alkylethersulphate sodium salt resulted in a higher grain yield than herbicides with fatty alcohol ethoxylate during both years.

Contrasts of herbicides with alkylethersulphate sodium salt Vs herbicides with sunflower oil, herbicides with fatty alcohol ethoxylate Vs herbicides with sunflower oil were non-significant during both years. The economic analysis of data (not given) showed that isoproturon + tribenuron at 769 g a.i. ha^{-1} + alkyleethersulphate sodium salt at 400 mL ha^{-1} was the most economical treatment, which led to the maximum net benefits and benefit cost ratio (data not given). It was followed by recommended doses of isoproturon + tribenuron at 1,025 g a.i. ha^{-1}.

The application of herbicides with or without adjuvants significantly affected the yield and yield related parameters of wheat. Grain yield related attributes were maximum with isoproturon+tribenuron plus alkylethersulfate sodium salt (Table 3). Enhancements in these traits were attributed to significant increases in the weed control efficiency of herbicides with adjuvants, thus less weed competiton for the utilizition of required demands of nutrients and water, leading to increase in yield related traits of wheat. These investigations are in harmony with those of Javaid and Tanveer (2013). They concluded that bromoxynil + MCPA at 450 g a.i. ha^{-1} along with alkylethersulphate sodium salt markedly resulted in the maximum number of spike bearing tillers of wheat than other herbicides and the weedy check. Baghestani et al. (2008) and Tagour et al. (2011) reported that herbicide application, either alone or in combination with adjuvants, significantly increased yield related parameters of wheat compared to the weedy check.

Substantial increases in the final grain yield due to the application of isoproturon+tribenuron with alkylethersulfate sodium salt were inflicted by positively affected yield components like spike bearing tillers, number of grains per spike and 1,000 grain weight. A similar conclusion was mentioned by Tagour et al. (2011). They argued that the addition of Arkopal N100 at 4 and 8% to Traxos (Pinoxadin+Clodinafop+Safener) increased its efficiency against *Polypogonmons peliensis* and *P. minor*, and resulted in the highest grain yield.

The results of this study revealed that it is possible to reduce the dose of isoproturon + tribenuronto 769 g ha^{-1} with the inclusion of alkylethersulfate sodium salt at 400 mL ha^{-1} instead of what is recommended by the manufacturer (1,025 g ha^{-1}) to obtain sufficient *P. minor* and *C. arvensis* control efficiency in order to harvest the maximum potential crop yield. Considering the studied weed species, the addition of fatty alcohalethoxylate and alkylethersulphate sodium salt had the lowest and highest effect on herbicides against little seed canary grass and field bindweed, respectively. This can be related to the different wettability of the weed species, the difference in retention and/or uptake of herbicide (Hess and Foy, 2000), the difference in leaf surface morphology of the weeds, leaf angle and critical surface tension of the target surface (Penner, 2000; Sanyal et al., 2006), which influences the deposition and spread of spray droplets, resulting in the subsequent absorption of the herbicide active ingredients into the leaf tissue.

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