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Weed control in maize (*Zea mays* L.) with effective minimum rates of foramsulfuron*

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Abstract: Dose-response experiments were conducted under controlled conditions to determine the effective minimum rates (ED_{90}) of foramsulfuron for 11 weed species that occur in maize growing areas in Turkey. Annual weeds were collected from maize fields in the cotyledon stage and transferred to pots containing a mixture of soil-turf (1:1 ratio). Perennial weeds were grown from rhizome pieces collected from infested fields. Weeds were then treated with different rates of foramsulfuron to determine the effective minimum rate (ED_{90}) for each weed species via dose-response experiments. Results showed that ED_{90} rates were lower than the recommended herbicide rate for most weed species. Weeds were grouped with respect to their sensitivities into 5 different groups: $ED_{90} < 25\%$, ED_{90} between 25% and 50%, ED_{90} between 50% and 75%, ED_{90} between 75% and 100%, and $ED_{90} > 100\%$ of the recommended herbicide rate. In additional field experiments the performance of these rates applied alone or in combination with ammonium-sulphate on weed and maize grain yield was evaluated, and ED_{90} rates were determined for some weed species. The results show that 25% of the herbicide rate alone insufficiently controlled weeds; however, the addition of AS improved the effect of this rate. In general, the 50% rate was as efficient as the recommended rate and provided similar maize yield as obtained from plots treated with higher rates or from weed-free control plots. As compared to the ED_{90} rates determined under controlled conditions, effective minimum rates observed under field conditions were similar for some weed species, but higher for some others. In the case of total weeds the ED_{90} rate of the herbicide corresponded to 54% of the recommended herbicide rate. Results of these experiments suggest that weed control in maize can be effectively achieved with about half the recommended rate of foramsulfuron, without a loss in yield.

Key words: Weed, maize, foramsulfuron, ED_{90}, dose-response, ammonium-sulfate

Mısır (*Zea mays* L.)'da Foramsulfuron'un etkili minimum dozlarıyla yabancı ot mücadelesi

Özet: Foramsulfuron'un Türkiye'de mısır ekim alanlarında rastlanan 11 yabancı ot türüne karşı etkili minimum dozlarının (ED_{90}) belirlenmesi amacıyla kontrollü koşullar altında doz-etki çalışmaları yürütülmüştür. Bu amaçla tek yıllık yabancı otlar mısır ekim alanlarından toplanarak 1/1 oranında torf–toprak karışımı içeren saksılara dikilmiştir. Çok yıllık yabancı otlar ise yine ekim alanlarından toplanan rizomlar aracılığıyla yetiştirilmiştir. Daha sonra foramsulfuron'un her bir

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yabancı ot türüne karşı etkili olduğu minimum dozların (ED_{90}) doz-etki denemeleri aracılığıyla belirlenmesi amacıyla bitkiler herbisitin farklı dozlarıyla uygulanmıştır. Sonuçlar herbisitin pek çok yabancı ot için belirlenen ED_{90} dozlarının önerilen dozdan daha düşük olduğunu göstermiştir. Yabancı otlar duyarlılıklarına ED_{90} dozları önerilen dozun %25'inden düşük olanlar, %25-50 arasında olanlar, %50-75 arasında olanlar, %75-100 arasında olanlar ve önerilenden daha yüksek olanlar olmak üzere 5 farklı gruba ayrılmıştır. Ayrıca tarla denemelerinde bu dozların yalnız başına ve amonyum-sülfat katkısıyla yabancı otlar üzerindeki performansı ile verim üzerine etkileri değerlendirilmiş ve bazı yabancı otlar için tarla koşullarında da ED_{90} dozları belirlenmiştir. Sonuçlar önerilenin %25 dozunun yalnız başına kullanıldığında genellikle tarla koşullarında yetersiz etki gösterdiğini, buna karşın bu doza amonyum-sülfat ilavesiyle etkinin arttığını göstermiştir. Herbisitin %50 dozu genellikle önerilen doz kadar etkili olmuş ve daha yüksek dozlarla ilaçlanan parsellerdeki ve aynı zamanda otsuz kontrol parsellerindeki verime benzer bir verim sağlamıştır. Kontrollü koşullara oranla tarla koşullarında belirlenen ED_{90} değerleri bazı yabancı otlar için benzer olarak tespit edilirken bazı yabancı otlar için daha yüksek olarak bulunmuştur. Tarla denemelerinde toplam yabancı otlar dikkate alındığında herbisitin ED_{90} değerinin önerilen dozun %54'üne tekabül ettiği tespit edilmiştir. Bu çalışmaların sonuçları mısır'da yabancı ot mücadelesinin foramsulfuron'un yarı dozunda dahi etkili bir şekilde yapılabileceğini ve verimde azalmaya sebep olmayacağını göstermiştir.

Anahtar sözcükler: Yabancı ot, mısır, Foramsulfuron, ED_{90}, doz-etki, amonyum-sülfat

Introduction

Maize is an important crop in Turkey. Because of the reduced profitability of cotton production in Turkey, maize production has increased during the past 10 years to 550,000 ha areas in 2007 (FAO 2009). Weeds are an important yield-limiting factor for maize production in Turkey, as in many other countries. Worldwide yield losses in maize due to weeds are estimated to be around 37% (Oerke and Dehne 2004); therefore, weed control plays an important role in maize production, ensuring an acceptable yield. Weed control in maize is carried out mainly by mechanical and chemical methods, but herbicide use is increasing, along with increases in growing areas and production costs. Among the limited number of registered herbicides in Turkey, post-emergence herbicides are preferred and are applied during the early stages of crop growth because most soil herbicides do not provide effective weed control. As intensive herbicide use is associated with some environmental and agronomic problems, it is important to develop an optimized herbicide use strategy for maize that can be achieved using effective minimum herbicide rates (Kudsk and Streibig 2003).

Some previous studies showed that herbicide rates can be adjusted to the sensitivities of different weed species, weed growth stages, and environmental conditions, and that the influences of these factors on herbicide efficacy can be quantified by conducting dose-response experiments (Kudsk 1989; Christensen and Olesen 1995; Kudsk and Streibig 2003; Pannacci and Covarelli 2009). Considering these factors it is possible to provide information about the effective minimum herbicide rate to be applied in any field situation. Although such studies have been carried out worldwide for more than 30 years, there is a lack of studies on the optimization of herbicide rates in Turkey. In addition, studies on the optimization of the rates of maize herbicides are limited.

Foramsulfuron has recently entered the Turkish maize herbicide market and is preferred by growers because of its high efficacy against most annual and some perennial weed species. As observations and previous experience with other herbicides suggested that most weed species could be controlled with significantly lower herbicide rates than recommended (Dogan et al. 2005), a reduction in costs could be possible if effective minimum rates are determined for this herbicide.

As such, the present study aimed to determine and compare the sensitivity of the most important weed species that occur in maize growing areas in Turkey using dose-response experiments under controlled and field conditions via effective minimum rates (ED_{90}). Furthermore, it was aimed to evaluate the effect of effective minimum rates on weeds and maize yield under field conditions.

Materials and methods

Dose-response experiments

Dose-response experiments were conducted in 2006-2007 at the research station of Adnan Menderes University, Faculty of Agriculture in Aydın, Turkey, in order to determine the effective minimum rates of foramsulfuron under controlled conditions. Experiments were conducted with 11 weed species, each included in a different number of experiments (Table 1). Weed species included in the experiments were common in the region in which the experiments were carried out (Dogan and Boz 2005).

Annual weeds were collected from maize fields at the cotyledon stage and transferred to pots containing a mixture of soil-turf (1:1 ratios). Perennial weeds were grown from rhizome pieces collected from infested fields. Each 1-L pot (110 × 107 mm) contained only 1 individual weed species (1 plant per pot). Weeds were then grown in pots in a screenhouse until the end of the experiment. During the experiments, before and after treatment all plants were watered as needed and no fertilizer was used.

When weeds reached suitable growth stages (Table 1) they were treated with 6 different rates of foramsulfuron (4.5, 9.0, 18.0, 27.0, 36.0, and 45.0 g a.i. ha^{-1}, each rate with 4-6 replications (depending on the weed species and experiment) applied as the registered herbicide formulation (Ekipp^{TM} 22.5 g a.i. l^{-1}, Bayer CropScience, Turkey). The rates used were 10%, 20%, 40%, 60%, 80%, and 100% of the registered rate for Turkey. Untreated plants of each weed species were used for comparison. Herbicides were applied via portable plot spray equipment with a TeeJet nozzle (11003) under 3 bar pressure, with a water volume of 300 L ha^{-1}. Mean temperature during the 1st (18 June 2006), 2nd (8 May 2007), and 3rd (11 June 2007) experiments were 32, 26, and 28 °C, and relative humidity was 27%, 58%, and 33%, respectively.

To assess the efficacy of the different herbicide rates, as well as to describe dose-response relationships, the above-ground parts of weeds were harvested from pots 3 weeks after treatment and their fresh weight was determined (Frans et al. 1986). After determining fresh biomass (g plant^{-1}), all weights were converted to a percentage by setting the mean weight

Table 1. Weed species, their frequencies, and growth stages in pot experiments

	Frequency (Number of experiments included)	**Experiments**		
		I. 2006	**II. 2007/1**	**III. 2007/2**
		18 June	**8 May**	**11 June**
		Growth stages		
Amaranthus retroflexus L.*	2	2-4	-	4-5
Amaranthus blitoides L.*	1	-	4-6	-
Chenopodium album L.*	3	4-6	5-6	5-6
Xanthium strumarium L.*	3	4-6	3-4	3-4
Datura stramonium L.*	3	3-5	3-4	3-4
Solanum nigrum L.*	1	-	-	3-4
Portulaca oleracea L.**	3	3-4	3-4	1-2
Tribulus terrestris L.**	3	3-4	3-4	3-4
Cyperus rotundus L.***	3	10-15	10-15	10-15
Sorghum halepense L. (Pers)***	2	-	15-20	10-15
Echinochloa cruss-galli L.***	2	-	5-10	10-15
Total number of experiments	**26**	**7**	**9**	**10**

*Number of leaves; **number of branches; ***height (cm) of untreated plants to 100. Dose-response curves were then fit to biomass percentage data and ED_{90} values were determined for each weed species using the following non-linear equation (Hannson and Ascard 2002).

$$Y = 100/[1 + 9 (x/ED_{90})^b] \qquad \text{(Eq. 1)}$$

In this equation Y denotes the response of weeds against rate x, ED_{90} denotes the herbicide rate providing 90% biomass reduction, and b denotes the slope of the dose-response curve.

After determination of ED_{90} values for each weed species and experiment, weeds were grouped into 5 categories with respect to their sensitivity to foramsulfuron via calculated ED_{90} values (Table 2).

Field experiments

In order to evaluate the field performance of the effective minimum rates of foramsulfuron, 2 experiments were carried out in 2007 in 2 different fields at the Adnan Menderes University Agricultural Faculty Research Station, Aydın, Turkey. The experimental design was randomized complete blocks with 4 replications for each treatment. Each plot was 21 m^{-2} and included 7 maize rows (70-cm row spacing and 20-cm plant distance). The Pioneer 31G68 variety of maize was planted on 5 May 2007. Common cultural practices were applied during the entire growing season. Based on the results of the pot experiments, foramsulfuron was applied at the rates of 11.25, 22.50, 33.75, and 45.0 g a.i. ha^{-1}, corresponding to 25%, 50%, 75%, and 100% of the recommended herbicide rate, respectively. The rates of 11.25 and 22.5 g a.i. ha^{-1} were applied alone and in combination with 1% ammonium-sulfate (AS) fertilizer (1 kg 100 L^{-1} of water) in order to observe whether the efficacy of these rates could be improved by the addition of AS. This required that AS be dissolved in a small amount of spray water and then mixed with the herbicide spray solution. Weedy control plots were added to the experiments to compare the efficacy of the different herbicide rates on weeds; weed-free control plots (hand-hoed weekly until row closure) were included in the experiments to compare yields. Herbicide was applied as described in the pot experiments on 31 May 2007 at 5-6 leaf stages of maize in both experiments. Mean temperature during the treatments on the 1st and 2nd experimental field was, respectively, 30 and 35 °C, relative humidity was 40% and 33%, light conditions were 687 and 1113 µmol m^{-2} s^{-1}, and wind speed was 1.3 and 1.5 km h^{-1}. Weed species, their growth stages, and densities at the time of application are shown in Table 3.

The efficacy of the treatments on weeds was determined by means of weed biomass (g m^{-2}). The above-ground parts of weeds were harvested from 4 representative sites (each 0.25 m^{-2}) from each plot 3 weeks after treatment. To make the results from 2 different experiments comparable, weed biomass data were converted to percentages by means of average weed biomass in untreated plots, as described in the pot experiments. Plots were harvested by hand at the end of the growing season and maize grain yield was determined for each plot. For both efficacy and yield evaluations 5 maize rows in the middle of each plot were considered. Experimental data, including percent of weed biomass and yield, were subjected to analysis of variance, and means were compared via standard errors of the means ($P < 0.05$). Furthermore, ED_{90} rates of the herbicide for main weed species and for total weeds were determined for field conditions, as previously described for the dose-response experiments. For ED_{90} determination under field conditions, 11.25 and 22.5 g a.i. ha^{-1} rates, without AS added, were considered. Because field-factor and field-treatment interaction did not significantly affect biomass in any of the weed species or yield values, data from both experiments were pooled and analyzed together, both for variance and dose-response analyses.

Table 2. Weed groups with respect to their sensitivity to foramsulfuron, via ED_{90}

Group	**1**	**2**	**3**	**4**	**5**
ED_{90} values (g a.i. ha^{-1})	< 11.25	11.25-22.5	22.5-33.75	33.75-45.00	> 45
Percentage of the recommended rate	< 25	25-50	50-75	75-100	> 100

Table 3. Weed species, their growth stages, and densities at the beginning of field experiments

Weed species	**Growth stages**		**Density (number of individuals m^{-2})**		
	Field 1	**Field 2**	**Field 1**	**Field 2**	**Average**
*Amaranthus retroflexus**	2-4	2-4	41	33	37.0
*Chenopodium album**	2-4	2-4	2	2	2.0
*Datura stramonium**	2-4	0-2	7	16	11.5
*Solanum nigrum**	0-2	0-2	1	10	5.5
*Xanthium strumarium**	1-3	2-3	9	3	6.0
*Cyperus rotundus***	8-10	10-15	22	1	11.5
*Echinochloa cruss-galli***	8-10	8-10	18	32	25.0
*Echniochloa colonum***	4-6	4-8	6	70	38.0
*Sorghum halepense***	-	10-25	-	6	6.0
*Digitaria sanguinalis****	4-6	6-8	5	5	5.0
*Portulaca oleracea****	2-4	2-4	15	25	20.0
	Total number of weeds		**126**	**203**	**167.5**

*Number of leaves; **height (cm), ***number of branches

Results

Dose-response experiments

The foramsulfuron ED_{90} values for different weed species and experiments show that in 22 out of 26 experiments under controlled conditions herbicide rates required for 90% weed control were below the recommended herbicide rate (Table 4). ED_{90} values of the herbicide in 7 cases were below 25% (group 1), in 9 cases between 25% and 50% (group 2), in 5 cases between 50% and 75% (group 3), and in 1 case between 75% and 100% (group 4) of the recommended herbicide rate.

Based on the ED_{90} values it can be concluded that *D. stramonium*, *T. terrestris, E. cruss-galli*, *S. halepense*, *A. retroflexus, A. blitoides*, and *S. nigrum* were highly sensitive to the herbicide and were controlled with less than 50% of the recommended herbicide rate in all experiments. Although *P. oleracea* was very sensitive in 2 of 3 experiments, this weed could not be sufficiently controlled in 1 experiment, even at the recommended rate. For adequate control of *C. album* the effective minimum herbicide rate should be between 50% and 75% of the recommended rate in all 3 experiments. In the case of *C. rotundus* a higher than recommended rate was necessary to obtain a 90% effect in 2 experiments, whereas this weed was controlled satisfactorily with a rate below the recommended rate in only 1 experiment. Moreover, differential results were obtained with *X. strumarium*, depending on the experiment, so that different ED_{90} rates were observed for this weed species in each experiment.

Field experiments

The main purpose of the field experiments was to evaluate the results from the pot experiments under field conditions. As shown in Table 5, the effects of the treatments were evaluated only for 5 weed species 3 weeks after treatment. Of these species, *C. album* and *S. halepense* were evaluated in only 1 experiment, because they had uniform distribution or a sufficient population density on untreated plots at the time of evaluation (3 weeks after treatment) in that experiment. Other weed species listed in Table 3 were not assessed separately because their distribution or density on untreated plots was not suitable for evaluation. Nonetheless, total biomass of the other weeds included in the sampling sites was determined and included in the total weed biomass.

Table 4. Effective minimum rates (ED_{90} g a.i. ha^{-1}) of foramsulfuron, depending on weed species and experiments

Weed species	**ED_{90}**	b	group	**ED_{90}**	b	group	**ED_{90}**	b	group
Experiment		**I**			**II**			**III**	
D. stramonium	9.2 ± 1.8	0.7 ± 0.2	1	5.1 ± 3.3	0.5 ± 0.3	1	18.7 ± 2.9	1.6 ± 0.4	2
C. album	32.0 ± 6.9	3.5 ± 1.1	3	28.5 ± 8.3	1.1 ± 0.2	3	22.8 ± 4.8	2.1 ± 0.5	3
T. terrestris	20.9 ± 5.0	1.1 ± 0.2	2	24.0 ± 15.2	0.6 ± 0.3	3	11.3 ± 2.8	1.1 ± 0.3	2
X. strumarium	> 45	-	5	36.7 ± 6.0	2.5 ± 0.5	4	18.2 ± 4.2	2.0 ± 0.4	2
C. rotundus	> 45	-	5	> 45	-	5	31.0 ± 5.9	5.6 ± 2.4	3
P. oleracea	> 45	-	5	< 4.5	-	1	16.3 ± 2.7	2.4 ± 0.7	2
E. cruss-galli	7.2 ± 1.8	1.4 ± 0.7	1	9.3 ± 2.6	8.3 ± 45.3	1		-	
S. halepense		-		16.5 ± 13.4	0.5 ± 0.4	2	17.0 ± 5.6	0.9 ± 0.5	2
A. retroflexus	15.3 ± 4.3	1.6 ± 0.4	2		-		11.4 ± 1.5	2.2 ± 0.3	2
A. blitoides		-		< 4.5	-	1		-	
S. nigrum		-			-		6.1 ± 1.5	6.1 ± 4.4	1

±: Standard error

Table 5. Percent biomass of different weed species in relation to weedy control plots and maize yield

Treatment	*A. retroflexus*	*C. album**	*P. oleracea*	*S. halepense**	*Echinochloa* spp.	Total weeds	Yield (tons ha^{-1})
Control (weed-free)	-	-	-	-	-	-	9.8
Control (weedy)	100	100	100	100	100	100	5.8
Rate (g a.i. ha^{-1})							
11.25 (25%)	29	46	75	65	27	41	7.6
11.25 (25%) + AS	4	18	71	33	10	21	8.4
22.5 (50%)	6	27	16	2	9	11	9.0
22.5 (50%) + AS	3	3	11	21	1	6	9.1
33.75 (75%)	1	9	16	7	3	6	9.2
45.00 (100%)**	1	10	2	0	1	3	9.8
SEM	14.4	23.9	42.2	36.1	10.5	7.2	0.66

* Results from only one experiment; **recommended rate. SEM standard error of the means ($P < 0.05$)

In the case of *A. retroflexus* and *C. album*, it was observed that all treatments reduced weed biomass significantly, as compared to the control, but that there were no significant differences between the herbicide rates applied. Results for *P. oleracea* show that only half the rate in combination with AS and the recommended rate provided significant biomass reduction, as compared to control plots. Results for *S. halepense* show that the biomass of this weed was not significantly reduced at the 25% rate, as compared to the control; however, rates over 50% reduced weed biomasses by 80%-100%, as compared to the control plots. In the case of *Echinochloa* species, it was difficult to separate the treated weeds on a species basis, so that all *Echinochloa* species were considered as 1 group for the assessments. Results show that all treatments reduced the biomass of this weed significantly. A weed control efficacy over 90% was obtained with all treatments, except for the 25% rate, when applied alone. All treatments reduced total weed biomass significantly, as compared to control plots; however, the efficacy of the 25% rate was significantly lower than that of higher rates.

Concerning the effect of adding AS to reduced rates, it was observed that the efficacy of the herbicide rates improved when AS was added, especially at the 25% rate; however, the increases in efficacy were in most cases not significant, but was significant in the case of total weeds, so that the effect of this rate on total weeds increased from 59% to 79% with the addition of AS.

It was observed that weeds caused on average 41% yield loss, when yields from weed-free and weedy control plots were compared (Table 5). Although all treatments increased the maize grain yield, as compared to weedy control plots, yields from plots treated with the 25% rate alone were significantly lower than yields from weed-free control plots. All other treatments, including the 25% rate, in combination with AS resulted in statistically similar yields as obtained in weed-free control plots.

As the last step of the research, effective minimum rates (ED_{90}) were calculated for some weed species, also under field conditions. As shown in Table 6, the ED_{90} rates determined for *A. retroflexus*, *Echinochloa* spp., and *S. halepense* were between 25% and 50% of the recommended rate corresponding to group 2. The ED_{90} rates determined for *P. oleracea* and *C. album* were between 75% and 100% of the recommended rate (group 4). The foramsulfuron ED_{90} rate for total weeds under field conditions was 24.2 g a.i. ha^{-1}. Although this ED_{90} rate should be placed under group 3, it should be noted that this rate corresponds exactly to 54% of the recommended herbicide rate.

Discussion

Results from both pot and field experiments show that weed sensitivity against foramsulfuron can be quantified by means of dose-response experiments, and that weeds can be classified with respect to their sensitivity via ED_{90} values. In most cases effective weed control can be achieved with considerably reduced rates and still provide maximum crop yield. Similar results were observed in some other studies concerning weed control with reduced herbicide rates in maize. In previous studies conducted in the same region of Turkey with nicosulfuron and 2,4-D-amine in maize, Dogan et al. (2005) observed that some important weed species, which were also included in the present study, differed in their sensitivity to each herbicide and that a mixture of both herbicides at reduced rates resulted in the highest weed control efficacy, as compared to full rates of either herbicide applied alone. In another study, conducted in Ontario, Nurs et al. (2007) reported that the efficacy of foramsulfuron is strongly influenced by weed species sensitivity and, depending on weed species, herbicide rates required for 90% weed control varied between 25 and 86 g a.i. ha^{-1}. Baghestani et al. (2007) evaluated the efficacy of some reduced rates of some post-emergence herbicides (including foramsulfuron) in Iran and reported that some weed species could be controlled with reduced herbicide rates. In a recent study Pannacci and Covarelli (2009) reported that

Table 6. Effective minimum rates (ED_{90}) of foramsulfuron and other regression parameters, depending on weed species and experiments under field conditions

	ED_{90} (g a.i. ha^{-1})	b	group
A. retroflexus	18.2 ± 5.8	2.7 ± 1.7	2
P. oleracea	35.4 ± 20.7	1.1 ± 0.8	4
Echinochloa spp.	20.1 ± 4.8	2.1 ± 0.9	2
*C. album**	41.3 ± 3.6	1.6 ± 0.1	4
*S. halepense**	17.9 ± 11.7	6.0 ± 7.8	2
Total weeds	24.2 ± 2.9	2.4 ± 0.5	3

*Data from only one experiment; ±: standard error some weeds that occur in maize in Italy could be controlled by 1/6 of the recommended herbicide rate of mesotrione, while some other weeds could not be controlled, even at the recommended rate. As is clear from the studies mentioned above, most results are in accordance with each other and with our results. Although in some cases different herbicides were used, most of the weed species included were similar. This highlights the relevance of weed species used in our experiments and the significance of our results.

Most studies concerning the determination of effective minimum rates via dose-response experiments have been carried out under controlled conditions, in which weeds are grown in pots without any concurrence. However, whether or not the results from such experiments can be reliable for field conditions remains controversial (Kudsk and Streibig 2003). Therefore, ED_{90} rates of the herbicide were determined under both controlled and field conditions in our experiments to compare the results from both conditions. As there were a limited number of weed species under field conditions, such a comparison could not be made for all weed species. However, comparable results were obtained for *A. retroflexus* and *S. halepense* under both controlled and field conditions, and both species had an ED_{90} rate between 25% and 50% of the recommended herbicide rate.

In contrast, the ED_{90} rates determined for *Echinochloa* spp. and *C. album* were higher under field conditions, as compared to the pot experiments. These differences can be attributed to the non-uniform distribution and density, and mixed growth stages of weeds in the field experiments, which can significantly affect herbicide performance. Furthermore, differential results for *Echinochloa* spp. can also be attributed to the fact that in the pot experiments ED_{90} rates were determined only for *E. cruss-galli*, whereas there was a mixed population of 2 different species in the field (*E. cruss-galli* and *E. colonum*) and the average number of *E. colonum* was higher than that of *E. cruss-galli*.

Results for *P. oleracea* were different in all experiments, even in the pot experiments, which makes it difficult to comment on the results for this weed. Further experiments are required to define the dose-response relationship for *P. oleracea* to allow a more definite conclusion.

As the results show, there were similarities and differences between experiments conducted under controlled and field conditions; however, the pot experiments showed that most of the weed species could be controlled with about 50% of the recommended rate, which was also the case for total weed species in the field experiments. Therefore, it can be concluded that the pot experiments provided information as reliably as did the field experiments.

Although one can claim that field experiments are more suitable for this purpose (Pannacci and Covarelli 2009), it should be noted that the pot experiments provided ED_{90} rates for more weed species than under field conditions (11 weed species in the pot experiments versus only 5 species in field experiments). As such, it is possible to classify more weed species into different sensitivity groups, allowing an estimation of the field response of any other non-present weed species by considering the response of relevant species present during the herbicide treatments. From these results it is clear that the results from the pot and field experiments should be considered jointly to make more practical recommendations for herbicide rate optimization.

Another aim of the field experiments was to evaluate the influence of the addition of AS on the efficacy of effective minimum rates. Results show that the addition of AS increased the efficacy in most cases, but the efficacy increases were not significant, which can be attributed to the variable weed conditions (non-uniform density, growth stage, etc.) under field conditions. Such an increase could be best confirmed with experiments under homogeneous field conditions, as well as under controlled conditions. Nevertheless, there are some studies in which the effect of foramsulfuron was increased with the aid of some adjuvants, including AS (Bunting et al. 2004; Stagnari et al. 2007).

In many studies it was reported that the addition of AS to spray solution increased the efficacy of different herbicides. Although the reason for increased efficacy due to the addition of AS could not be explained, it is thought that plant uptake of the herbicide is increased by means of reduced surface tension and altered PH of the herbicide solution (Hartzler and Foy 1983; Bunting et al. 2004). Increased efficacy of some other maize herbicides at reduced rates via the addition of ammonium-sulfate under field conditions in Turkey has already been reported in some of our previous studies (Dogan and Boz 2002; Dogan et al. 2005).

To determine whether 1% AS treatment causes any herbicidal or fertilizer effect on weed species, Dogan (2004) carried out pot experiments in which different weeds and maize plants were treated with 1% AS alone (only in water) or in combination with nicosulfuron solution (another herbicide used in maize worldwide as well as in Turkey). Results showed that the efficacy of the herbicide against *P. oleracea* and *C. rotundus* was significantly increased by the addition of AS, but caused no maize injury. AS did not show any herbicide or fertilizer effect on the weed species tested. This finding shows that the addition of AS stimulates an herbicide effect, not directly, but by some processes like retention or uptake, as was suggested by other studies (Hartzler and Foy 1983; Bunting et al. 2004).

As the results of the present study are summarized, it can be suggested that foramsulfuron rates can be reduced by about 50%, considering weed species. This rate provides comparable weed control as well as yield under farming conditions as does the full rate or even mechanical control repeated several times (weed-free control). The efficacy of herbicide could be improved by the addition of ammonium-sulfate, especially in the case of less sensitive weed species or under unsuitable conditions (growth stage or climatic conditions). Thus, it is possible to reduce herbicide expenditure and prevent the possible side effects of intensive use of this herbicide.

As weed species included in these experiments are important worldwide and foramsulfuron is also applied worldwide for weed control in maize, the results presented herein may provide useful information for growers and weed scientists from other countries with similar weed composition and climatic conditions.

Although it is widely discussed whether or not effective minimum herbicide rates cause the selection of resistant weed biotypes, this question remains unanswered. Despite the application of reduced herbicide rates for more than 25 years, this suspicion was not confirmed in any scientific study or under farming conditions. Furthermore, it should be stressed here that the concept of "effective minimum rates" is an integral part of the "integrated weed management strategies" and is not necessarily associated with a lower degree of weed control. It is related to the minimum herbicide rate for maximum weed control and is even suggested for the management of herbicide resistance by some scientists (Kudsk and Streibig 2003; Kudsk 2008). Therefore, it is not easy to comment on the relationship between the occurrence of herbicide resistance and the herbicide rate; however, strategies for weed resistance management are very well known and they should be used regardless of the herbicide rate applied.

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References

Baghestani, MA, Zand E, Soufizadeh S, Eskandari A, Azar RP, Veysi M, Nassirzadeh N (2007) Efficacy evaluation of some dual purpose herbicides to control weeds in maize (*Zea mays* L.). Crop Prot 26: 936-942.

Bunting, JA, Sparque CL, Riechers DE (2004) Proper adjuvant selection for foramsulfuron efficacy. Crop Prot 23: 361-366.

Christensen S, Olesen JE (1995) Adaptive weed control in an integrated wheat management system for winter wheat. In: Proceedings of 9th EWRS (European Weed Research Society) Symposium, Budapest, pp. 663-669.

Dogan MN, Boz Ö (2002) Einfluss von Ammonium-Sulfat auf die Wirksamkeit von Maisherbiziden unter Feldbedingungen in der Türkei. J Plant Dis Protect Sp Iss XVIII: 885-892.

Dogan MN (2004) Ein Beitrag zur Verbesserung herbizider Wirkung durch Ammonium-Sulfat als Zusatstoff. 7. Türk-Alman Tarımsal Araştırma Sonuçları Sempozyumu, 24-30 Mart, Ankara, Cuvillier Verlag – Göttingen: 121-126.

Dogan, MN, Boz Ö (2005) Comparison of weed problems in main and second crop maize (*Zea mays* L.) growing areas in Turkey. Asian Journal of Plant Sciences 4: 220-224.

Dogan, MN, Boz Ö, Ünay A (2005) Efficacies of reduced herbicide rates for weed control in maize (*Zea mays* L.) during critical period. Journal of Agronomy 4: 44-48.

FAO statistics (2009) http://faostat.fao.org, 16.01.2009.

Frans R, Talbert R, Marx D, Crowley H (1986) Experimental design and techniques for measuring and analysing plant responses to weed control practices. In: Research Methods in Weed Science, Third edition, edited by Camper ND, pp. 485, Southern Weed Science Society, Chapter 2: 29-46.

Hanson D, Ascard J (2002) Influence of developmental stage and time of assessment on hot water weed control. Weed Res 42: 307-316.

Hartzler RG, Foy CL (1983) Efficacy of three postemergence grass herbicides for soybeans. Weed Sci 31: 557-561.

Kudsk P (1989) Experiences with reduced doses in Denmark and the development of the concept of factor-adjusted doses. In: Proceedings of Brighton Crop Protection Conference-Weeds, Brighton, pp. 545-554.

Kudsk P, Streibig JC (2003) Herbicides –a-two-edged sword. Weed Res 43: 90-102.

Kudsk P (2008) Optimising herbicide dose: a straightforward approach, to reduce the risk of side effects of herbicides, Environmentalist 28: 49-55.

Nurs RE, Hamill AS, Swanton CJ, Tardif FJ, Sikkema PH (2007) Weed control and yield response to foramsulfuron in corn. Weed Tech 21: 453-458.

Oerke, EC, Dehne HW (2004) Safequarding production–losses in major crops and the role of crop protection. Crop Prot 23: 275-285.

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

Stagnari F, Chiarini M, Pisante M (2007) Influence of fluorinated surfactants on the efficacy of some post-emergence sulfonylurea herbicides. J Pestic Sci 32: 16-23.