RESEARCH

Field bindweed (*Convolvulus arvensis* L.) and redroot pigweed (*Amaranthus retroflexus* L.) control in potato by pre- or post-emergence applied flumioxazin and sulfosulfuron

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Field bindweed (*Convolvulus arvensis* L.) is one of the most serious weeds in potato (*Solanum tuberosum* L.), but selective herbicides controlling this weed have not been reported. A field experiment was conducted in 2010 and repeated in 2011 in Greece to study the efficacy of herbicides flumioxazin and sulfosulfuron, applied pre- or post-emergence, on field bindweed and redroot pigweed (*Amaranthus retroflexus* L.), as well as their phytotoxicity on potato. Gas chromatography-mass spectrography (GC-MS) and high-performance liquid chromatography (HPLC) analyses were conducted for possible herbicide residues in potato tubers. Also, the efficacy of these herbicides on field bindweed generated from root fragments was investigated in greenhouse pot experiments. In pots, both herbicides provided 78% to 100% control of field bindweed generated from root fragments. In field, both herbicides when applied pre-emergence at 72 to 144 g ai ha^{-1} provided 65% to 100% field bindweed control. However, the corresponding post-emergence applications did not provide satisfactory weed control. All treatments provided excellent control of redroot pigweed. Potato growth was not significantly affected by herbicide application in 2010. However, in 2011, post-emergence applications of flumioxazin caused significant crop injury and yield reduction. The results of this study indicate that satisfactory control of field bindweed and redroot pigweed, as well as high potato yield can be obtained by the pre-emergence application of flumioxazin or sulfosulfuron at 72 to 144 g ai ha^{-1}, without herbicide residues on potato tubers.

Key words: Herbicide residues, phytotoxicity, *Solanum tuberosum*.

INTRODUCTION

Field bindweed (*Convolvulus arvensis* L.), also called creeping jenny, European bindweed, and wild morning-glory, is a deep-rooted perennial weed of the morning glories (Convolvulaceae) family, and it reproduces by both seeds and root fragments (DeGennaro and Weller, 1984; Mitich, 1991). Field bindweed has been declared as a noxious weed and it is one of the most serious weeds of agricultural fields in temperate regions of the world. It competes with crop plants for water and nutrients and additionally its vines climb on plants shading crops, lodging small grains, and hindering harvest (Mitich, 1991; Bond et al., 2007). Redroot pigweed (*Amaranthus retroflexus* L.) is one of the most troublesome annual weeds in Greek potato fields and the most widely distributed species of the genus *Amaranthus* in Europe (Damanakis, 1983; Hanf, 1983). In favorable conditions it can grow to 2 m tall and produce over a million seeds. It competes with crops for water and nutrients and additionally it shades crops because of its greater height (Buchanan and Burns, 1971).

Weed control with pre-emergence or early post-emergence applied herbicides is the most common practice in potato (*Solanum tuberosum* L.) grown in Greece and worldwide (Eleftherohorinos et al., 2000; Tonks et al., 2000; Wilson et al., 2002). The fact that potato growers have few available herbicide options (i.e. metribuzin, pendimethalin, linuron, rimsulfuron, and prosulfocarb) (Bailey et al., 2001) and the reduced efficacy of the herbicides used in potato crop could account for the field bindweed spread in Greek potato fields (I. Vasilakoglou, unpublished data, 2009). Also, field bindweed has been described as the most serious foreign weed menace in UK (Firbank et al., 2002), while Tóth et al. (1999) reported that this weed widely spread throughout Hungary.

Mechanical cultivation provides minimal control of field bindweed due to its deep and extensive rootstocks, as well as its high ability to produce vigorously new plants. Moreover, mechanical cultivation can facilitate spread of plants by dispersing root fragments (Bond et al., 2007).

Flumioxazin is an *N*-phenylphthalimide herbicide registered for use in soybean (*Glycine max* L.), peanuts

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(*Arachis hypogaea* L.), and trees (Taylor-Lovell et al., 2001; Kelly et al., 2006). It controls several key weed species of potato, including redroot pigweed, common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.), and barnyardgrass (*Echinochloa crus-galli* [L.] P. Beauv.) (Wilson et al., 2002). Sulfosulfuron is a sulfonylurea herbicide that is registered for pre- and post-emergence weed control in wheat. Also, it has been tested for possible use in broadleaf crops as potato in Poland (Kutzior et al., 1999) and tomato in Israel (Eizenberg et al., 2003). Sulfosulfuron inhibits the emergence of serious weeds, including redroot pigweed, black nightshade (*Solanum nigrum* L.), jimsonweed (*Datura stramonium* L.), common cocklebur (*Xanthium strumarium* L.), and wild mustard (*Sinapis arvensis* L.) (Eizenberg et al., 2003). Both herbicides could control triazine-resistant weeds observed in potato (Eleftherohorinos et al., 2000), although sulfosulfuron, in contrast to flumoxazin, represents a mode of action that has already lead to the selection of herbicide-resistant weed biotypes (HRAC, 2012).

Reports of research on field bindweed control in potato are relatively limited in literature. Because flumioxazin and sulfosulfuron have been shown to control several weeds that are problematic in potato, the objectives of this study were i) to evaluate, in pot experiments, the sensitivity of field bindweed plants, generated from root fragments, to pre- or post-emergence applied flumioxazin and sulfosulfuron, ii) to evaluate, under field conditions, the efficacy of these herbicides on field bindweed and redroot pigweed, their phytotoxicity on potato cv. Spuda (the most common potato cultivar in Greece), as well as their most appropriate application rate and timing, and iii) to detect possible residues of these herbicides on potato tubers.

MATERIALS AND METHODS

Pot experiment

The pot experiment was conducted at the Technological and Educational Institute of Larissa, centre Greece, during 2010. Experiment was carried out using 20 cm diameter by 30 cm deep plastic pots filled with a mixture of sandy clay loam (SCL) soil:sand (4:1 v/v). The characteristics of the soil used in the experiment were clay 291 g kg^{-1}, silt 200 g kg^{-1}, sand 509 g kg^{-1}, organic matter 12 g kg^{-1}, and pH (1:1 H_2O) 7.5. Field bindweed plants for the pot experiment were generated from root fragments. Three root fragments (6, 10, and 15 cm long) of field bindweed were planted in each pot and covered with 3 cm of soil. All pots were placed in a greenhouse and irrigated as needed. Pots were maintained at temperatures of 10 to 16 °C during the night and 18 to 26 °C during the day (optimum for field bindweed growth). Emergence was approximately completed 2 wk after planting. The treatments consisted of three rates of flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione) and sulfosulfuron (*N*-[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]-2-(ethylsulfonyl)imidazol[1,2-*a*]pyridine-3-sulfonamide) applied pre-emergence (PRE) or post-emergence (POST) when field bindweed plants were at the six- to ten-leaf growth stage (at approximately 5 wk after planting). Both herbicides were applied at 36, 72, and 108 g ai ha^{-1}. In POST applications, flumioxazin and sulfosulfuron treatments were applied in mixture with a non-ionic surfactant (a mixture of oleic acid, fat alcohol polyalkoxylate phosphate, and methyl oleate/palmitate) (Dash HC, BASF Agro, Limburgerhof, Germany) at 0.1% (v/v). Also, an untreated control was included. All herbicide treatments were applied in 300 L ha^{-1} of water at 280 kPa using an air-pressurized hand-held field sprayer (AZO-Sprayers, Ede, The Netherlands) with a 2.4 m wide boom fitted with six 8002 flat fan nozzles (Teejet Spray System, Wheaton, Illinois, USA).

A completely randomized design with three replicates was used. The experiment was conducted twice. Field bindweed control was assessed by counting number of both survived and emerged new plants (from root fragment buds) per pot at 3, 5, 7, and 9 wk after the PRE treatments. Also, the fresh weight of all survived plants in each pot was weighed at 9 wk after treatments.

Field experiment

Two field experiments were conducted in 2010 (season 1) and 2011 (season 2) to determine the effects of application rate and timing of flumioxazin and sulfosulfuron on field bindweed and redroot pigweed control and potato yield. In season 1, the experiment was established at a commercial farm in Livanates, centre Greece (38º41'26" N, 23º02'23" E, 40-50 m a.s.l.), on a clay loam (CL) soil whose characteristics were sand 460 g kg^{-1}, silt 150 g kg^{-1}, clay 390 g kg^{-1}, organic matter content 16 g kg^{-1}, and pH (1:2 H_2O) 7.3. In season 2, the experiment was established at the Technological and Educational Institute Farm of Thessaloniki in northern Greece (40º37'06" N, 22º44'10" E, 0-1 m a.s.l.) on a sandy loam (SL) soil whose characteristics were sand 644 g kg^{-1}, silt 280 g kg^{-1}, clay 76 g kg^{-1}, organic matter content 10 g kg^{-1}, and pH (1:2 H_2O) 7.6. Mean monthly temperature and rainfall data recorded near the experimental areas are shown in Figure 1.

Nitrogen, P, and K at 120, 60, and 60 kg ha^{-1}, respectively, were incorporated before potato planting. Variety Spuda of potato was planted at 1200 kg ha^{-1} on 25 July 2010 (season 1) and on 20 March 2011 (season 2). Potato seed pieces were planted at 20-cm intervals in rows spaced 60 cm apart. The crop was not hilled according to common practice of Greek potato growers. Plots were irrigated as needed throughout growing seasons with overhead sprinklers to maintain minimum available soil water content of 65% (standard grower practice). Natural

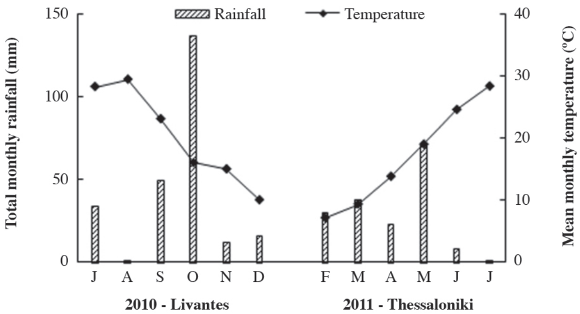

Figure 1. Total monthly rainfall and mean monthly temperature during experiments.

field bindweed and redroot pigweed infestation of 15 to 25 and 45 to 65 plants m^{-2}, respectively, emerged each season. The other annual weeds observed at very low densities were not evaluated and were hand-removed. Insect and pathogen control was imposed as needed during growing seasons.

A randomized complete block design was used for each experiment with four replicates per treatment. Plot size was 2.5 × 7.0 m including four rows of potato. Treatments consisted of three rates of flumioxazin and sulfosulfuron applied PRE and POST 3 wk after planting when the first potato stems were at the six-to twelve-leaf growth stage. In season 1, both herbicides were applied at 36, 72, and 108 g ai ha^{-1}. However, in season 2, herbicides were applied at 72, 108, and 144 g ai ha^{-1}, because of the low efficacy of the lowest rate observed in season 1. In POST application, flumioxazin and sulfosulfuron treatments were applied in mixture with a non-ionic surfactant (Dash HC) at 0.1% (v/v). Also, two untreated (weedy and weed-free) controls were included. An air-pressurized hand-field plot sprayer, with a 2.4 m wide boom fitted with six 8002 flat fan nozzles was calibrated to deliver 300 L ha^{-1} water at 280 kPa.

Assessments were made at 3, 6, and 8 wk after PRE application of herbicides. Field bindweed and redroot pigweed plants present in the center 1.2 × 6 m^2 of each plot were counted. Potato stem number was counted at 3 and 6 wk after PRE application. In addition, potato injury (plant death and reduced growth) was visually estimated using a scale of 0% (no injury) to 100% (complete plant death) at 6 and 8 wk after PRE application. On 28 November 2010 and on 7 July 2011, potato tubers from 1.2 × 6 m^2 located in the two centre of each plot were harvested by hand, 1 wk after the complete vine senescing. The total tuber yield of potato was recorded. Also, 2 kg samples were taken from each plot for further examination for possible residues detection.

Herbicide residue analysis

Regarding the determination of flumioxazin, the sample preparation protocol for residue analysis of flumioxazin in potato samples was adopted from Pihlström et al. (2007) with some modifications. In particular, 500 g of each sample was chopped in small pieces and homogenized. An aliquot of 50 g was transferred into an Erlenmeyer flask and 200 mL of a mixture of ethyl-acetate/acetonitrile (80/20 v/v) and 50 g anhydrous sodium sulfate were added. Subsequently, the sample was homogenized for 10 min. A portion of the obtained clear supernatant was centrifuged for 5 min at 3000 rpm and filtered through 0.45 μm disposable filters. Then the sample was evaporated to dryness by a gentle stream of N and reconstituted with 1 mL hexane prior to gas chromatography-mass spectrography (GC-MS) analysis. The analysis detection limit was 0.01 mg kg^{-1}.

Regarding the determination of sulfosulforon, the potato samples were prepared according to Kang's method with slight modifications (Kang et al., 2011). In particular, 500 g of each sample was chopped in small pieces and homogenized. Then, 100 g of sample were placed into an Erlenmeyer flask followed by the addition of 200 mL phosphate buffer (0.1 mol L^{-1}, pH 9.5)/acetonitrile, 90/10 v/v. After the sample was homogenized/extracted for 10 min, a portion of the extract was transferred to a 50 mL Teflon centrifuge tube and centrifuged for 10 min at 4000 rpm. A 20 mL sample of the clear supernatant was acidified by adding drops of concentrated phosphoric acid (w = 85%, ϱ = 1.7 g mL^{-1}) in order to obtain a pH of 2.5. Samples were further purified by a simple solid phase extraction (SPE) protocol using OASIS HLB cartridges (Waters). The SPE procedure consisted of the following steps: i) conditioning of the SPE sorbent by adding 2 mL acetonitrile and 2 mL water, ii) sample loading (3 mL), iii) washing with 1 mL phosphate buffer (pH 2.5), and iv) sample elution with 1 mL acetonitrile. The final sample was directly analyzed by high-performance liquid chromatography (HPLC). The analysis detection limit was 0.001 mg kg^{-1}.

Statistical analyses

For the greenhouse data (field bindweed plant number and fresh weight), a combined over repetition time ANOVA was performed. Variances not meeting ANOVA assumptions were transformed appropriately. In particular, field bindweed plant number and fresh weight data before the ANOVA were $\sqrt{(x+1)}$ and $\log_{10}(x+1)$ transformed, respectively, in order to reduce their heterogeneity.

Field bindweed and redroot pigweed plant number data, as well as potato stem number, injury and tuber yield data were subjected to a combined over-season ANOVA. Because the ANOVA indicated significant season × herbicide treatment interaction, data were analyzed separately for each season. Potato data were not transformed before the ANOVA as it was not necessary, but weed plant number data were $\sqrt{(x+1)}$-transformed to reduce their heterogeneity.

The MSTAT program (MSTAT-C, 1988) was used to analyze variances.

RESULTS AND DISCUSSION

Pot experiment

ANOVA indicated that at 9 wk after PRE application all herbicide treatments significantly (P < 0.001) reduced field bindweed stem number and fresh weight; however, both herbicides were slightly more effective after PRE application (Table 1). In particular, PRE-applied sulfosulfuron rates reduced field bindweed stem number and fresh weight by 79% to 100% and 82% to 100%, respectively. The corresponding reductions caused by POST application were 78% to 90% and 84% to 88%. Flumioxazin applied PRE caused field bindweed stem number and fresh weight reduction from 98 to 100%. However, POST application of this herbicide caused stem number and fresh weight reduction which ranged from 89% to 96% and 90% to 98%, respectively.

The recorded greater field bindweed susceptibility to flumioxazin compared with that to sulfosulfuron could be attributed to their differences in activity against this weed and possibly to their absorption differences (Devine and Vanden Born, 1991). The greater susceptibility of field bindweed (generated from root fragments) to PRE applications of both herbicides, compared with that to their POST applications could be attributed to greater herbicide absorption by the weed roots compared with that by weed leaves and stems (WSSA, 2007). However, Eizenberg et al. (2003) found that POST application of sulfosulfuron resulted in the most efficient control of field bindweed, maybe due to the fact that in this experiment weed plants were generated from seeds.

The greater efficacy of all herbicides in pot experiment compared to those in field experiments could be attributed to greater spray volume reached the field bindweed plants (as a result of the absence of potato plants) and to better weed growth conditions which resulted in greater herbicide absorption by the weed (Devine and Vanden Born, 1991). This greater efficacy could be additionally attributed to the limited root development and the increased root/herbicide exposure, as well as to the limited degradation of herbicides in pots.

Field experiment

At 8 wk after PRE application in both seasons, field bindweed plant number was significantly affected (P < 0.001) by herbicide treatments (Table 2). Similarly with the pot experiment, both herbicides were more effective when they were PRE-applied. However, herbicide efficacy in season 2 was greater than that in season 1, when herbicides were PRE-applied. The greater content in sand and the lower organic matter percentage of the soil in season 2, compared with season 1, which resulted in lower herbicide adsorption, could respond for these differences (Eleftherohorinos et al., 2004; WSSA, 2007). In particular, sulfosulfuron and flumioxazin PRE-applied in season 1 reduced field bindweed plant number by 30 to 65% and 12 to 82%, respectively. The corresponding reductions caused by POST applications were 0% to 48% and 0% to 77%. In season 2, PRE application of 108 and 144 g ai ha^{-1} reduced by 100% field bindweed plant number. The reduction caused by POST applications ranged from 13% to 62%. Regarding redroot pigweed, in both seasons, all herbicide treatments brought this weed under excellent control (data not shown).

Although an across application timing analysis was not performed, averaged across season and assessment time, both herbicides provided lower control of field bindweed when POST-applied. Again, the greater susceptibility of field bindweed to PRE applications of both herbicides, compared with POST applications, could be attributed to greater herbicide absorption by weed roots compared with those by weed leaves and stems (WSSA, 2007). Wilson et

Table 1. Effects of sulfosulfuron and flumioxazin on field bindweed stem number and fresh weight at 9 wk after pre-emergence application in pots. Means are averaged across two experiments.

Herbicide	Application timing	Rate	Squared-root		Fresh weight	
		g ai ha^{-1}	(stems pot^{-1}) + 1		Log_{10}[(g pot^{-1}) + 1]	
Sulfosulfuron	PRE	36	1.90	2.6[1]	0.38	1.38
		72	1.30	0.7	0.06	0.14
		108	1.00	0.0	0.00	0.00
	POST	36	1.92	2.7	0.35	1.25
		72	1.61	1.6	0.31	1.05
		108	1.48	1.2	0.28	0.90
Flumioxazin	PRE	36	1.00	0.0	0.00	0.00
		72	1.10	0.2	0.03	0.07
		108	1.00	0.0	0.00	0.00
	POST	36	1.55	1.4	0.25	0.78
		72	1.38	0.9	0.13	0.36
		108	1.22	0.5	0.05	0.13
Control	-	-	3.65	12.3	0.94	7.81
se_{df}=72			0.10		0.03	

PRE: pre-emergence; POST: post-emergence; se: standard error; df: error degrees of freedom.
[1]Back-transformed values.

Table 2. Efficacy of sulfosulfuron and flumioxazin on field bindweed, 8 wk after pre-emergence application in field.

Herbicide	Application timing	Season 1			Season 2		
		Rate	Squared-root		Rate	Squared-root	
		g ai ha^{-1}	plants m^{-2} + 1		g ai ha^{-1}	plants m^{-2} + 1	
Sulfosulfuron	PRE	36	3.55	11.6[1]	72	3.19	9.2
		72	2.63	5.9	108	1.00	0.0
		108	2.61	5.8	144	1.00	0.0
	POST	36	4.30	17.5	72	4.36	18.0
		72	4.29	17.4	108	3.62	12.1
		108	3.11	8.7	144	3.18	9.1
Flumioxazin	PRE	36	3.95	14.6	72	2.66	6.1
		72	3.11	8.7	108	1.00	0.0
		108	2.00	3.0	144	1.00	0.0
	POST	36	4.64	20.5	72	4.69	21.0
		72	3.55	11.6	108	4.36	18.0
		108	2.21	3.9	144	4.00	15.0
Control		-	4.20	16.6	-	5.01	24.1
se_{df}=36			0.68			0.63	

PRE: pre-emergence; POST: post-emergence; se: standard error; df: error degrees of freedom.
[1]Back-transformed values.

al. (2002) found that flumioxazin applied PRE at 35 and 70 g ai ha^{-1} provided excellent broadleaf weed control. Also, Eizenberg et al. (2003) found that sulfosulfuron provided excellent control of redroot pigweed.

In season 1, potato stem number was not significantly affected by any of the herbicide treatments (Table 3). However, in season 2, POST-applied sulfosulfuron and flumioxazin treatments reduced potato stem number by 12% to 18% and 81% to 95%, respectively, at 6 wk after PRE application. The other herbicide treatments did not significantly affect potato stem number.

Potato growth was also not affected by the herbicide treatments in season 1 (data not shown). However, in season 2, herbicide phytotoxicity on potato plants range from 3% to 12% and 11% to 98% after PRE and POST application, respectively (Table 4). Generally, flumioxazin caused greater phytotoxicity on potato plants than sulfosulfuron. Visible injury caused by sulfsulfuron was present as signs of leaf chlorosis (especially in terminal growth) and standing, while injury by flumioxazin was present as signs of stem and leaves browning and necrosis. However, phytotoxicity was reduced at 8 wk after PRE application due to plant regrowth. Similarly, Wilson et al. (2001) found that potato injury caused by the flazasulfuron was slight and disappeared at 3 wk after treatment.

At harvest in season 1, potato yield was not affected by the herbicide treatments, but was reduced by 57% due to field bindweed and redroot pigweed competition (Table 5). In season 2, potato yield was affected by herbicide treatments ($P < 0.001$), as well as by the weed competition ($P < 0.001$). In particular, as compared to weed-free control, sulfosulfuron treatments reduced potato yield by 14% to 28%. However, the reduction caused by PRE and POST treatments of flumixazin ranged from 4% to 11% and 53% to 69%, respectively. In season 2, weed competition caused 60% potato yield reduction.

The similar potato yield obtained in plots where all herbicide treatments were applied in season 1, compared with the yield obtained in the weed-free control, could be attributed to the very low phytotoxicity observed, due to delayed emergence of potato in season 1 as a result of the high temperature observed after planting (Figure 1). Furthermore, the reduced competition of the controlled weeds could account for the lack of yield differences. Also, in season 2, injury of PRE-applied herbicides was less than 12%. Similarly, Wilson et al. (2002) found that flumioxazin was safe to four potato varieties when applied PRE, maybe due to herbicide metabolism in potato (Dayan and Duke, 1997). The increased yield recorded in most of the herbicide treated plots in season 2, in comparison with that of the untreated control, could be attributed to the control of field bindweed and redroot pigweed which

Table 3. Potato stand as affected by sulfosulfuron and flumioxazin, at 6 wk after pre-emergence application.

Herbicide	Application	Season 1		Season 2	
		Rate	Stems	Rate	Stems
		g ai ha^{-1}	0.1 ha^{-1}	g ai ha^{-1}	0.1 ha^{-1}
Sulfosulfuron	PRE	36	4190	72	4059
		72	4336	108	3706
		108	4227	144	3901
	POST	36	4761	72	3565
		72	4286	108	3457
		108	4807	144	3328
Flumioxazin	PRE	36	4464	72	3743
		72	4227	108	3585
		108	4336	144	3746
	POST	36	4336	72	770
		72	4105	108	326
		108	4287	144	198
Weedy Control		-	4511	-	3822
Weedy-free Control		-	4148	-	4059
se_{df}=39			875		543

PRE: pre-emergence; POST: post-emergence; se: standard error; df: error degrees of freedom.

Table 4. Phytotoxicity of sulfosulfuron and flumioxazin on potato at 6 and 8 wk after pre-emergence application in 2011.

Herbicide	Application timing	Rate	Phytotoxicity %	
		g ai ha^{-1}	6 WAT_{PRE}	8 WAT_{PRE}
Sulfosulfuron	PRE	72	4	3
		108	4	3
		144	7	4
	POST	72	22	11
		108	34	13
		144	43	16
Flumioxazin	PRE	72	5	3
		108	5	7
		144	12	8
	POST	72	91	85
		108	98	86
		144	98	90
Weedy control		-	0	0
Weed-free control		-	0	0
se_{df}=39			4.7	3.9

PRE: pre-emergence; POST: post-emergence; WAT_{PRE}: weeks after PRE treatment; se: standard error; df: error degrees of freedom.

Table 5. Potato yield as affected by PRE- or POST-applied sulfosulfuron and flumioxazin.

Herbicide	Application timing	Season 1		Season 2	
		Rate	Yield	Rate	Yield
		g ai ha^{-1}	Mg ha^{-1}	g ai ha^{-1}	Mg ha^{-1}
Sulfosulfuron	PRE	36	20.0	72	34.3
		72	20.2	108	32.1
		108	20.7	144	30.7
	POST	36	18.0	72	32.1
		72	20.7	108	32.1
		108	23.3	144	28.9
Flumioxazin	PRE	36	21.3	72	38.4
		72	17.7	108	37.0
		108	18.5	144	35.4
	POST	36	21.3	72	18.6
		72	21.0	108	12.4
		108	17.9	144	13.6
Weedy control		-	9.5	-	16.0
Weed-free control		-	22.1	-	40.0
se_{df}=39			5.0		4.8

PRE: pre-emergence; POST: post-emergence; se: standard error; df: error degrees of freedom.

resulted in reduced potato competition from these weeds. Increased yield after weed control by flumioxazin in potato was also reported by Wilson et al. (2002).

Although an across application timing analysis was not performed, potato tuber yield was greater in plots where herbicides were PRE-applied compared to that in plots where applied POST. This fact could be attributed to higher efficacy and the lower phytotoxicity of the PRE treatments, compared with those of POST treatments. Kelly et al. (2006) found that phytotoxicity of flumioxazin on sweet-potato (*Ipomoea batatas* [L.] Lam.) was lower after PRE application than after POST application.

Residue analysis

The GC/MS and HPLC analytical methods applied on potato tuber samples showed that potato tubers of all plots were free from any of the target pesticides. Especially, results of analyses of samples collected from plots where the greatest rates of both herbicides were applied are presented in Figures 2 and 3. The fact that no herbicide residues were detected on potato tubers indicated that these herbicides could be safely used for potato production. Also, these herbicides from alternative modes of action might sufficiently provide new management tools for the suppression of herbicide resistant weeds in potato production. However, the tolerance of further potato varieties to sulfosulfuron and flumioxazin requires further investigation.

CONCLUSIONS

The results of this study indicate that sulfosulfuron and flumioxazin are effective in controlling field bindweed and redroot pigweed in potato. The greater weed control

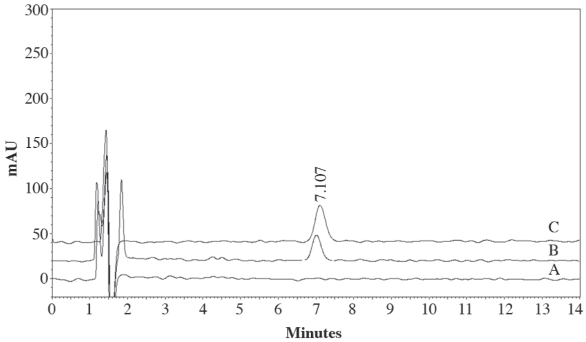

Figure 3. The HPLC chromatogram of the sulfosulfuron analysis in A) potato samples collected from the plots where the greatest rate was applied, B) corresponding spiked potato sample and C) sulfosulfuron standard solution.

and the lower potato phytotoxicity were achieved with the pre-emergence application of both herbicides, while no herbicide residues were detected on potato tubers.

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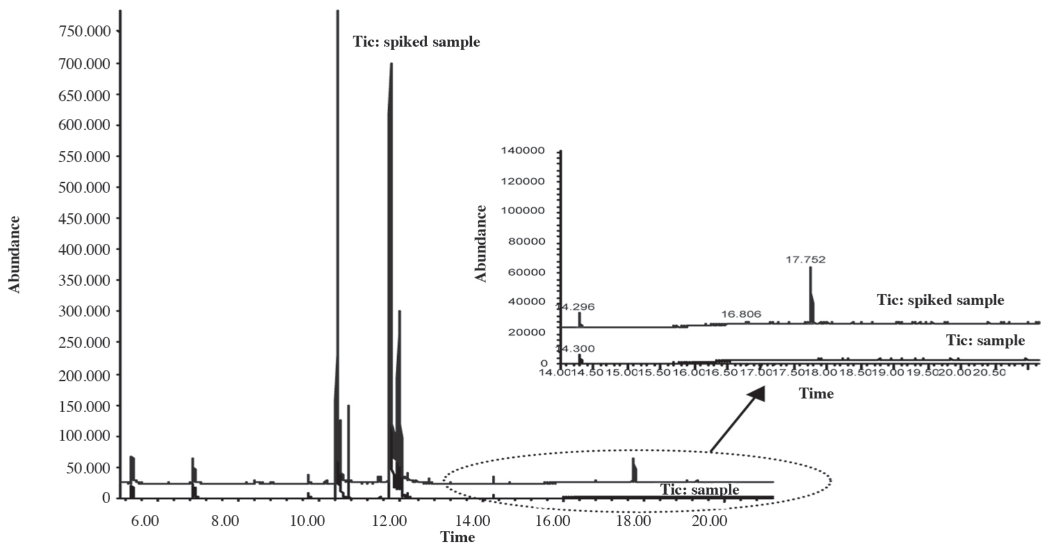

Figure 2. The GC-MS chromatogram of the flumioxazin analysis in A) potato samples collected from the plots where the greatest rate was applied and B) corresponding spiked potato sample.

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