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Article

Adjuvants to Improve Phenmedipham + Desmedipham + Ethofumesate Efficacy Against Weeds in Sugar Beet (*Beta vulgaris*)

*Adjuvantes para Melhorar a Eficácia do Fenmedifame + Desmedifame + Etofumesato em Plantas Daninhas na Beterraba (**Beta vulgaris**)*

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ABSTRACT - The efficacy of reduced (411.5 and 617.2 a.i. ha^{-1}) and recommended (823.0 g a.i. ha^{-1}) rates of phenmedipham + desmedipham + ethofumesate on the control of *Amaranthus retroflexus*, *Amaranthus blitoides*, *Chenopodium album*, and *Tribulus terrestris* in sugar beet field was investigated when they were tank-mixed with and without Adigor (0.5% *v/v*), Ammonium sulphate (2% *v/v*), Citogate (0.2% *v/v*), D-Octil (0.3% *v/v*), Hydro-Max (0.5% *v/v*), and Volck (0.5% *v/v*). When the herbicide was applied alone, there was no significant difference between the rates of 617.2 and 823.0 g a.i. ha^{-1} for reduction of total weed density and biomass. Significantly, the adjuvants decreased total weed density and biomass. However, there was no significant difference among the performance of adjuvants. The sugar beet root and sucrose yields were increased significantly by increasing herbicide rate as a result of an improvement in weed control. Although herbicide efficacy was influenced in a similar manner by all the adjuvants, the best results were found as follows: root yield was increased up to 9.66% (71.31 Mg ha^{-1}) by applying the recommended rate of phenmedipham + desmedipham + ethofumesate plus Adigor compared to weed-free check (64.68 Mg ha^{-1}) whereas sucrose yield was increased up to 26.48% (13.21 t ha^{-1}) by applying the recommended rate of phenmedipham + desmedipham + ethofumesate plus HydroMax compared to weed-free check (10.45 t ha^{-1}). From an economic and ecological standpoint, these two adjuvants can be suggested to optimize the recommended rate of phenmedipham + desmedipham + ethofumesate in weed management.

Keywords: activator adjuvant, herbicide mixture, surfactant.

*RESUMO - Foi investigada a eficácia de doses reduzidas (411,5 e 617,2 g i.a. ha^{-1}) e recomendadas (823,0 g i.a. ha^{-1}) de fenmedifame + desmedifame + etofumesato no controle de **Amaranthus retroflexus, Amaranthus blitoides, Chenopodium album** e **Tribulus terrestris** na cultura da beterraba com a mistura em tanque dos herbicidas, com e sem Adigor (0,5% v/v), sulfato de amônio (2% v/v), Citogate (0,2% v/v), D-Octil (0,3% v/v), Hydro-Max (0,5% v/v) e Volck (0,5% v/v). Quando o herbicida foi aplicado isoladamente, não houve diferença significativa entre as taxas de 617,2 e 823,0 g i.a. ha^{-1} na redução da densidade total de plantas daninhas e biomassa. Os adjuvantes levaram à redução significativa da densidade total de plantas daninhas e da biomassa. No entanto, não houve diferença significativa de desempenho entre eles. Os rendimentos da beterraba e da sacarose tiveram incremento significativo após o aumento da dose do herbicida, em razão de uma melhoria no controle de plantas daninhas. Embora todos os adjuvantes tenham influenciado a eficácia do herbicida de maneira semelhante, os melhores resultados*

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foram os seguintes: o rendimento de raízes aumentou para 9,66% (71,31 Mg ha^{-1}) com a aplicação da dose recomendada de fenmedifame + desmedifame + etofumesato junto com Adigor, em comparação com a testemunha livre de plantas daninhas (64,68 Mg ha^{-1}), enquanto o rendimento de sacarose aumentou 26,48% (13,21 t ha^{-1}) aplicando-se a dose recomendada de fenmedifame + desmedifame + etofumesato mais HydroMax, em comparação com a testemunha (10,45 t ha^{-1}). Do ponto de vista econômico e ecológico, esses dois adjuvantes podem ser sugeridos para a otimização da taxa recomendada de fenmedifame + desmedifame + etofumesato no manejo de plantas daninhas.

Palavras-chave: adjuvante ativador, mistura de herbicidas, surfatante.

INTRODUCTION

It is an undisputed fact that food production tends to increase arithmetically while population growth tends to increase geometrically. Food production can be increased by intensive farming; however, it has high hidden costs (Anderson and Gugerty, 2010). In these agricultural systems, light, water, and fertilizer-use efficiency of a crop can be influenced when other plants are grown in the vicinity. Therefore, a critical item in intensive farming is timely and effectual weed removal (Blackshaw et al., 2007).

Sugar beet (*Beta vulgaris* L.) is a herbaceous biennial plant which belongs to the family Chenopodiaceae. It is commercially cultured to product sugar. During 2010-2015, annual cultivation area of sugar beet in Iran was approximately 100,000 ha yr^{-1} to take 600,000 Mg sugar yr^{-1}. This is an average yield of 51 Mg root ha^{-1}. (ISFS, 2016).

Weed control in sugar beet which has slow initial development is very challenging. As a result, sugar beet cannot compete with weeds successfully (Blackshaw et al., 2007). Based on 10% yield loss, the critical period of weed control in sugar beet start 5 days after planting (Salehi et al., 2006). However, the range of this period depends on different factors (Martínez et al., 2015). In such a situation, namely, a long critical period for weed competition, an integrated weed management is required in sugar beet fields. For this reason, 1 to 2 months after spraying post-herbicides in sugar beet, the field should be hand-weeded at least once as a prevalent agronomic practice. By this method, selection pressure on weeds for herbicide resistance can be reduced (Caseiey et al., 1991). Herbicide mixtures, which act at different sites of action and have a synergistic effect, are also useful to reduce selection pressure on weeds for resistance (Delye et al., 2013) and the respective costs (Izadi-Darbandi et al., 2013). Post-emergence herbicides, such as phenmedipham, desmedipham and ethofumesate, are separately recommended to control grass and broadleaf weeds in sugar beet. It was proven that there was a synergistic effect by tank-mixing these three herbicides (Dale et al. 2006; Jursík et al., 2011). As a result, they are mixed into one product (Betanal Progress OF) by the manufacturers.

Reducing the side-effects from herbicides and improving their efficacy can be achieved by using adjuvants (Rashed-Mohassel et al., 2010). An adjuvant is defined as a non-herbicide material which is added to a herbicide product by manufacturers or into tanks by users (Hazen, 2000) which can be divided into the utility and activator adjuvants. The former is used to make the spray application process easier by reducing any negative effects on application (e.g., safener, water conditioner, UV absorbent, compatibility agents, and etc.). The latter is used to enhance the efficacy of herbicide directly after it has been deposited on the target surfaces (Penner, 2000). Activator adjuvants can be divided into penetrant (e.g., oil), wetting (e.g., surfactant), sticker (e.g., latex and terpene), and acidifier (e.g., acid and fertilizer) agents (Izadi-Darbandi and Aliverdi, 2015). The efficacy of an activator adjuvant depends on its interaction with plant species and herbicides (Aliverdi et al., 2009).

The recommended rate is written on herbicide labels according to an optimum application condition but labels rarely contain information with advice on how to reduce rates under optimum conditions. However, reducing herbicide rate as compared to the recommended rate is possible, and one research priority is to reduce the side effects of herbicides (Pannacci and Covarelli, 2009).

Therefore, the objectives of this research were to determine the efficacy of phenmedipham + desmedipham + ethofumesate at recommended and reduced rates against weeds in sugar beet and to compare the efficacy of some activator adjuvants in this regard.

MATERIALS AND METHODS

The experiment was conducted at the Barakat Agro-Industrial Co., Joveyn, (36°423" N, 57°253" E, and 1100 m a.s.l.), Khorasan-Razavi, Iran on a fine-loamy soil (50% sand, 12% clay and 38% silt, 0.75% organic matter) with a pH 7.6 and EC 1.4 dS m^{-1} from February to December 2015. Mean annual temperature and precipitation on site were 18.7 °C and 253 mm, respectively. Seedbed preparation included mouldboard ploughing in February, followed by two passes with a field disk in April. A starter fertilizer of 50 kg ha^{-1} urea (46% N) and 100 kg ha^{-1} single superphosphate (16% P_2O_5) was broadcast and incorporated by a shallow disk. Then, the seedbed was harrowed. Sugar beet (*B. vulgaris* L. var. *Laetitia*) seeds were planted on April 11 in rows spaced 50 cm apart at a 3-4 cm depth. Each plot was 10 m long by 2.5 m wide. Row orientation was east-west. During growth season, 50 kg ha^{-1} urea was broadcast three times on the soil surface with a 30 day interval.

The experiment was set up as a factorial based on a randomized complete block design, using two factors (herbicide rate and adjuvant) with three replications. Herbicide rates were 411.5, 617.2 and 823.0 g a.i. ha^{-1} of Betanal Progress OF (27.43% EC, 9% phenmedipham, 7% desmedipham, plus 11% ethofumesat; Bayer, Germany). These rates were 50, 75 and 100% of the recommended rate. The adjuvant factor consisted of herbicide applications with and without six adjuvants. Table 1 shows the names and rates of the adjuvants. Moreover, a weedy check and full season weed-free check plots were included for comparison. When the crop was at the 3-4 true-leaf stage (in May 11), the treatments were applied by a calibrated lance sprayer fitted with an 11002 flat fan standard nozzle delivering 210 L ha^{-1} at a pressure of 200 kPa.

Table 1 - Active and inert ingredients of adjuvants

Adjuvant	Compound	Rate (% *v/v*)	Cost (Dollars ha^{-1})	Manufacturer
Adigor	48.8% methylated rapeseed oil + 28.2% ethoxylated alcohols	0.5	9.6	Syngenta, Switzerland
Ammonium sulphate	($(NH4)_2SO_4$): 21% ammonium cation + 24% sulphate anion	2	27.6	Merck, Germany
Citogate	100% alkyl aryl polyglycol ether (a non-ionic surfactant)	0.2	2.6	Zarnegaran Pars, Iran
D-Octil	70% sodium dioctylsulfosuccinate (an anionic surfactant) + 0.05% Mo + 0.1% Cu	0.3	16.1	AMC, Spain
Hydro-Max	90% *Yucca schidigera* extract + 2% humic acid + 5% non-ionic surfactant	0.5	9.3	Harrell's, USA
Volck	80% petroleum oil + 18% water + 2% emulsifier	0.5	1.9	Afrashimikumesh, Iran

With the exception of ammonium sulfate (Starke et al., 1996), the adjuvants were applied based on the recommended rates on their labels.

Samplings were performed 3 and 5 weeks after treatment (WAT). In each sampling, the density of each weed (*Amaranthus retroflexus*, *Amaranthus blitoides*, *Chenopodium album* and *Tribulus terrestris*) was separately measured within a quadrate of 0.25 m^2. Then, the weeds were harvested at the stem base close to the soil surface and oven-dried at 70 °C for 48 h and weighed. The data were multiplied by four to analyse the data based on one square meter. Then, the experiment site was completely hand-weeded at 9 WAT. The sugar beet roots within 2 m^2 area of plot were manually harvested on December 6 and weighed to determine root yield. The samples of 20 roots per plot were sent to the Joveyn Sugar Company Laboratory to determine sucrose yield. To find the percentage of reduced density and biomass of weeds, the data were compared to the amount found in the weedy check. To find the percentage of reduction in sugar beet root and sucrose yield, the data were compared to the amount found in the weed-free check. Normality of data ranged between 0.88-0.96, based on the Shapiro-Wilk statistical test. All data were subjected to *ANOVA*, using *PROC GLM* in *SAS*, version 9.1. When the treatment effect was significant, the means were compared using Fisher's least significant difference (LSD) test at a 0.05 significance threshold.

RESULTS AND DISCUSSION

There was a significant difference among the herbicide rates for reduction of weed density and biomass at 3 and 5 WAT (Tables 2 and 3) except for biomass of *C. album* and density of *T. terrestris* at 3 WAT (Table 2). The application of 411.5 and 823.0 g a.i. ha^{-1} had the lowest and the highest herbicidal effect on density and biomass of the weeds, respectively. Except for biomass of *A. blitoides* and *T. terrestris* at 5 WAT (Table 3), there was no significant difference between 617.2 and 823.0 g a.i. ha^{-1} in reduction of density and biomass of weeds at 3 and 5 WAT (Tables 2 and 3). By applying the recommended rate of phenmedipham + desmedipham + ethofumesate, total weed density was controlled by 72.13% and 74.46% and total weed biomass was controlled by 60.89% and 79.83% at 3 and 5 WAT, respectively (Tables 2 and 3). However, the level of weed control was significantly lower with the reduced rates than the recommended rate in both samplings. Nonetheless, there was a significant reduction in total weed density and biomass as a response to increasing herbicide rate from 411.5 to 617.2 g a.i. ha^{-1}, whereas there was no further decrease of total weed density and biomass above 617.2 g a.i. ha^{-1} (namely 823.0 g a.i. ha^{-1}). Weed control level was variable in various species and ranged from 52.77% in *A. retroflexus* to 87.95% in *T. terrestris* at 5 WAT.

With hand-weeding throughout the growing season, yields were 64.68 Mg root ha^{-1} and 10.45 Mg sucrose ha^{-1}. These amounts were reduced to 21.05 Mg root ha^{-1} and 2.89 Mg sucrose ha^{-1} as a result of weed competition. In other words, 67.47% of root yield and 72.32% of sucrose yield were lost because of weed competition (Table 4). Density and sucrose of sugar beet were not affected by the treatments (data not shown). In the case of root and sucrose yields, differences among herbicide rates were significant ($p\leq0.01$) (Table 4). Generally, root and sucrose yields increased when increasing the phenmedipham + desmedipham + ethofumesate rates. Nonetheless, the application of 411.5, 617.2 and 823.0 g a.i. ha^{-1} resulted in 75.92, 49.10 and 13.59 % reduction in root yield and 68.54, 35.57 and 3.70% reduction in sucrose yield, compared to the amount obtained in the weed-free check. There were no significant interactions between herbicide rate and adjuvant for root and sucrose yields (Table 4).

When the tested adjuvants were added to the spray solution (Tables 2 and 3), biomass of *A. retroflexus* and density of *A. blitoides*, *C. album* and *T. terrestris* decreased at 3 WAT; whereas biomass of *A. retroflexus* and *C. album* and density of all weeds decreased at 5 WAT.

Adding adjuvants to the spray solution had a significant effect on reduction of total weed density and biomass. There was a remarkable increase in the efficacy of reduced and recommended herbicide rates, particularly the rate of 411.5 g a.i. ha^{-1}, when the adjuvants were added to the spray solutions at both sampling times. However, there was no significant difference among the adjuvants to improve herbicide efficacy (Tables 2 and 3). Nonetheless, there was a high level of control of total weed biomass (97.21 and 96.37% at 3 and 5 WAT, respectively) when the highest herbicide rate (823.0 g a.i. ha^{-1}) was applied with the Adigor adjuvant, but it was not statistically significant with other adjuvants.

As judged by ANOVA (Table 4), the adjuvant factor had a significant effect ($p\leq0.01$) on sugar beet sucrose and root yields. There was a significant increase in root and sucrose yields when some adjuvants were applied. The resulting sugar beet root and sucrose yields by applying 823.0 g a.i. ha^{-1} plus some adjuvants were higher than in the weed-free check (negative data). However, there were no significant differences among the performance of adjuvants ($p\leq0.05$). Overall, the highest root yield (71.31 Mg ha^{-1}) was found by applying the recommended rate plus Adigor. The highest sucrose yield (13.21 Mg ha^{-1}) was found by applying the recommended rate plus HydroMax. However, these amounts were not significant when applying the same rate plus other adjuvants (Table 4).

The recommended rate of phenmedipham + desmedipham + ethofumesate did not effectively control the broad-leaved species on the experimental site. By applying the recommended rate of this herbicide, total weed density was reduced by 72.17% and 74.46% as compared to the weed-free check at 3 and 5 WAT, respectively. Low herbicide efficacy may be due to high weed density

Table 2 - Percentage (%) of reduction in density and biomass of weeds as compared to the amount obtained in the weedy check at 3 WAT of phenmedipham + desmedipham + ethofumesate at three rates with and without adjuvants

Treatment		*A. retroflexus* (2)		*A. blitoides*		*C. album*		*T. terrestris*		Total + other (3)	
Herbicide rate (g a.i. ha^{-1})	Adjuvant (1)	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
0 (Weedy check)		100.67 no. m^{-2}	237.67 g m^{-2}	25.67 no. m^{-2}	32.64 g m^{-2}	9.33 no. m^{-2}	3.89 g m^{-2}	13.67 no. m^{-2}	13.24 g m^{-2}	154.33 no. m^{-2}	189.84 g m^{-2}
		(%)									
411.5	-	57.61	34.70	14.29	35.05	35.69	40.44	17.09	29.38	-1.43 (4)	8.27
	Adigor	68.87	76.84	63.64	72.74	82.13	45.93	21.97	53.17	54.35	70.04
	$(NH4)_2SO_4$	73.51	63.18	19.49	43.97	100.0	100.0	56.10	29.65	62.17	57.95
	Citogate	72.18	66.65	51.95	52.94	89.28	64.44	78.05	44.84	68.04	63.68
	D-Octil	67.55	34.05	50.65	62.35	74.99	32.90	53.66	52.57	62.61	71.26
	HydroMax	82.78	66.54	22.08	50.11	89.28	66.66	60.98	48.76	65.86	62.05
	Volck	82.78	88.71	33.77	52.11	85.70	76.17	56.10	69.91	66.52	82.26
617.2	-	76.16	72.84	72.73	60.75	67.84	30.16	60.98	86.00	71.52	40.01
	Adigor	92.05	87.82	54.55	67.85	92.85	94.43	85.37	87.41	83.26	83.93
	$(NH4)_2SO_4$	86.75	94.05	75.32	91.61	78.56	84.32	31.72	52.16	75.65	90.05
	Citogate	89.40	97.12	75.33	76.83	100.0	100.0	70.73	50.20	83.47	88.40
	D-Octil	86.75	82.48	44.16	53.00	78.56	80.72	60.98	68.80	77.82	75.78
	HydroMax	73.51	79.69	51.95	62.56	85.71	63.84	39.04	60.32	64.78	75.81
	Volck	81.45	85.01	68.83	83.11	74.99	88.00	53.67	68.30	74.56	82.03
823.0	-	81.45	79.71	64.93	65.59	85.70	87.57	85.37	87.95	72.17	60.89
	Adigor	97.35	99.16	87.01	93.69	96.42	91.60	87.80	91.92	89.13	97.21
	$(NH4)_2SO_4$	97.35	97.00	66.24	82.82	100.0	100.0	85.36	75.85	85.21	80.63
	Citogate	95.69	95.72	77.92	86.75	85.71	70.01	75.61	92.04	86.08	80.49
	D-Octil	97.35	93.72	88.31	88.33	100.0	100.0	82.93	91.19	85.65	74.43
	HydroMax	94.37	97.49	93.50	89.99	96.42	86.97	92.68	63.92	81.52	88.46
	Volck	99.00	99.18	84.41	88.87	92.85	83.12	80.49	83.51	91.52	93.56
$LSD_{0.05}$ herbicide rate (H)		8.51	10.24	15.00	14.07	11.56	24.58	23.10	15.11	6.73	11.96
$LSD_{0.05}$ adjuvant (A)		13.00	15.64	22.91	21.49	17.67	37.54	35.29	23.08	10.28	18.28
$LSD_{0.05}$ H × A		22.53	27.10	39.68	37.22	30.60	65.03	61.13	39.97	17.82	31.66
ANOVA	d.f.	Mean square									
Block	2	1781.3**	200.9 ns	1306.6 ns	180.8 ns	319.1 ns	937.0 ns	1246.8 ns	1013.9 ns	1265.5**	387.4 ns
Herbicide rate (H)	3	2650.8**	6129.9**	1225.2**	5534.4**	1188.6*	4028.5 ns	387.4 ns	6414.0**	5387.3**	3554.5**
Adjuvant (A)	6	141.5 ns	898.8*	1137.1*	426.1 ns	968.8*	1463.7 ns	708.9*	919.6 ns	1172.2**	1639.2**
H × A	12	172.6 ns	550.2*	804.8 ns	415.9 ns	401.6 ns	1085.5 ns	1188.0 ns	478.8 ns	579.4**	329.1 ns
Error	40	186.4	269.7	578.3	508.8	343.9	1553.1	172.6	586.9	116.6	368.1
CV (%)	-	16.3	20.3	40.0	32.4	21.7	52.1	51.2	36.6	15.1	25.9

(1) Adjuvant rates were mentioned in Table 1; (2) Means followed by the same letter within a column are not significantly different according to the least significant difference (LSD) test; (3) Other weeds were found on the experimental site; (4) Negative data suggest an increase as compared to the amount obtained in the weed-free check.

which occurred on site. Previous studies also reported that when weed densities were higher than 100 plants m^{-2}, they were not sufficiently controlled by the recommended rate of bromoxynil and oxyfluorfen in onions (Schumacher and Hatterman-Valenti, 2007) and of mesotrione in maize (Pannacci and Covarelli, 2009). The reduced rates of phenmedipham + desmedipham + ethofumesate provided a low level of control as compared to the recommended herbicide rate. Therefore, the reduced rates can cause high economic risk. These results justify that the efficacy of phenmedipham + desmedipham + ethofumesate should be optimized with adjuvants.

The adjuvants were significantly effective at improving the efficacy of phenmedipham + desmedipham + ethofumesate on weed control. Therefore, maximum yields were achieved when the recommended rate was applied with the adjuvants. This indicates that the physical injury to the sugar beet which occurred by the weed-free check as a result of severe weed infestation was higher than the physiological injury which occurred by applying the herbicide.

Enhancement of herbicidal activity by adjuvants may be due to increased adsorption of the active ingredient into the tissues. The applied adjuvants are known as activator adjuvants, which are used to enhance the efficacy of a herbicide once it has been deposited on the target

Table 3 - Percentage (%) of reduction in density and biomass of weeds as compared to the amount obtained in the weedy check at 5 WAT of phenmedipham + desmedipham + ethofumesate at three rates with and without adjuvants

Treatment		*A. retroflexus* (2)		*A. blitoides*		*C. album*		*T. terrestris*		Total + other (3)	
Herbicide rate (g a.i. ha^{-1})	Adjuvant (1)	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass
0 (Weedy check)		24.00 no. m^{-2}	229.74 g m^{-2}	39.00 no. m^{-2}	116.05 g m^{-2}	9.67 no. m^{-2}	78.50 g m^{-2}	20.67 no. m^{-2}	58.02 g m^{-2}	94.00 no. m^{-2}	482.55 g m^{-2}
		(%)									
411.5	-	22.22	52.28	6.83	14.03	27.53	-5.21 ††††	38.69	20.14	17.02	25.42
	Adigor	51.39	61.57	54.70	25.36	65.49	57.13	69.34	54.03	57.80	51.08
	$(NH4)_2SO_4$	70.83	68.78	54.70	32.37	72.39	44.20	61.28	73.10	57.09	55.01
	Citogate	62.50	63.39	53.84	47.84	68.94	45.29	61.28	63.14	59.22	56.68
	D-Octil	40.27	66.41	56.41	54.03	79.29	56.79	61.28	71.26	54.25	62.07
	HydroMax	79.16	85.22	50.42	40.16	72.39	46.13	61.28	70.88	61.34	64.43
	Volck	40.28	69.14	39.31	43.74	82.74	79.92	54.82	76.99	46.10	64.96
617.2	-	43.05	81.38	73.50	37.12	55.14	73.26	79.02	48.96	62.76	65.00
	Adigor	86.11	77.60	76.92	70.21	100.0	100.0	85.48	88.06	82.98	80.30
	$(NH4)_2SO_4$	72.22	84.57	63.25	68.61	79.29	88.42	87.09	95.38	71.27	81.44
	Citogate	77.78	94.66	65.81	53.88	79.29	68.79	88.70	92.44	73.40	78.45
	D-Octil	86.11	90.05	82.05	72.55	86.19	94.49	80.64	87.49	81.91	82.57
	HydroMax	73.61	96.68	92.31	70.04	79.30	82.89	72.57	86.35	78.01	85.33
	Volck	84.72	84.05	75.21	58.41	75.84	83.88	74.18	81.61	77.66	74.56
823.0	-	52.77	76.64	82.91	72.98	68.94	78.61	88.70	86.41	74.46	79.83
	Adigor	91.66	92.93	91.45	95.78	79.29	92.62	95.16	98.58	83.33	96.37
	$(NH4)_2SO_4$	86.11	98.23	88.89	97.82	89.64	99.15	90.32	97.30	75.88	93.54
	Citogate	87.50	94.06	89.74	95.49	86.19	92.42	93.54	98.41	84.75	91.03
	D-Octil	87.50	94.34	90.59	92.99	100.0	98.25	98.38	97.38	87.23	92.28
	HydroMax	80.55	96.04	94.87	95.30	96.55	97.70	91.93	97.33	77.65	91.99
	Volck	88.89	92.00	94.87	94.97	96.55	96.38	98.38	98.04	86.52	90.92
$LSD_{0.05}$ herbicide rate (H)		10.16	9.70	7.96	13.30	10.73	13.85	6.04	5.86	4.88	6.54
$LSD_{0.05}$ adjuvant (A)		15.52	14.82	12.17	20.31	16.40	21.15	9.22	8.96	7.46	9.99
$LSD_{0.05}$ H × A		26.89	25.68	21.07	35.19	28.41	36.64	15.98	15.52	12.92	17.31
ANOVA	d.f.	Mean square									
Block	2	884.7*	196.5 ns	486.5 ns	1891.7 *	216.0 ns	83.7 ns	309.3*	24.5 ns	33.7 ns	13.7 ns
Herbicide rate (H)	3	5047.7**	3782.9**	11194.5**	16172.3*	2379.7**	13218.0*	6793.7**	6493.3**	5680.9**	7168.0**
Adjuvant (A)	6	1679.3**	429.9 ns	580.3**	938.9 ns	1432.8**	1496.4*	212.4 ns	1457.6**	595.0**	584.4**
H × A	12	364.5 ns	84.0 ns	357.3*	173.8 ns	240.3 ns	515.0 ns	113.1 ns	246.2**	178.7**	93.7 ns
Error	40	265.6	242.1	163.1	454.7	296.4	493.0	93.8	88.4	61.3	110.0
CV (%)	-	23.3	18.9	18.1	33.5	22.0	29.6	12.4	11.7	11.3	14.1

(1) Adjuvant rates was mentioned in Table 1; (2) Means followed by the same letter within a column are not significantly different according to the least significant difference (LSD) test; (3) Other weeds were found on the experimental site; (4) Negative data suggest an increase as compared to the amount obtained in the weed-free check.

surfaces (Izadi-Darbandi and Aliverdi, 2015). A reduction in surface tension of the spray solution after wetting agents are added (e.g., Citogate and D-Octil surfactants in the experiment) may not only enhance the adhesion of droplets to the leaf surface but also improve the contact area of droplets on the leaf surface (Aliverdi et al., 2009). A disruption in cuticular waxes of the leaf surface after the addition of penetrant agents (e.g., Adigor, HydroMax and Volck oils in experiment) can facilitate the penetration of the active ingredient into the tissues, particularly when the water solubility of active ingredients is low, such as for phenmedipham + desmedipham + ethofumesate (Somervaille et al., 2012). The aforementioned active ingredients have a logarithm of octanol-water partition coefficient (log K_{ow}) equal to 3.55, 2.27 and 2.70 at room temperature, respectively (Roberts et al., 1998). Acidification of the spray solution by adding acidifier agents (e.g., ammonium sulphate in the experiment) can maintain a greater proportion of weak-acid herbicides in their non-dissociated form via conjugating the NH_4+ ion with the herbicide to form an herbicide-NH_4 molecule which can permeate through the plasma membrane more easily and rapidly (Aliverdi et al., 2014). Previous studies have also reported that the efficacy of phenmedipham + desmedipham was improved by adding ammonium nitrate to the spray solution via the aforementioned process (Starke et al., 1996).

Table 4 - Percentage (%) of reduction in root and sucrose yields (Mg ha^{-1}) of sugar beet as compared to the amount obtained in the weed-free check after spraying phenmedipham + desmedipham + ethofumesate at three rates with and without adjuvants

Treatment			Root yield [2]	Sucrose yield
Herbicide rate g a.i. ha^{-1}		Adjuvant [1]	(Mg ha^{-1})	
0 (Weed-free check)		-	64.68	10.45
0 (Weedy check)		-	21.05	2.89
			(%)	
411.5		-	75.92	68.54
		Adigor	40.59	27.78
		$(NH4)_2SO_4$	37.64	26.17
		Citogate	35.58	22.08
		D-Octil	44.27	33.19
		HydroMax	35.53	22.96
		Volck	38.52	26.74
617.2		-	49.10	35.57
		Adigor	12.12	3.85
		$(NH4)_2SO_4$	25.20	10.93
		Citogate	15.64	3.97
		D-Octil	14.49	1.08
		HydroMax	13.98	1.03
		Volck	11.54	3.85
823.0		-	13.59	3.70
		Adigor	-9.66 [3]	-10.99
		$(NH4)_2SO_4$	-4.07	-18.03
		Citogate	-3.53	-15.02
		D-Octil	-8.80	-21.69
		HydroMax	-3.86	-26.48
		Volck	-3.07	-15.57
$LSD_{0.05}$ herbicide rate (H)			7.76	7.21
$LSD_{0.05}$ adjuvant (A)			11.86	11.01
$LSD_{0.05}$ H × A			20.54	19.0
ANOVA	d.f.		Mean square	
Block	2		569.5* [4]	1458.8**
Herbicide rate (H)	2		12059.2**	11942.9**
Adjuvant (A)	6		1212.7**	1488.4**
H × A	12		84.5 ns	136.5 ns
Error	40		155.0	133.7
CV (%)	-		37.4	32.4

[1] Adjuvant rates was mentioned in Table 1; [2] Means followed by the same letter within a column are not significantly different according to the least significant difference (LSD) test; [3] Negative data suggest an increase as compared to the amount obtained in the weed-free check; [4] ns: not significant; * $p \leq 0.05$, ** $p \leq 0.01$.

The results revealed that the activity of the tested herbicide was influenced in a similar manner by all adjuvants. Under these conditions, a farmer can select a proper adjuvant based on economical and/or ecological standpoints. Ammonium sulphate has the highest cost (Table 1) and is a chemically synthesized fertilizer. Although Volck has the lowest cost, it is a non-environmentally friendly mineral oil-based adjuvant. Citogate and D-Octil have a medium cost but they are chemically synthesized surfactants. Adigor and Hydro-Max, which are environmentally friendly vegetable oil-based adjuvants, also have a medium cost.

It can be concluded that the reduced rates of phenmedipham + desmedipham + ethofumesate resulted in a potential economic risk, unfortunately. On the other hand, the recommended rate efficacy should be optimized with adjuvants or integrated with other weed management practices. From an economic and ecological standpoint, it can be recommended that farmers should add

Adigor and Hydro-Max adjuvants to the recommended rate of phenmedipham + desmedipham + ethofumesate to optimize its efficacy against weeds in sugar beet. Weed flora was mainly composed of broad-leaved species on the experimental site. In addition, grass and broad-leaved species respond very differently to herbicides and adjuvants, hence more systematic research is required to repeat this experiment on a site which is infested by grass species.

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REFERENCES

Aliverdi A, Ganbari A, Rashed-Mohassel MH, Nassiri-Mahallati M, Zand E. Overcoming the antagonistic effect from spray carrier minerals on imazethapyr activity. Agron J. 2014;106(5):1569-73.

Aliverdi A, Rashed-Mohassel MH, Zand E, Nassiri-Mahallati M. Increased foliar activity of clodinafop propargyl and/or tribenuron-methyl by surfactants and their synergistic action on wild oat (*Avena ludoviciana*) and wild mustard (*Sinapis arvensis*). Weed Biol Manage 2009;9:292-9.

Anderson L, Gugerty MK. Environmental impacts of agricultural technologies. ESPAR Brief. 2010;65:1-18.

Blackshaw RE, Anderson RL, Lemerle D. Cultural weed management. In: Upadhyaya MK, Blackshaw RE, editors. Non-chemical weed management, principles, concepts and technology. Wallingford: 2007.p.35-47.

Caseiey JC, Cussans GW, Atkin RK. Herbicide resistance in weeds and crops. London: Intechopen; 1991.

Dale TM, Renner KA, Kravchenko AN. Effect of herbicides on weed control and sugar beet (*Beta vulgaris*) yield and quality. Weed Technol. 2006;20(1):150-6.

Delye C, Jasieniuk M, Corre VL. Deciphering the evolution of herbicide resistance in weeds. Trends Genet. 2013;29(11):649-58.

Hazen JL. Adjuvants: terminology, classification, and chemistry. Weed Technol. 2000;14(4):773-84.

Iranian Sugar Factories Syndicate - ISFS. Production data of sugar beet in Iran. 2016. http://www.isfs.ir/amartakhassosi1.htm

Izadi-Darbandi E, Aliverdi A, Hammami H. Behavior of vegetable oils in relation to their influence on herbicides' effectiveness. Ind Crops Prod. 2013;44:712-7.

Izadi-Darbandi E, Aliverdi A. Optimizing sulfosulfuron and sulfosulfuron plus metsulfuron-methyl activity when tank-mixed with vegetable oil to control wild barley (*Hordeum spontaneum* Koch.). J Agric Sci Technol. 2015;17:1769-80.

Jursík M, Soukup J, Venclová V, Holec J. Post herbicide combinations for velvetleaf (*Abutilon theophrasti*) control in sugar beet. Weed Technol. 2011;25:14-8.

Martínez JM, Valero JAJ, Padilla AD, Buendía MRP. Competition and critical periods in spring sugar beet cultivation. J Plant Prot Res. 2015;55:336-42.

Pannacci E, Covarelli G. Efficacy of mesotrione used at reduced doses for post-emergence weed control in maize (*Zea mays* L.). Crop Prot. 2009;28:57-61.

Penner D. Activator adjuvants. Weed Technol. 2000;14:785-91.

Rashed-Mohassel MH, Aliverdi A, Hamami H, Zand E. Optimizing the performance of diclofop-methyl, cycloxydim, and clodinafop-propargyl on littleseed canarygrass (*Phalaris minor*) and wild oat (*Avena ludoviciana*) control with adjuvants. Weed Biol Manage. 2010;10:57-63.

Roberts TR, Hutson DH, Lee PW, Nicholls PH, Plimmer JR. Metabolic pathways of agrochemicals. Part 1: Herbicides and plant growth regulators. Cambridge: The Royal Society of Chemistry: 1998.

Salehi F, Esfandiari H, Rahimian-Mashhadi H. Critical period of weed control in sugar beet in Shahrekord region. Iranian J Weed Sci. 2006;2:1-12.

Schumacher CE, Hatterman-Valenti HM. Effect of dose and spray volume on early-season broadleaved weed control in *Allium* using herbicides. Crop Prot. 2007;26(8):1178-85.

Somervaille A, Betts G, Gordon B, Green V, Burgis M, Henderson R. Adjuvants: oils, surfactants and other additives for farm chemicals. Kingston: Grains Research and Development Corporation; 2012.

Starke RJ, Renner KA, Penner D, Roggenbuck FC. Influence of adjuvants and desmedipham plus phenmedipham on velvetleaf (*Abutilon theophrasti*) and sugarbeet response to triflusulfuron. Weed Sci. 1996;44(3):489-95.