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Effects of Soil Residues of Sulfosulfuron and Mesosulfuron Methyl + Iodosulfuron Methyl Sodium on Sunflower Varieties

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ABSTRACT

The effects of the residues of sulfosulfuron (75%) and mesosulfuron methyl (3%) + iodosulfuron methyl sodium (0.6%) (MM+IMS), applied at two spraying times and three application rates on two sunflower cultivars (*Helianthus annuus* L. cv. Sanbro and cv. Aitana) seeded 12 months after treatment (MAT) were studied. Specifically, their effects on the shoot length, seed yield, and yield components, including plant length, head diameter (HD), and 1000-seed weight were investigated. Field studies were conducted over a period of two years at two locations in Ankara, Turkey. Sulfosulfuron and MM+IMS were applied post-emergence to winter wheat in 2008 at 0, 9.75, 19.5 and 39 g active ingredient (ai) ha⁻¹ and 0, 4.5, 9 and 18 g total ai ha⁻¹, respectively. Sunflower cultivars were sowed after winter wheat crop in 2009. Sunflower yield was found to be the most sensitive biological parameter to the herbicidal residue in the soil, while the 1000-seed weight was the least sensitive. Sunflower yield reduction caused by sulfosulfuron ranged from 71 to 100% and 27 to 81% in site 1 and site 2 depending on the application time, variety, and application rate, respectively. Sunflower yield at site 1 was reduced 15-76% for cv. Sanbro and 20-83% for cv. Aitana when MM+IMS treated early respectively, whereas, at site 2, the same treatment resulted in 22-36% yield reduction for cv. Sanbro and 28-43% for cv. Aitana. The yield reduction caused by the same MM+IMS rates were 49-85% for cv. Sanbro and 60-87% for cv. Aitana when MM+IMS treated late at site 1 and 49-84% for cv. Sanbro and 47-87% for cv. Aitana at site 2, respectively. Generally, the sunflower yields decreased as the dose of the chosen herbicide increased at both sites. The responses of sunflower cultivars to residues of sulfosulfuron were very similar, whereas slight differences were observed between sunflower cultivars with regard to the response to MM+IMS residue. Sulfosulfuron residues were more phytotoxic to the sunflower varieties than were MM+IMS at both sites.

Keywords: Phytotoxicity; Sulfosulfuron; Mesosulfuron methyl + iodosulfuron methyl sodium; Soil residue; Rotational crop; Sunflower

Sulfosulfuron ve Mesosulfuron Methyl + Iodosulfuron Methyl Sodium'un Topraktaki Kalıntılarının Ayrıçığı Çeşitlerine Etkileri

ESER BİLGİSİ

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ÖZET

İki uygulama zamanı ve üç uygulama dozunda uygulanan sulfosulfuron (% 75) ve mesosulfuron methyl (% 3) + iodosulfuron methyl sodium (% 0.6) (MM+IMS)'un kalıntılarının 12 ay sonra ekilen iki ayçiçeği çeşidindeki etkileri araştırılmıştır. Özellikle bu herbisitlerin kalıntılarının fide uzunluğu, verim ve bitki uzunluğu, tabla çapı, bin dane ağırlığı gibi verim unsurlarına etkileri incelenmiştir. Arazi çalışmaları Ankara (Türkiye)'de iki alanda iki yıl boyunca sürdürülmüştür. Sulfosulfuron ve MM+IMS 2008 yılında kışlık buğdaya sırasıyla 0, 9.75, 19.5 ve 39 g aktif madde ha⁻¹ ile 0, 4.5, 9 ve 18 g toplam aktif madde ha⁻¹ dozda çıkış sonrası uygulanmıştır. Ayçiçeği çeşitleri kışlık buğdaydan sonra 2009 yılında ekilmiştir. Bin dane ağırlığı herbisitlerin kalıntılarında en az etkilenen biyolojik parametre iken ayçiçeği veriminin topraktaki herbisit kalıntılarına karşı en hassas biyolojik parametre olduğu görülmüştür. Ayçiçeğinde Sulfosulfuron'dan kaynaklanan verim düşüklüğü uygulama zamanı, ayçiçeği çeşidi ve uygulama dozuna bağlı olarak 1. alanda % 71-100 ve 2. alanda % 27-81 oranında değişmiştir. Ayçiçeği verimi erken dönemde MM+IMS uygulaması yapılan 1. alanda Sanbro çeşidinde % 15-76 ve Aitana çeşidinde % 20-82 oranında düşerken 2. Alanda Sanbro çeşidinde % 22-36 ve Aitana çeşidinde % 28-43 oranında düşmüştür. Ayçiçeği veriminde, geç dönemde uygulanan MM+IMS dozlarından kaynaklanan azalma 1. alanda Sanbro çeşidi için % 49-85 ve Aitana çeşidi için % 60-87 oranlarında, 2. alanda ise Sanbro çeşidinde % 49-84 ve Aitana çeşidinde % 47-87 oranında olmuştur. Her iki alanda da ayçiçeği verimi genellikle seçilen herbisit dozunun artmasına bağlı olarak azalmıştır. Ayçiçeği çeşitlerinin Sulfosulfurona tepkileri birbirlerine oldukça yakinken MM+IMS kalıntısına ayçiçeklerinin tepkileri arasında küçük bir farklılık gözlenmiştir. Her iki alanda da ayçiçeği çeşitleri için sulfosulfuron kalıntıları MM+IMS kalıntılarında daha fitotoksiktir.

Anahtar Kelimeler: Fitotoksisite; Sulfosulfuron; Mesosulfuron methyl + iodosulfuron methyl sodium; Topraktaki kalıntı; Mönavebe bitkisi; Ayçiçeği

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1. Introduction

Sunflower oil is one of the most popular types of oil in Turkish cuisine and has a long history of use. Approximately half of Turkey's total oil needs have been supplied by sunflower oil. In 2012, 1.2 million tons of sunflower seed were obtained from 5.05 million decares, which provided 54.2% of Turkey's needs (TUIK 2013). Turkey was also the country to import the most sunflower in 2010/11 because of insufficient sunflower production (SS 2013). Sunflower is commonly produced at crop-rotation systems in most sunflower production areas of Turkey, sometimes after wheat harvest. The Central Anatolia Region ranked among the top three regions in Turkey for sunflower production; this region has a terrestrial climate, with slightly alkaline soil (pH: 8 at 82%) that is low in organic matter (<1-2% at 50%).

Many factors can restrict the production of sunflower crops, including climatic conditions such as precipitation, diseases, insects, and weeds, as well as herbicidal residue in the soil, at times.

The edaphic and climatic conditions of the Central Anatolia region may cause damage to subsequently planted crops when residual herbicides are applied, especially Sulfonylurea (SU) and Imidazoline herbicides. SU herbicides are commonly used to control annual and perennial grassy weeds, as well as certain noxious broadleaf weeds. Most of the registered SU herbicides leave residues in soil, which can have undesirable effects on the following crop, non-target fish, aquatic plants, and other plants and animals.

Sulfosulfuron and MM+IMS are members of SU herbicides registered for the control of weeds in wheat crop at the rates of 15-19.5 g ai ha⁻¹ and 9-10.8 g total ai ha⁻¹, respectively (RBKÜ 2009). The major dissipation pathways of these herbicides are leaching, hydrolysis, microbial break down and adsorption by soil particles (Maheswari & Ramesh 2007). In some years, degradation of these herbicides may be slower than expected, especially in low-organic matter content and alkaline soil types or low rainfall (Eleftherohorinos et al 2004; Lyon et al 2003; Moyer & Hamman 2001).

The persistence of sulfosulfuron and MM+IMS in soil and their residual effects on sequential crops have been reported by many researchers. Work by Shinn et al (1998) indicated that barley, pea and canola yields were significantly reduced by sulfosulfuron residues and yield reduction in barley and canola increased with the rate, but not in pea. Similarly, Grey et al (2012) reported that sulfosulfuron residues caused carryover injury to soybean and cotton. Geier & Stahlman (2001) showed that sulfosulfuron, 216 days after treatment at 30 g ai ha⁻¹ reduced sunflower density by 39%. Also, Kelley & Pepper (2003) reported 17% sunflower grain yield reduction when sowed 17 MAT due to residual effect of high sulfosulfuron rate (140 g ai ha⁻¹) in a site. In another study, it has been reported that sunflower seed yields were reduced from 1.450 to 20 kg ha⁻¹ in one site and from 1.830 to 540 kg ha⁻¹ in another site depending on increasing sulfosulfuron rates from 0 to 139 g ha⁻¹ at 19 to 20 MAT (Lyon et al 2003). In addition to this, the same authors suggested that successful production of sunflower may require a minimum re-crop interval between treatment and planting of >36 months. Shaker et al (2006) demonstrated that sulfosulfuron and MM+IMS caused toxicity symptoms on some of the following pulse crops, such as lentil and chickpea. Mansoori et al (2009 & 2012) also reported that soil residues of sulfosulfuron and MM+IMS can cause injury to sunflower seedlings.

Commercial herbicide labels contain many important information and recommendations, and the re-cropping recommendation for residual herbicides is one of the important of them. The re-cropping recommendation may vary depending on the herbicide, soil type, climatic features, application rate and sensitive crops to herbicide residue.

Sulfosulfuron label for Turkey has information about subsequent sunflower crop planned to be sown safely in the same field. However, MM+IMS label for Turkey does not contain any information on subsequent sunflower crop (AWGH 2008). In mesosulfuron-methyl and iodosulfuron-methyl sodium labels for Australia, minimum re-cropping intervals have been expressed as 12 months or over for safe sunflower cropping (AODH 2013; HH 2013). If residual herbicides are applied in semi-arid regions, required re-cropping intervals should be known for the selection of the right following crops.

Although there are many studies on the effects of soil residues of sulfosulfuron on consecutive sunflower crops, there is only limited information with relation to the effect of MM+IMS soil residues on following sunflower crops. The objective of this study was to determine the effects of sulfosulfuron and MM+IMS applications previously done at three rates, two times and two experimental sites on the biological parameters of two sunflower varieties grown after winter wheat in crop rotation systems in the Central Anatolian Region of Turkey.

2. Material and Methods

Field experiments were conducted in two different areas in two consequent years in a dry land cropping environments near Ankara, Turkey. The soil types at both sites were loamy-clay and slightly alkaline. Some additional physical and chemical properties of the soils in the trial fields were presented in Table 1. Thirty years' average annual precipitation and mean air temperature at both sites were 350 mm and 11.3 °C, respectively. During trials, precipitation at both sites was 33% below the average while average daily air temperature was 0.8 °C above

Table 1- Soil characteristics of the two experimental fields

Çizelge 1- İki deneme alanının toprak özellikleri

Site	Soil type			pH (1:2.5 soil to water)	Total salt (%)	CaCO ₃ (%)	Organic matter (%)	EC (dS m ⁻¹)
	Sand (%)	Loam (%)	Clay (%)					
1	27.6	30.9	41.6	7.92	0.037	31.07	2.49	0.935
2	32.5	26.3	41.2	7.93	0.039	15.85	1.46	0.994

the normal. The field experiment was a split-split-plot in a randomized complete block design with four replications. Herbicide application times (05.04.2008 for early application and 19.04.2008 for late application), herbicide doses (0, 9.75, 19.5 and 39 g ai ha⁻¹ doses for sulfosulfuron and 0, 4.5, 9 and 18 g total ai ha⁻¹ doses for MM+IMS) and sunflower varieties (cv. Sanbro and cv. Aitana) were arranged as the main plot, the sub-plot and the sub-sub-plot, respectively. Sub-sub-plot size was 3 x 8 m, and there were 0.5-m alleyways between plots and 1 m between blocks.

The field experiments were carried out at two sites using adapted protocols described by Kelley & Peeper (2003). Winter wheat Bezostaja-1 was sown at 140 kg ha⁻¹ on October 25, at site 1 and at 160 kg ha⁻¹ on October 17, at site 2 in 2007. Agricultural practices for wheat and subsequent sunflower were given in Table 2. Commercial products of herbicides were applied to wheat in early and middle April at the rates of 9.75 (half of recommended dose), 19.5 (recommended dose) and 39 (double dose) g ai ha⁻¹ with a non-ionic surfactant for sulfosulfuron and at 4.5 (half of recommended use rate), 9 (recommended use rate) and 18 (double rate) g total ai ha⁻¹ with biopower for MM+IMS. Different rates of herbicides were sprayed using a knapsack sprayer with anti-drift flat-fun nozzle (Lechler AI 110-015), 50 cm nozzle spacing, at 200 L ha⁻¹ carrier volume when winter wheat seedlings reached one to three tillers and first to third node detectable stage. After the harvest of winter wheat, sub-plots to be cultivated with winter wheat were individually moldboard plowed (25 cm depth), and cultivated

with a standard cultivator (25 cm depth). The same soil cultivation practices were repeated for each sub-plot to avoid movement of soil between plots to prepare a seedbed for subsequent sunflower.

Trials, carried out on subsequent sunflower plantings, were conducted in the same winter wheat plots described above. Each sub-plot consisted of 24 beds with 3 sunflower plants each. Sunflowers were seeded at 35-cm intervals in 70-cm wide rows using a hand grain drill to a depth of 5-7 cm, and then thinned to one plant per bed after emergence. The weeds emerged between sunflowers were hand-weeded on May 23-24, 2008. Additional agronomic practices were presented in Table 2.

Sunflowers were evaluated for shoot length (30 days after emergence), plant length, head diameter, 1000-seed weight, and yield at crop maturity (Alonso-Prados et al 2002; Kelley & Peeper 2003; Ullah et al 2001; Kaya et al 2009). Five randomly chosen sunflower plants in three rows from the center of each plot were counted at one month after emergence and at crop ripening (Kelley & Peeper 2003). Plant height, shoot height and head diameter were measured from the soil surface to the tip of the plant stem, up to the shoot tip and from one edge of the head to the other, respectively (Alonso-Prados et al 2002; Khan et al 2003; Tyagi et al 2013). Sunflower seed yields were determined from each of 5 plants mentioned above per plot. The sunflower seeds were cleaned manually to remove immature seeds and sunflower seed yields adjusted to 10% moisture. The weight of 1000 seeds was calculated by counting 1000 randomly selected sunflower seeds from each plot.

Table 2- Agronomical practices at two sites

Çizelge 2- İki deneme alanında yapılan tarımsal uygulamalar

Site	Wheat				Sunflower				
	Seeding	Harvest	Tillage		Seeding	Emergence of seeds	Thinning	Weeding (by hand)	Harvest
			Autumn	Spring					
1	25.10.2007	13.07.2008	05.10.2008 24.10.2008	14.03.2009 08.04.2009	18.04.2009	06.05.2009	16.05.2009	23.05.2009	05.09.2009
2	17.10.2007	17.07.2008	06.10.2008 29.10.2008	17.03.2009 11.04.2009	19.04.2009	07.05.2009	17.05.2009	24.05.2009	12.09.2009

Means were separated using Fisher's protected LSD at the 5% level of significance. Analysis of variance was conducted using SPSS statistical software (SPSS 2004).

3. Results and Discussion

3.1. Effect of sulfosulfuron and MM+IMS residues on shoot and plant height

Sunflower shoot lengths, grown in sulfosulfuron applied plots dramatically decreased compared with controls depending on the increase on sulfosulfuron rates. This was especially obvious with label rates and double rates, at the both sites for two varieties, except one where the treatment in plots was applied only for half of recommended rate at site 1 (Table 3). Shoot lengths were not affected by herbicide application times when sulfosulfuron treatments were made to the winter wheat at recommended and double rates, however, the effect of application time on sulfosulfuron

residues was significant when applied at the half rate, except site 2 for cv. Sanbro. This unexpected result may cause hormesis, stimulatory effect of low concentration of an herbicide on the growth of plant (Wiedman & Appleby 1972; Cedergreen 2008). Reduction of shoot lengths measured in MM+IMS treated plots, was similar to findings obtained from sulfosulfuron, particularly in the plots sown with the Sanbro variety (Table 4). Shoot reduction in the plots sown with cv. Aitana was slightly less compared to cv. Sanbro, especially at half and recommended rate treatments (Table 4). This slight shoot length reduction on cv. Aitana may have stemmed from the features of this variety since; it grows slower than cv. Sanbro. Previous studies also showed that sulfosulfuron and MM+IMS residues could cause severe shoot reduction on sunflower seedlings (Alonso-Prados et al 2002; Mansoori et al 2009).

Plant heights were reduced significantly by the residues of sulfosulfuron at all the application rates

Table 3- Effects of residues of sulfosulfuron applied at two spraying times and three rates on seed yield and yield components of sunflower varieties seeded 12 months after treatment in Central Anatolian Region

Çizelge 3- Orta Anadolu Bölgesinde 2 ilaçlama zamanı ve 3 uygulama dozunda uygulanan sulfosulfuronun kalıntılarının 12 ay sonra ekilen ayçiçeği çeşitlerinin verim ve verim unsurlarına etkisi

Variety	Application time	Rate g ai ha ⁻¹	cv. Sanbro				cv. Aitana							
			Shoot length (cm)	Plant length (cm)	Head diameter (cm)	Yield (kg da ⁻¹)	1000-seed weight (g)	Shoot length (cm)	Plant length (cm)	Head diameter (cm)	Yield (kg da ⁻¹)	1000-seed weight (g)		
Site 1	Early	Control	17.61	117.16	14.29	140.4	45.60	10.38	112.99	13.83	150.75	43.90		
		9.75	15.29	70.99	6.82	40.44	40.70	11.88	66.60	6.61	36.97	39.10		
		19.5	8.03	61.43	3.40	31.74	38.88	5.20	58.98	3.21	34.1	38.33		
		39	7.53	46.08	3.05	18.4	38.75	3.84	34.77	2.08	21.57	39.53		
		9.75	8.92	55.27	3.57	25.02	37.95	5.75	48.07	2.83	24.25	40.15		
	Late	19.5	7.97	50.77	3.13	13.22	37.18	5.48	43.88	2.59	16.61	39.15		
		39	5.65	-	-	-	-	4.72	-	-	-	-		
		LSD (0.05)	2.69	10.21	1.29	13.31	NS	1.48	8.53	1.19	15.00	NS		
		Site 2	Early	Control	19.12	133.03	14.89	159.85	47.20	13.59	123.43	15.18	166.56	45.00
				9.75	14.69	111.26	12.55	116.8	40.33	10.71	98.60	11.31	109.18	40.68
19.5	11.38			86.63	8.97	75.11	37.78	8.39	79.53	6.86	80.57	40.15		
39	9.10			78.02	8.34	63	38.98	6.98	73.47	6.82	54.84	35.25		
9.75	12.01			95.91	10.94	59.52	40.65	7.04	73.75	7.55	61.84	38.10		
Late	19.5		10.69	79.88	7.89	65.92	38.90	6.73	60.51	4.69	56.82	33.45		
	39		9.58	48.03	4.32	33.06	30.30	5.84	49.72	3.50	32.32	32.85		
LSD (0.05)	2.84	9.28	1.46	12.56	2.78	1.94	10.16	1.30	20.49	NS				

-, plants died; NS, not significant

in both sites compared with non-treated controls for both varieties (Table 3). But sunflowers sown in the plots that were applied to double rates of sulfosulfuron in site 1 were killed. In site 1, late applications of sulfosulfuron at two treatment rates caused high reduction in plant height compared to early application (Table 3). In site 2, reduction in plant height depended on application time of sulfosulfuron, which was very similar to site 1 (Table 3). Plant heights were affected by sulfosulfuron application rate and site. In general, reduction of plant height in plots sprayed earlier was lower than late treated ones (Table 3). This difference may be caused by degradation of more sulfosulfuron molecules in the soil during the fourteen days.

Plant heights at both sites were similar to the non-treated control when MM+IMS was applied

early at half of the recommended rate (Table 4). Plant heights in the plots sowed Sanbro cultivar in site 1 were higher than non-treated control. Hormesis stated above may have resulted in this circumstance (Cedergreen 2008). However, MM+IMS applied lately caused reduction in plant heights at the same herbicide rate at both sites. It was noted that high rates of MM+IMS, 9 and 18 g total ai ha⁻¹ caused severe injury and reduced plant height significantly at the two sites (Table 4). Stunting was greater in late applied plots compared to early applications. Similar results were obtained from both sunflower varieties. The effect of application time on herbicide residue was important for all the treatment. Stunting in plots treated with sulfosulfuron was higher compared to MM+IMS because sulfosulfuron residues were more phytotoxic than MM+IMS residues.

Table 4- Effects of residues of mesosulfuron methyl + iodosulfuron methyl sodium applied at two spraying times and three rates on seed yield and yield components of sunflower varieties seeded 12 months after treatment in Central Anatolian Region

Çizelge 4- Orta Anadolu Bölgesinde 2 ilaçlama zamanı ve 3 uygulama dozunda uygulanan mesosulfuron methyl + iodosulfuron methyl sodium kalıntılarının 12 ay sonra ekilen ayçiçeği çeşitlerinin verim ve verim unsurlarına etkisi

Variety	Application time	Rate		cv. Sanbro				cv. Aitana				
		g total ai ha ⁻¹	Shoot length (cm)	Plant length (cm)	Head diameter (cm)	Yield (kg da ⁻¹)	1000-seed weight (g)	Shoot length (cm)	Plant length (cm)	Head diameter (cm)	Yield (kg da ⁻¹)	1000-seed weight (g)
Site 1	Early	Control	17.61	117.16	14.29	140.38	45.60	10.38	112.99	13.83	150.75	43.90
		4.5	12.51	122.32	13.50	118.86	41.10	9.02	104.44	11.32	120.38	41.60
		9	9.53	84.79	7.54	55.91	41.13	6.77	74.24	6.51	63.07	40.55
	Late	18	9.18	77.56	6.39	34.26	40.55	5.99	59.94	3.94	25.26	40.70
		4.5	11.60	78.46	9.30	71.83	41.53	7.89	72.15	7.17	59.79	40.83
		9	9.30	70.19	7.27	33.15	38.95	6.51	60.29	5.53	34.23	40.55
			18	8.68	58.47	4.90	20.49	40.48	5.33	46.42	3.19	19.08
		LSD (0.05)	2.30	8.13	1.55	13.77	3.21	NS	8.93	1.58	22.34	NS
Site 2	Early	Control	19.12	133.03	14.89	159.85	47.20	13.59	123.43	15.18	166.56	45.00
		4.5	16.76	124.59	13.66	123.90	40.13	12.88	115.65	13.91	119.58	39.48
		9	14.93	118.69	12.79	118.15	40.13	11.87	114.17	14.23	115.57	39.70
	Late	18	12.28	119.65	13.39	101.16	41.13	8.76	102.28	13.74	94.85	40.65
		4.5	12.03	94.57	11.06	81.37	41.65	8.94	88.39	8.78	88.44	38.55
		9	11.55	92.43	10.12	58.73	40.83	7.45	80.48	8.76	58.33	40.60
			18	7.28	75.18	8.30	24.98	40.10	6.80	59.68	4.57	21.57
		LSD (0.05)	2.10	10.04	1.58	16.77	2.64	2.77	8.89	1.12	24.73	3.15

NS, not significant

The stunting effect of residue of commonly used SU herbicides, including sulfosulfuron and MM+IMS, on field crops, such as corn, grain sorghum, lentil, soybean and sunflower, have been known for a long time. This inhibitory effect of sulfosulfuron and MM+IMS can vary depended on duration, application rate, soil type and precipitation.

3.2. *Effect of sulfosulfuron and MM+IMS residues on 1000-seed weight*

All treatments reduced 1000-seed weight with increasing application rates of sulfosulfuron compared to the control (Table 3). But, the reductions observed in the weight of 1000-seed were not statistically significant, except in the plots sown with Sanbro variety at site 2. Nevertheless, in sulfosulfuron applied plots, significant differences in 1000 seed weight were recorded due to the growth decline in plants (Table 3). Effects of the MM+IMS applications on 1000-seed weight were important compared to the control; however, there were no differences among treatment, except for in a plot applied double rate MM+IMS (Table 4). This considerable difference may be caused by the growth retardation in seeds due to inhibition of ALS enzymes.

Effects of herbicide residues on 1000-seed weight weren't studied in detail by weed scientists and agronomists. Our results are in agreement with the findings of Aksoy (2009) who determined that a slight decline occurred in 1000-seed weight when lentil seeds sowed in the plots previously applied sulfosulfuron and MM+IMS in the dry farming system.

3.3. *Effect of sulfosulfuron and MM+IMS residues on head diameter (HD) and yield*

Sunflower HD and yield declined dramatically as the herbicides application rates increased from 0 to double of the recommended rate at both sites (Table 3-4). The HD and the yield reduction caused by sulfosulfuron and MM+IMS residues in the soil at both sites were lower in the early-applied treatments than from those late-applied ones for two sunflower varieties. The most detrimental effect of sulfosulfuron residues was observed on plants grown

in the plots treated by double rates of sulfosulfuron at site 1 (Table 3). Total loss of sunflower yield in these plots occurred because of high levels of sulfosulfuron residue; however the plants in plots treated by double rate of sulfosulfuron at site 2 were severely stunted, but were not killed. Reduction in HD and yield at site 1 was more severe than site 2 due to higher level of sulfosulfuron residue in the soil. The response of cv. Aitana to sulfosulfuron residue was very similar to the response of cv. Sanbro at both sites (Table 3). Among the yield component characters, HD was the most important biological parameter. However, the effect of HD on the yield was limited because most of seeds in the sunflower head were not mature and the others were empty in the time of harvest, especially in plots treated high rates.

MM+IMS treatments in previous year significantly reduced seed yield of two sunflower varieties at the both sites as the rate was increased. Similar to the findings obtained from sulfosulfuron treated plot, at site 1, higher HD and yield reduction was observed compared to site 2. Response of sunflower varieties to MM+IMS residue was slightly varied depending on the application rates at both sites (Table 4). Response of crop varieties to herbicide residues could be different due to their varied inheritance (Punyadee 2007). Crop cultivars may also exhibit different response to sulfonylurea herbicides (Bailey et al 2004; Crooks et al 2004; Serim & Maden 2013).

The degradation of sulfosulfuron was depended on soil reaction, organic matter content and precipitation (Shinn et al 1998). The soils which contain high amount of organic matter can absorb more sulfosulfuron, and in acidic soils, sulfosulfuron can easily degrade because of breaking of the sulfonylurea bridge (Moyer & Hamman 2001; EPM 2003). The level of carryover injury caused by sulfosulfuron on sunflower may be small since bioavailability of sulfosulfuron in these soils is decreased. In our study, the soils in site 1 contained higher amount of organic matter than site 2. The main empirical expectation in our study was that sunflower yield and yield components reduction in

site 2 should be higher than site 1. Contrary to our expectation, the decline in yield and its component was more severe in site 1. This unexpected result may be caused more sulfosulfuron molecules absorbed from soil organic matter in site 1 while more sulfosulfuron molecules was degraded by soil microorganism in site 2 during this time interval. A similar discrepancy between soil organic matter content and sunflower injury was found by Lyon et al (2003), who concluded that the greater pH and lower organic matter content may be induced microbial degradation of sulfosulfuron and thus decrease in herbicide concentration in the soil.

Sunflower seed yields obtained in the plots treated with early application of sulfosulfuron and MM+IMS were greater than seed yields taken from the other plots. The reason of this significant difference might be that plots treated with early application of sulfosulfuron and MM+IMS received more precipitation. The difference in rainfall between the herbicide application times was 29.7 mm. This precipitation amount might contribute more sulfosulfuron and MM+IMS degradation, resulting in less sunflower injury. Our results were consistent with that of Asha (2009); the persistence of sulfosulfuron decreased with increase in moisture level.

4. Conclusions

Our findings were obtained in a limited range of soil and environmental conditions and these results may not give an exact conclusion since Turkey has different soil types and climatic systems. But, this study indicated that sulfosulfuron and MM+IMS residues can remain in the soils of Central Anatolian Region at high levels. Especially, these herbicide residues can cause severe damage when there is not sufficient rainfall. Twelve months' re-cropping intervals from herbicide treatment on winter wheat to sowing sunflower seed, were inappropriate taking into consideration of the soil structure and climatic conditions in the region. Sulfosulfuron and MM+IMS should be used at early spring time and at a reduced rate to avoid carryover effect of these herbicides. This information supports a recommendation to

restrict use of sulfosulfuron and MM+IMS in winter wheat especially if standard sunflower varieties, such as cv. Sanbro and cv. Aitana, are chosen as a rotational crop. However, additional trials are needed to investigate the response of sunflower to sulfosulfuron and MM+IMS in different soil and climatic conditions and to the other SU herbicides.

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