Available online at www.sciencedirect.com
ScienceDirect
Crop Protection 26 (2007) 936–942
Crop Protection
www.elsevier.com/locate/cropro

Efficacy evaluation of some dual purpose herbicides to control weeds in maize (*Zea mays* L.)

Mohammad Ali Baghestani[a], Eskandar Zand[a], Saeid Soufizadeh[a,b,*], Ali Eskandari[a], Reza PourAzar[c], Mozhgan Veysi[d], Navid Nassirzadeh[a]

[a]*Department of Weed Research, Plant Protection Research Institute, P.O. Box 19395-1454, Tehran, Iran*
[b]*Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, P.O. Box 14115-4111, Tehran, Iran*
[c]*Ahvaz Agricultural and Natural Resources Research Center, Khuzestan, Iran*
[d]*Kermanshah Agricultural and Natural Resources Research Center, Kermanshah, Iran*

Received 26 August 2006; accepted 29 August 2006

Abstract

Field experiments were conducted in 2005 at 4 locations in Iran, to evaluate maize yield response and control of weeds with nicosulfuron at 40, 60, and 80 g ai/ha, foramsulfuron at 337.5, 450, and 562.5 g ai/ha, rimsulfuron at 5, 7.5, and 10 g ai/ha as dual purpose herbicides, and 2,4-D plus MCPA as reference standard. All herbicides were applied at three- to six-leaf stage of maize. Results indicated that nicosulfuron and foramsulfuron at the highest dose provided satisfactory control of broadleaved and grass weeds in maize. Application of nicosulfuron at 80 g ai/ha resulted in the highest maize yield after the weed-free check. However, 2,4-D plus MCPA plots had the lowest grain yield among all treatments. This could be attributed to the spectrum of weed control with this herbicide, since the grass weeds escaped control where maize was sprayed with 2,4-D plus MCPA.

Keywords: Dual purpose herbicides; Broadleaved weed; Grass weed; Maize yield

1. Introduction

Maize is a major crop in Iran and ranks third, behind wheat and rice in hectares grown (FAO (Food and Agricultural Organization), 2005). Grain yield in maize can be severely reduced by competition with weeds (Najafi and Tollenaar, 2005). A broad spectrum of grasses and broadleaved weeds infests maize fields. *Amaranthus* spp. (pigweed), *Chenopodium album* L. (common lambsquarters), *Abutilon theophrasti* Medik. (velvetleaf), *Cirsium arvense* (L.) Scop. (Canada thistle), *Convolvulus arvensis* L. (field bindweed), *Sorghum halepense* (L.) Pers. (johnsongrass), *Echinochloa crus-galli* (L.) Beauv. (barnyardgrass), *Cyperus rotundus* L. (purple nutsedge), *Digitaria sanguinalis* (L.) Scop. (large crabgrass) and *Setaria* spp. (foxtail) are among the most common and problematic weeds in maize in Iran (Mousavi, 2001). These weeds can cause substantial yield reduction if not satisfactorily controlled.

In Iran, herbicides have been the main means of weed control for more than 30 years (Zand et al., 2006). Today, high-yielding agriculture heavily depends on herbicides, as they constitute a vital and integral component of weed management practices (Rao, 2000; Baghestani et al., 2005). However, there are very few herbicide options available for weed control in maize in Iran. Currently, herbicides used for control of weeds include pre-plant incorporated application of atrazine plus allachlor, and EPTC, and post-emergence application of 2,4-D plus MCPA (Mousavi, 2001; Hadizadeh et al., 2006). But, none of these options currently keep the weed community at an acceptable level and cannot provide satisfactory control of weeds. In addition, these herbicides are used at high rates. Evolution of weeds resistant to these herbicides especially 2,4-D plus MCPA, and atrazine, economic aspects, negative effects of herbicides in the environment and the risk of contamination of food have resulted in determination of alternative

*Corresponding author. Tel.: +98 21 224 03695; fax: +98 21 224 13430.
E-mail address: ssoufizadeh2004@yahoo.com (S. Soufizadeh).

0261-2194/$ - see front matter
doi:10.1016/j.cropro.2006.08.013

weed management strategies which help minimize herbicide application rate and resistance, and costs for weed control (Coble, 1994). One alternative tactic based on herbicides to manage herbicide-resistant weeds may include the use of newly released dual purpose herbicides with new modes of action. Using these herbicides, it will be possible to switch from high-dose to low-dose herbicides, providing rotational options with current herbicides, and thus increasing the number of modes of action available for use.

Nicosulfuron, foramsulfuron, and rimsulfuron are among the newly released dual purpose sulfonylurea herbicides. The use of these herbicides offers the opportunity for a new mode of action for weed management in maize. These herbicides act through inhibition of acetolactate synthase, the first enzyme in the pathway in the biosynthesis of branched-chain amino acids, valine, leucine and isoleucine in chloroplasts. They first affect meristemic tissues where growth ceases soon after treatment. Chlorosis and the necrosis of these tissues soon follow, with dieback to the mature parts of the plant taking a further 3–4 wk (Rao, 2000). These herbicides have been reported to be very effective on grasses, broadleaved weeds, and rhizomatous perennial temperate weeds in maize (Bhowmik et al., 1992; Bruce and Kells, 1997; Koeppe et al., 2000; Lum et al., 2005). Another priority of these herbicides over those currently used on maize is that they act at very low doses. This will reduce the environmental safety concerns lie back behind application of herbicides.

For maize in Iran, no data exists describing whether or not the post-emergence application of nicosulfuron, foramsulfuron and rimsulfuron would increase weed control and improve maize yield. Therefore, the main objective of the present study was to determine if these post-emergence herbicides provide better weed control and higher maize yield than application of 2,4-D plus MCPA as reference standard.

2. Materials and methods

2.1. Field studies

Field experiments were conducted in 2005 at four locations in Iran. Sites description, schedule of events and soil texture are shown in Table 1. The experimental design at all locations was a randomized complete block with four replications. Naturally occurring weed populations were used in the experiments. Weed composition at each location is presented in Table 2. Each plot consisted of four 8-m rows, spaced 0.75 m apart. The seedbed at all locations was prepared using a moldboard plow followed by disking, and smoothing with land leveler. Based on soil chemical analysis, and Iran Water and Soil Research Institute recommendations, necessary fertilizers were applied at each location.

2.2. Herbicide treatments and application

Treatments consisted of a full-season hand weeding control and post-emergence applications of nicosulfuron SC 4% at 40, 60, and 80 g ai/ha, foramsulfuron OD 22.5% at 337.5, 450, and 562.5 g ai/ha, rimsulfuron DF 25% at 5, 7.5, and 10 g ai/ha, and 2,4-D plus MCPA as reference standard at three- to six-leaf stage of maize. Herbicides were applied using an Elegance 18 electric knapsack sprayer equipped with flooding nozzle and calibrated to deliver 300 L/ha of spray solution at a pressure of 2.5 bar. Herbicide application was performed in one-half of each plot, and the other half was kept as its control (Zand et al., 2006).

Table 1
Schedule of events, soil textures, and maize planting dates at different locations in 2005

Location	Soil texture	Planting date
Ahvaz	Silty clay loam	16 July 2005
Kermanshah	Silty clay loam	23 April 2005
Karaj	Clay loam	7 May 2005
Varamin	Sandy clay	11 May 2005

Table 2
Weed composition of the experimental fields at each location in 2005 (+ mark indicates the weed species present at each location)

Weed species	Location			
	Ahvaz	Kermanshah	Karaj	Varamin
Abutilon theophrasti Medik.	–	+	–	–
Amaranthus retroflexus L.	–	+	+	+
Acroptilon repens (L.) DC.	+	–	–	–
Chenopodium album L.	–	–	+	–
Cyperus esculentus L.	+	–	–	+
Digitaria sanguinalis (L.) Scop.	–	–	+	–
Echinochloa crus-galli (L.) Beauv.	+	–	–	–
Physalis alkekengii L.	+	–	–	–
Panicum miliaceum L.	–	+	–	–
Portulaca oleraceae L.	–	–	–	+
Sorghum halepense (L.) Pers.	+	+	+	+
Cleome viscosa L.	+	–	–	–

2.3. Data collection and analysis

Percent weed population reduction was measured separately for each weed species by counting the number of weeds prior to and 30 days after treatment within a fixed 1.5 m^2 quadrate in the herbicide treated half of each plot. All other weeds emerged between these two stages were hand removed. Percent weed biomass reduction was measured using two 0.375 m^2 quadrates that were dropped in the treated and untreated halves of each plot. All weeds were cut at the soil surface, separated by species, and oven dried at 75 °C for 72 h. The reduction was calculated by dividing weed biomass in the treated half by weed biomass in the untreated half and multiplying by 100. Maize grain yield was measured at economic maturity.

All data were subjected to analysis of variance (ANOVA) using SAS statistical software (SAS Institute, 2000).

The assumptions of variance analysis were tested by insuring that the residuals were random, homogenous, with a normal distribution about a mean of zero. If the assumptions of variance were not adequately met, percent weed biomass and population reductions were subjected to an arcsine square root transformation. Maize yield data were subjected to a $\log(x+1)$ transformation where required. Means were separated using Duncan multiple range test (DMRT) set at 0.05. Data were analyzed separately by location because weather conditions, soil texture, planting dates and weed species were different at each location.

3. Results and discussion

3.1. Weed control

At Ahvaz, nicosulfuron at 80 and 60 g ai/ha controlled *S. halepense* at least 97%, which was significantly different from all other treatments (Table 3). *E. crus-galli* was satisfactorily controlled nearly by all herbicide treatments. Nicosulfuron at the highest dose provided the highest reduction in *Cyperus esculentus* L. (yellow nutsedge) population while foramsulfuron at 337.5 g ai/ha controlled 73.5% of *C. esculentus*. As observed in Table 3, nicosulfuron and rimsulfuron at the highest dose provided the highest reduction in grass weed populations. Bhowmik et al. (1992), and Bruce and Kells (1997) reported that nicosulfuron was very effective on rhizomatous perennial temperate weeds. Koeppe et al. (2000) stated that rimsulfuron was highly active on *S. halepense*, *D. sanguinalis*, and *E. crus-galli*. Grass weed biomass reduction ranged from 84% to 100%, however, herbicide treatments better controlled *S. halepense* compared with other grass weeds (Table 3). All treatments failed to control broadleaved weeds satisfactorily (Table 3). Nonetheless, the highest reduction in broadleaved weed populations was provided by nicosulfuron at 80 g ai/ha. *Physalis alkekengii* L. (Chinese lantern plant) was controlled less effectively compared with *Acroptilon repens* (L.) DC. (Russian knapweed) and *Cleome viscosea* L. (jazmin de rio). However, all treatments reduced broadleaved weed biomass at least 91% (Table 3). These results indicate that dual purpose herbicides did not have any preference on current broadleaved weed herbicide 2,4-D plus MCPA in this respect. However, broadleaved weed biomass was reduced at least 91% after spraying with herbicide treatments. The higher reduction in broadleaved weed biomass compared with broadleaved weed population indicates that all treatments had caused negative impact on weed growth and as a result biomass production, although they were less effective in terms of weed killing. Contrary to our results at Ahvaz,

Table 3
Effect of different herbicide treatments on percent weed populations and biomass reductions 30 days after herbicide application (DAHA) at Ahvaz in 2005

Treatments	Dose (g ai/ha)	Weed species					
		S. halepense		*E. crus-galli*		*C. esculentus*	
		Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)
Nicosulfuron	40	91.2bc[a]	99.2b	82.6bcd	86.1d	96.9a	96.7a
Nicosulfuron	60	97.7a	99.6ab	88.4abc	84.9d	97.0a	97.5a
Nicosulfuron	80	100a	99.9a	93.8a	91.6bc	99.1a	98.0ab
Foramsulfuron	337.5	80.4e	97.9c	73.5d	89.8c	91.0b	84.9d
Foramsulfuron	450	83.1e	96.8d	79.4cd	92.7abc	96.8a	86.2cd
Foramsulfuron	562.5	87.1d	98.3c	86.4abc	94.4ab	97.8a	90.0b
Rimsulfuron	5	90.6bc	97.9c	88.2bcd	91.2bc	88.9b	86.6cd
Rimsulfuron	7.5	89.2cd	98.4c	84.3abc	93.0abc	98.4a	88.0bc
Rimsulfuron	10	93.9b	99.2b	100a	96a	91.3ab	95.6a
2,4-D + MCPA	1012.5	—	—	—	—	—	—
		A. repens		*P. alkekengii*		*C. viscosa*	
Nicosulfuron	40	71.5ab[a]	94.6cd	47.2bcd	97.1bc	77.8ab	98.4a
Nicosulfuron	60	82.4a	95.9bc	27.9ef	97.2bc	74.6abc	98.8a
Nicosulfuron	80	84.5a	98.5a	63.1a	99.4a	88.4a	99.3a
Foramsulfuron	337.5	54.0b	91.7fg	27.9ef	96.5cd	67.9bc	95.2c
Foramsulfuron	450	65.9ab	91.4g	41.6bcde	97.1bc	56.9cd	96.6b
Foramsulfuron	562.5	73.3ab	94.1cde	55.0ab	98.9a	65.7bcd	98.7a
Rimsulfuron	5	78.0a	91.0g	35.4de	95.2d	56.1cd	95.9bc
Rimsulfuron	7.5	67.2ab	92.4efg	19.8f	96.2cd	47.7d	96.2bc
Rimsulfuron	10	79.2a	97.2ab	39.8cde	98.4ab	74.4abc	98.7a
2,4-D + MCPA	1012.5	76.7a	98.3a	52.8abc	98.7ab	84.2ab	98.5a

[a]Means within each column followed by same letter are not significantly different at 0.05 probability level according to DMRT.

Koeppe et al. (2000) reported that rimsulfuron was very effective on broadleaved weeds such as *Amaranthus retroflexus* L. (redroot pigweed) and *C. album*.

Statistical analysis showed significant differences in percent weed population and biomass reductions among all treatments at Kermanshah (Table 4). Foramsulfuron provided acceptable control of *S. halepense* (94.5%) at the highest dose. Although being the highest, foramsulfuron at 562.5 g ai/ha controlled *Panicum miliaceum* L. (wild-proso millet) 84.7% only, indicating its higher efficiency in control of *S. halepense*. Similar results were obtained for percent grass weed biomass reduction. Contrary to our results at this location, many researchers have found that nicosulfuron provides excellent early-season control of *P. miliaceum* (Morton, 1993; Rabaey and Harvey, 1997; Williams and Gordon Harvey, 2000). 2,4-D plus MCPA, foramsulfuron at 562.5 g ai/ha and rimsulfuron at 10 g ai/ha controlled *A. retroflexus* population at least 84%. Similarly and with the exception of rimsulfuron at 10 g ai/ha, control of *A. theophrasti* with 2,4-D plus MCPA and foramsulfuron at 562.5 g ai/ha was 88.3% and 88.7%, respectively. Percent broadleaved weed biomass reduction agreed with the result of percent broadleaved weed population reduction. However, *A. retroflexus* biomass reduction was at least 91% when sprayed with 2,4-D plus MCPA, and rimsulfuron at the highest dose. The highest broadleaved weed survival was occurred where nicosulfuron at 40 g ai/ha was applied. However, where nicosulfuron dose was increased to 80 g ai/ha, control of *A. retroflexus* and *A. theophrasti* increased to 84.6% and 52.3%, respectively. Generally, application of foramsulfuron at 562.5 g ai/ha gave broadleaved weed control similar to that obtained by 2,4-D plus MCPA, while it also gave a relatively satisfactory control of grass weeds especially *S. halepense*. As a result, 2,4-D plus MCPA could be replaced by this herbicide at Kermanshah.

At Karaj, percent *S. halepense* population reduction was highest when foramsulfuron at the highest dose was applied (Table 5). However, other treatments controlled this weed less than 81%. *D. sanguinalis* control was not satisfactory at this location. The highest reduction in *D. sanguinalis* population and biomass (81.1% at each) was achieved with foramsulfuron at the highest dose (Table 5). Nicosulfuron at 40 g ai/ha provided the highest reduction in *S. halepense* biomass (86.9%). As observed, rimsulfuron acted poorer on grass weeds compared with foramsulfuron and nicosulfuron. Our results are not consistent with findings of Koeppe et al. (2000) who stated that rimsulfuron provides satisfactory control of *S. halepense* and *D. sanguinalis*. 2,4-D plus MCPA reduced *A. retroflexus* population 92% (Table 5). However, foramsulfuron at 337.5 g ai/ha, 2,4-D plus MCPA, and rimsulfuron at 7.5 g ai/ha controlled *C. album* population at least 94%, while the highest weed survival was occurred where foramsulfuron at 450 g ai/ha was applied. Percent *A. retroflexus* biomass reduction ranged from 91% to 98%, while other treatments resulted in reductions less than 90% (Table 5). Percent *C. album* biomass reduction was highest (88%) when treated by 2,4-D plus MCPA, and foramsulfuron at the highest dose. In contrast, *C. album* biomass was lowest when maize was sprayed with foramsulfuron and nicosulfuron at the lowest dose. Considering both broadleaved and grass weeds suppression efficiency, 2,4-D plus MCPA and foramsulfuron at 562.5 g ai/ha can be proposed for weed control at Karaj.

At Varamin, all dual purpose herbicides failed to control weeds effectively (Table 6). Where treated by foramsulfuron and nicosulfuron at the highest dose, control of

Table 4
Effect of different herbicide treatments on percent weed populations and biomass reductions 30 DAHA at Kermanshah in 2005

Treatments	Dose (g ai/ha)	Weed species							
		S. halepense		*P. miliaceum*		*A. retroflexus*		*A. theophrasti*	
		Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)
Nicosulfuron	40	34.3e[a]	35.6e	70.0de	70.7cd	36.0d	49.4e	24.6f	26.7f
Nicosulfuron	60	49.7d	49.7d	78.0b	78.4b	50.3bc	60.9cd	29.5ef	30.7ef
Nicosulfuron	80	69.6bc	69.8c	80.4ab	80.4b	84.6a	88.1a	52.3d	53.3d
Foramsulfuron	337.5	58.4cd	60.1cd	69.5de	71.4c	51.4bc	61.8cd	33.4ef	29.3ef
Foramsulfuron	450	79.3b	80.0b	76.5bc	78.3b	62.5b	72.9b	64.1c	65.1c
Foramsulfuron	562.5	94.5a	95.1a	84.7a	85.2a	88.9a	91.9a	88.3a	88.4a
Rimsulfuron	5	17.9f	24.0f	66.7e	67.3d	39.7cd	52.5de	36.4e	38.1e
Rimsulfuron	7.5	35.5e	36.4e	73.3cd	73.7c	52.3bc	62.6c	47.4d	56.1cd
Rimsulfuron	10	50.5d	54.8d	80.9ab	80.7b	84.7a	88.7a	77.7b	77.2b
2,4-D + MCPA	1012.5	—	—	—	—	89.7a	92.8a	88.7a	88.6a

[a]Means within each column followed by same letter are not significantly different at 0.05 probability level according to DMRT.

Table 5
Effect of different herbicide treatments on percent weed populations and biomass reductions 30 DAHA at Karaj in 2005

Treatments	Dose (g ai/ha)	Weed species							
		S. halepense		*D. sanguinalis*		*A. retroflexus*		*C. album*	
		Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)
Nicosulfuron	40	43.5cd[a]	86.9a	50.8cde	52.3bc	35.6ef	63.3c	40.6b	25.9f
Nicosulfuron	60	62.8bc	62.0ab	66.8abc	60.7abc	47.0de	71.6c	52.0b	30.1ef
Nicosulfuron	80	80.8ab	62.1ab	74.2ab	77.0ab	76.0abc	93.0ab	86.0a	51.0d
Foramsulfuron	337.5	73.6ab	44.4b	60.8bcd	50.6bc	48.3de	72.3c	95.4a	25.8f
Foramsulfuron	450	78.9ab	49.6ab	65.4abcd	61.3abc	58.3cd	82.9b	39.9b	64.8c
Foramsulfuron	562.5	93.8a	60.3ab	81.1a	81.1a	80.7ab	97.2a	51.4b	87.2a
Rimsulfuron	5	35.2f	47.9b	40.6e	44.6c	23.9f	66.0c	85.4a	37.8e
Rimsulfuron	7.5	48.3def	77.4ab	49.0de	58.2abc	36.8ef	63.0c	94.0a	55.4d
Rimsulfuron	10	49.2def	45.4b	55.1cde	65.6abc	69.9bc	89.3ab	55.3b	77.2b
2,4-D + MCPA	1012.5	—	—	—	—	92.0a	91.6ab	95.0a	88.0a

[a]Means within each column followed by same letter are not significantly different at 0.05 probability level according to DMRT.

Table 6
Effect of different herbicide treatments on percent weed populations and biomass reductions 30 DAHA at Varamin in 2005

Treatments	Dose (g ai/ha)	Weed species							
		S. halepense		*C. esculentus*		*A. retroflexus*		*P. oleraceae*	
		Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)	Weed population reduction (%)	Weed biomass reduction (%)
Nicosulfuron	40	47.94b[a]	53.4ab	35.2c	26.1cd	23.8d	46.6bcde	40.4c	42.2b
Nicosulfuron	60	52.43b	55.2ab	37.5c	34.9bc	45.0cd	64.1b	43.6c	23.2c
Nicosulfuron	80	77.2a	65.0a	73.4ab	46.3a	56.7bc	58.9bc	70.5ab	48.0b
Foramsulfuron	337.5	47.2b	55.7ab	38.0c	30.7bc	44.4cd	44.0bcde	34.5c	22.5c
Foramsulfuron	450	51.4b	53.8ab	59.4b	47.9a	31.1de	60.5b	55.2bc	39.1b
Foramsulfuron	562.5	79.1a	56.9ab	78.5a	41.1ab	67.6b	52.3bcd	68.9ab	64.7a
Rimsulfuron	5	24.4c	46.7ab	37.2c	19.12 d	27.8d	24.3e	36.7c	12.2c
Rimsulfuron	7.5	25.5c	48.4ab	38.4c	47.6a	33.3d	33.3ed	34.7c	19.4c
Rimsulfuron	10	40.9bc	44.8b	39.5c	33.0bc	40.7cd	37.0cde	35.2c	72.0a
2,4-D + MCPA	1012.5	—	—	—	—	93.3a	89.5a	86.1a	72.5a

[a]Means within each column followed by same letter are not significantly different at 0.05 probability level according to DMRT.

C. esculentus and *S. halepense* ranged from 73% to 79%, while control of these two grass weeds dropped to below 60% when they were sprayed with other treatments, which is consistent with the results obtained from percent grass weed population reduction. Percent broadleaved weed population reduction was significantly different among treatments. 2,4-D plus MCPA controlled more than 93% and 86% of *A. retroflexus* and *Portulaca oleraceae* L. (common purslane), respectively. However, percent broadleaved weed control dropped to below 70% when other treatments were applied on maize. As in percent weed control, 2,4-D plus MCPA reduced *A. retroflexus* and *P. oleraceae* biomass (86.1% and 72.55%, respectively) more than other herbicide treatments. In general, at Varamin 2,4-D plus MCPA can still be considered as the best option providing adequate broadleaved weed control.

3.2. Maize yield

At Ahvaz, the weed-free yield was significantly different from all herbicide treatments (Table 7). After the weed-free plot, yield was highest when nicosulfuron was applied at a dose of 80 and 60 g ai/ha, respectively. The lowest yielding maizes were present in the foramsulfuron at 337.5 g ai/ha and 2,4-D plus MCPA treated plots, respectively. As observed, application of 2,4-D plus MCPA did not give a satisfactory grain yield. This could be attributed to the spectrum of weed control with herbicide; grass weeds

Table 7
Maize grain yield obtained under different herbicide treatments at different locations in 2005

Treatments	Dose (g ai/ha)	Grain yield (kg/ha)			
		Ahvaz	Kermanshah	Karaj	Varamin
Nicosulfuron	40	4525.0cd[a]	7417.5i	6080.0cd	6952.5c
Nicosulfuron	60	5850.0b	9280.0d	6333.3c	6617.5cd
Nicosulfuron	80	6275.0b	9700.0c	7647.5b	8095.0b
Foramsulfuron	337.5	3150.0g	8075.0h	5880.0cd	6222.5d
Foramsulfuron	450	3973.0de	9100.0e	6377.5c	6787.5cd
Foramsulfuron	562.5	4495.0cd	10560.0a	7520.0b	7647.5b
Rimsulfuron	5	3633.6efg	8530.0g	3917.5f	4730.0fg
Rimsulfuron	7.5	3866.7def	8712.5f	4517.5e	4887.5f
Rimsulfuron	10	5025.0c	9267.5d	5520.0d	5577.5e
2,4-D + MCPA	1012.5	3225.0fg	6550.0j	3865.0f	4220.0g
Full season hand weeding		6984.0a	10390.0b	8512.5a	9315.0a

[a]Means within each column followed by same letter are not significantly different at 0.05 probability level according to DMRT.

escaped control where maize was sprayed with this herbicide. In contrast, nicosulfuron at 80 g ai/ha not only caused the highest reductions in broadleaved weed population and biomass but also provided a satisfactory control of grass weeds. These results agree with Lum et al. (2005) who reported that nicosulfuron application on maize resulted in yields similar to that in the weeded control. Bruce and Kells (1997) and Rabaey and Harvey (1997) also found that nicosulfuron gives an effective control of perennial grasses. At Kermanshah, however, plots treated with foramsulfuron at 562.5 g ai/ha resulted in the highest yield, while 2,4-D plus MCPA plots had the lowest yield (Table 7). This is confirmed by an acceptable control of weeds with foramsulfuron at 562.5 g ai/ha. Similar to Ahvaz, the difference between the highest and lowest yielding treatments could be attributed to differences in spectrum of weed control. The weed-free check was ranked second in terms of grain yield. This might be attributed to the probable damage of hand weeding on maize crop. Zand et al. (2006) also found that herbicide treated wheats yielded higher than the weed-free plot. Similarly, they attributed this observation to the probable damage of hand weeding on wheat crop. At Karaj and Varamin, the weed-free plot significantly had higher maize yield than herbicide treated plots. Plots treated with 2,4-D plus MCPA resulted in the lowest yield. In herbicide treatments at both locations, yield was highest when nicosulfuron and foramsulfuron at the highest dose were applied, respectively. However, rimsulfuron at all doses could not give a satisfactory maize yield. This is confirmed by low weed populations and biomass reductions in these treatments.

In conclusion, this study reveals that nicosulfuron at 80 g ai/ha is a suitable option for the post-emergence control of broadleaved and grass weeds in maize in Iran. Since hand weeding is a costly and time-consuming job for a crop such as maize, the use of this herbicide treatment offers an opportunity for an efficient and cost-effective weed control method in maize. Also, 2,4-D plus MCPA could be replaced by nicosulfuron at 80 g ai/ha since it gives an acceptable control of broadleaved weeds while it provides satisfactory grass weed control. This would especially be beneficial from an ecological point of view since application of dual purpose herbicides allows reduced herbicide consumption rate.

References

Baghestani, M.A., Zand, E., Rahimian Mashhadi, H., Soufizadeh, S., 2005. Morphological and physiological characteristics which enhance competitiveness of winter wheat (*Triticum aestivum*) against *Goldbachia laevigata*. Iranian J. Weed Sci. 1, 111–126.

Bhowmik, P.C., O'Toole, B.M., Andaloro, J., 1992. Effects of nicosulfuron on quachgrass (*Elytrigia repens*) control in corn (*Zea mays* L.). Weed Technol. 6, 52–56.

Bruce, A.B., Kells, J.J., 1997. Quackgrass (*Elytrigia repens*) control in corn (*Zea mays*) with nicosulfuron and primisulfuron. Weed Technol. 11, 373–378.

Coble, H.D., 1994. Future directions and needs for weed science research. Weed Technol. 8, 410–412.

FAO (Food and Agricultural Organization), 2005. FAOSTAT database for agriculture. Available online at: http://faostat.fao.org/faostat/collection?subset = agriculture.

Hadizadeh, M.H., Alimoradi, L., Fereidoonpour, M., 2006. Evaluation of sulfonyl-urea herbicides in grain corn (*Zea mays* L.). In: Proceedings First Iranian Weed Science Congress. Tehran, Iran, pp. 519–523.

Koeppe, M.K., Hirata, C.M., Brown, H.M., Kenyon, W.H., O'Keefe, D.P., Lau, S.C., Zimmerman, W.T., Green, J.M., 2000. Basis of selectivity of the herbicide rimsulfuron in maize. Pesticide Biochem. Physiol. 66, 170–181.

Lum, A.F., Chikoye, D., Adesiyan, S.O., 2005. Control of *Imperata cylindrical* (L.) Raeuschel (speargrass) with nicosulfuron and its effect on the growth, grain yield and food components of maize. Crop Prot. 24, 41–47.

Morton, C.A., 1993. Selectivity and Efficacy of Sulfonylurea Herbicides and Wild-Proso Millet Competition in Field and Sweet Corn. Ph.D. Thesis. University of Wisconsin-Madison. pp. 48–59.

Mousavi, M.R., 2001. Integrated Weed Management: Principles and Methods, first ed. Meiad Press.

Najafi, H., Tollenaar, T., 2005. Response of corn at different leaf stages to shading by redroot pigweed (*Amaranthus retroflexus* L.). Iranian J. Weed Sci. 1, 127–140.

Rabaey, T.L., Harvey, R.G., 1997. Sequential applications control wooly cupgrass (*Eriocloa villosa*) and wild-proso millet (*Panicum miliaceum*) in corn (*Zea mays*). Weed Technol. 11, 537–542.

Rao, V.S., 2000. Principles of Weed Science, second ed. Science Publishers, Inc, New Hampshire.

SAS Institute, 2000. The SAS System for Windows, Release 8.0. Carry, NC: Statistical Analysis Systems Institute.

Williams, B.J., Gordon Harvey, R., 2000. Effect of nicosulfuron timing on wild-proso millet (*Panicum miliaceum*) control in sweet corn (*Zea mays*). Weed Technol. 14, 377–382.

Zand, E., Baghestani, M.A., Soufizadeh, S., PourAzar, R., Veysi, M., Bagherani, N., Barjasteh, A., Khayami, M.M., Nezamabadi, N., 2006. Broadleaved weed control in winter wheat (*Triticum aestivum* L.) with post-emergence herbicides in Iran. Crop Protection. doi:10.1016/j.cropro.2006.06.014.