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Control of Field Dodder (*Cuscuta campestris*) Parasitizing Tomato with ALS-Inhibiting Herbicides

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Field dodder is a parasitic plant that attaches to the stems and leaves of broadleaf plants, including weeds, field crops, vegetables, and ornamentals, throughout most agricultural regions of the world. Effective field dodder control is extremely difficult to achieve, due to the nature of attachment and close association between host and parasite, which requires a highly effective and selective herbicide to destroy the parasite without crop damage. Previous studies have demonstrated the tolerance of certain tomato varieties to dodder parasitism. The aim of the present study was to evaluate the ability of sulfonylurea herbicides to control field dodder under greenhouse and field conditions. Two greenhouse studies and three field studies were conducted to evaluate the efficiency and crop selectivity of the sulfonylurea herbicides sulfosulfuron, rimsulfuron, halosulfuron, and flazasulfuron in controlling field dodder parasitizing tomato plants. Sulfosulfuron at 50 or 100 g ai ha^{-1} was effective and safe for tomato in field dodder control, while the other herbicides exhibited little or no dodder control.

Nomenclature: Flazasulfuron; halosulfuron; rimsulfuron; sulfosulfuron; field dodder, *Cuscuta campestris* Yuncker.; tomato, *Lycopersicon esculentum* L.

Key words: Parasitic plants, processing tomato, weed control.

Cuscuta campestris es una planta parasítica que se adhiere a los tallos y las hojas de plantas de hoja ancha, incluyendo malezas, cultivos extensivos, vegetales y ornamentales enla mayoría de las regiones agrícolas del mundo. El control efectivo de *C. campestris* es extremadamente difícil de alcanzar debido a la naturaleza de adherencia y asociación cercana entre el hospedero y el parásito, lo que requiere un herbicida selectivo altamente efectivo para destruir el parásito sin dañar al cultivo. Estudios previos han demostrado la tolerancia de ciertas variedades de tomate al parasitismo del *C. campestris*. El objetivo del presente estudio fue evaluar la habilidad de herbicidas sulfonylureas para controlar *C. campestris* bajo condiciones de invernadero y de campo. Dos estudios de invernadero y tres estudios de campo se realizaron para evaluar la eficiencia y selectividad en el cultivo de los herbicidas sulfonylurea: sulfosulfuron, rimsulfuron, halosulfuron y flazasulfuron en el control de *C. campestris* parasitando plantas de tomate. Sulfosulfuron a 50 ó 100 g ia ha^{-1} fue efectivo y seguro al tomate para el control de *C. campestris*, mientras que los otros herbicidas mostraron poco o ningún control de esta maleza.

The genus *Cuscuta* includes obligate holoparasitic plants, commonly known as dodder, with 170 different species distributed throughout the world parasitizing trees, shrubs, weeds, and crops (Dawson et al. 1994; Holm et al. 1997). Most of the 170 species, of which nine species are known in California (Ashton et al. 1976; Hickman 1993), are found primarily in the Americas from Canada to Argentina, and 12 species are found in the Middle East and Israel (Abu-Irmaileh 1987; Dawson et al. 1994; Nemli 1987). Worldwide, the most widespread and damaging species is field dodder. Dodder is a nonspecific parasite that attacks stems and leaves of a wide range of host species—crop and weeds, dicots, and some monocots (it only wraps around grasses but does not parasitize them) (Dawson et al. 1994: Holm et al. 1997; Hutchison and Ashton 1980; Parker and Riches 1993). The same crop may serve as a host of several dodder species, and in some cases dodder can parasitize different plants simultaneously (Cudney et al. 1992; Dawson 1984; Peters and Linscott 1988).

In previous studies, field dodder infestation reduced tomato vegetative growth and the number of fruits per plant but had no effect on individual tomato fruit size or maturation (Lanini 1992). Individual dodder plants were observed to cover 2 m of tomato row at harvest, with tomato yield reductions of 50 to 75% when infested with field dodder. It was estimated that 10% of the tomato plants in the United States are infested with dodder, ranking it among the worst weeds in California, New Jersey, and Florida (Figure 1; Davis et al. 1998).

Dodder is listed in the USDA Crop Profiles (http://www.ipmcenters.org/cropprofiles/docs/CAtomatoes-processing.pdf, accessed June 2012), as one of the most difficult weeds to control in processing tomato fields (Lanini et al. 1999). Effective control of dodder is extremely difficult to achieve because dodder seeds can remain viable in soil for 10 to 30 yr or more, depending on the species and environmental conditions, and continue to germinate and emerge throughout the warm seasons (Lanini and Kogan 2005). Lanini (2004) found that growing wheat (*Triticum aestivum* L.) followed by corn (*Zea mays* L.) in a field heavily infested with lespedeza dodder (*Cuscuta pentagona* Engelm.) reduced the number of dodder plants infesting tomato by 90%. Thus, control measures that reduce seed production, reduce infestations in subsequent years. Once dodder germinates

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Figure 1. Field dodder infestation in a tomato field near Davis, CA (photo).

and attaches to a host, the nature of attachment and association between host and parasite excludes mechanical control and requires a highly selective herbicide to destroy the parasite without crop damage (Fer 1984). Several different methods for dodder control in crops have been reviewed (Cudney et al. 1992; Dawson et al. 1994; Fer 1984; Parker and Riches 1993).

In preliminary greenhouse studies, acetolactate synthase (ALS)-inhibiting herbicides were found to selectively suppress field dodder parasitizing tomato (Y. Goldwasser, unpublished data). The sulfonylurea herbicides are systemic herbicides that inhibit ALS, also called acetohydroxyacid synthase, a key plant enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine, and valine (Schloss 1995). Blockage of this pathway interferes with protein synthesis and cell growth. These herbicides are absorbed through roots, shoots, and foliage of plants and rapidly translocate through the plants' xylem and phloem systems, accumulating in meristematic growing points of the plant such as apical buds, tips of roots, shoots, leaves, and reproductive structures. Sulfonylurea herbicides are effective when applied PRE and POST at low rates on annual and perennial grasses and broadleaf weeds. These herbicides are degraded by microbial action and chemical hydrolysis and can persist in the soil from several weeks to several years, depending mainly on the specific herbicide and its application rate.

Plant selectivity to ALS-inhibiting herbicides is predominantly through plants' ability to rapidly degrade the active ingredient to nontoxic metabolites, unlike susceptible species that are unable to detoxify the herbicide. Plants can metabolize sulfonylurea herbicides through the hydroxylation of the phenyl ring by cytochrome P450 (Frear et al. 1991; Hinz and Owen 1997). The mode of tolerance of specific Solanaceae crop species to sulfonylurea herbicides has not been examined, but is probably due to metabolism of the herbicide to nonphytotoxic products, as reported for black nightshade (*Solanum nigrum* L.) tolerance to chlorsulfuron (Senseman 2007). Resistance could also be due to an altered ALS binding site as in selected mutations in transgenic crops. Sulfonylurea-resistant weed biotypes selected in the field by heavy use of one of the herbicides usually have cross-resistance to other sulfonylurea herbicides. The mechanism of resistance in this case is an altered herbicide-binding site in the ALS target enzyme (Beyer et al. 1988).

Dodder-tolerant tomato varieties were identified and tested in previous studies as a tool for combating field dodder parasitism in the field (Goldwasser et al. 2001). The aim of the present study was to evaluate four sulfonylurea herbicides for the control of field dodder under greenhouse and field conditions in order to expand the possibilities of effective dodder management.

Materials and Methods

Plant Material. *Dodder*. Field dodder seeds used in the Israel greenhouse studies were collected from parasitized tomato plants in Or Hanner, Israel (31°33′30″N, 34°36′07″E) in the summer of 1996. In the U.S. greenhouse experiments, field dodder seeds were collected from a heavily infested tomato field in Davis, CA, in the summer of 1998. Seeds from both locations were air-dried, cleaned, and placed in a plastic container at room temperature (United States) or at 4 C in a refrigerator (Israel) until use. In order to promote effective seed germination, seeds were scarified prior to seeding by soaking them in concentrated sulfuric acid for 40 min, rinsing them with water, and drying them at room temperature (Hutchison and Ashton 1979).

Tomato. Commercial varieties of processing tomato seeds were used, with 'Brigade' used in the Israel (IS) greenhouse studies, 'Halley 3155' in the California (CA) greenhouse studies, 'Lipton U-97' in the 2002 Fresno field study, 'Peto 771' in the 2003 Yolo field study, 'Heinz 9995' in the second Yolo field study, and 'Heinz 2401' in the third Yolo field study. The tomato varieties used in these studies were all sensitive to dodder.

Greenhouse Studies. *Israel Greenhouse Experiment*. The experiment was conducted in a greenhouse (35/20 C maximum/minimum) at the Newe Yaar Research Center in the Jezreel Valley in Northern Israel in the winter of 2001. Ten-liter pots filled with local clay-loam soil (55% clay, 23% silt, and 20% sand; 2% organic matter; pH 7.1) were placed in the greenhouse. Three tomato seeds were sown in the center of each pot at 2-cm depth and the pots were hand-watered as needed throughout the experiment. Three days after sowing (DAS), 10 to 20 scarified field dodder seeds per pot were sown at a 5-mm depth. After tomato plant emergence, plants were thinned to one tomato plant per pot. Tomato emerged at 6 to 8 DAS, while dodder emerged 3 to 5 DAS and started to attach to tomatoes seedlings within 2 to 4 d. Herbicide treatments were applied 14 d after tomato emergence by a motorized sprayer equipped with an 8001-E TeeJet nozzle delivering 200 L ha^{-1} at 206 kPa. Tomato seedlings at application were 5 to 7 cm high, at the two- to four-leaf stage and were parasitized by young twining dodder seedlings. The treatments were flazasulfuron at 50 or 100 g ai ha^{-1}, rimsulfuron at 100 or 200 g ai ha^{-1}, and sulfosulfuron at 50 or 100 g ai ha^{-1}. A surfactant, 0.2 % v/v of DX, 800 g L^{-1} alkaryl polyether alcohol, was added to all herbicide solutions. Three sets of controls were utilized to isolate the net effect and the interaction of the herbicides and field dodder on tomato plants: no herbicide and dodder present (H–,D+);

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herbicide but no dodder (H+,D–); and no dodder and no herbicide (H–,D–).

Tomato and dodder growth were visually assessed weekly on a 0 to 100% scale: 0% representing healthy vigorous plants, and 100% representing dead plants. The experiment was terminated 75 d after treatment (DAT): dodder was separated from tomato plants, tomato fruits were picked and sorted according to green and red fruit, and finally tomato plants were cut at soil level. Fresh weight of dodder, tomato foliage, and tomato fruits were determined. Field dodder and tomato foliage dry weight were recorded following oven-drying for 48 h at 70 C.

CA Greenhouse Experiments. Two experiments were conducted in a temperature-controlled greenhouse (28/21 C max/min) at the University of California, Davis, in the winter of 2003. Supplemental light (550 µmol m^{-2} s^{-1}) was provided during periods of low irradiance and during the evening for a total of 15 h of light per day. Two-liter pots were filled with modified UC soil mix (Anonymous 2009) and placed in the greenhouse. Three seeds of tomato were sown in the center of each pot at a 1-cm depth and pots were subirrigated as needed throughout the experiment. Twenty scarified field dodder seeds were sown in each pot at a 5-mm depth, 5 d after tomato seeding. After tomato plants emerged, tomato seedlings were thinned to one plant per pot with a single attached field dodder, leaving the best developed tomato plant. Herbicide treatments were applied 12 DAS by a track sprayer equipped with a 65015-E nozzle delivering 234 L ha^{-1} at 206 kPa. Tomato seedlings were at the two- to three-leaf stage and parasitized by young twining dodder. Treatments included halosulfuron at 70 or 100 g ai ha^{-1}, rimsulfuron at 150 or 250 g ha^{-1}, and sulfosulfuron at 100 g ha^{-1}. To all herbicide solutions, a 0.25% v/v silicone surfactant (Kinetic, Helena Chemical Company, Collierville, TN) was added. Three sets of controls were utilized in order to isolate the net effect and the interaction of the herbicides and field dodder on tomato plants: no herbicide but dodder present (H–,D+); herbicide but no dodder (H+,D–); and no dodder plus no herbicide (H–,D–).

Both experiments were terminated at 47 DAS by clipping tomato plants 1 cm above ground level and separating the dodder from tomato plants. The fresh weights of dodder and tomato were determined.

Field Studies. Three post-attachment dodder control field experiments were conducted in commercial processing tomato fields in California, each heavily infested by field dodder.

Fresno County Experiment. Processing tomato was direct seeded in double lines on 152-cm-wide beds on March 11, 2002 (36°30′59′N, 120°21′53′W). Herbicides were applied 32 DAS to tomato plants at the two- to three-leaf stage that were parasitized by young twining dodder, averaging 15 cm in length. Herbicides were applied using a handheld CO_2 backpack sprayer calibrated to deliver 336 L ha^{-1} (8004 flat fan nozzle at 206 kPa). Treatments were halosulfuron at 70 g ha^{-1}, rimsulfuron at 150 g ha^{-1}, and sulfosulfuron at 25, 50, or 100 g ha^{-1}. A silicone surfactant (Kinetic) was added to all treatments at 0.25% v/v. The field was overhead irrigated 8 DAT. Initial dodder density was determined by counting the number of parasitized tomato plants on the day of herbicide application. Tomato growth reduction ratings were conducted 12 and 70 DAT, with 0% representing healthy, vigorous plants and 100% representing dead plants. Visual assessment of dodder control was taken 70 DAT, with 0% representing no control and 100% representing complete control. Tomato fruit were hand-harvested from a 4-m center section of each plot and separated into red, green, or rot (unmarketable) fruit, and yields were estimated for each treatment.

Yolo Field Experiment 1. Tomato was seeded in double lines on 152-cm-wide beds on May 30, 2008 (38°30′49″N, 121°42′25″W). Portions of tomato rows with infestations of dodder were selected for treatment. Herbicide treatments were applied on July 2, when tomato plants were at the five- to six-leaf stage, and the dodder averaged 20 cm in length. Treatments included imazethapyr at 50 g ai ha^{-1}, fomesafen at 210 g ai ha^{-1}, imazosulfuron at 210 or 840 g ai ha^{-1}, rimsulfuron at 35 or 70 g ha^{-1}, sulfosulfuron at 50 or 100 g ha^{-1}, or imazamox at 35 or 53 g ai ha^{-1}. Prior to application, the length of the tomato row occupied by dodder was measured, and additional measurements were made at regular intervals after application to assess the effectiveness of treatments. Tomato fruit were hand-harvested on September 17, 2008, from a 4-m center section of each plot and separated into red, green, or rotten (unmarketable) fruit, and yields were estimated for each treatment.

Yolo Field Experiment 2. A second Yolo County experiment was conducted in the same field as Yolo experiment 1 (38°30′42″N, 121°42′21″W). Treatments were identical to the Fresno County experiment: application of halosulfuron at 70 g ai ha^{-1}, rimsulfuron at 150 g ai ha^{-1}, and sulfosulfuron at 25, 50, or 100 g ai ha^{-1}. A silicone surfactant (Kinetic) was added to all treatments at 0.25% v/v.

Processing tomato Heinz 2401 was direct-seeded in double lines on 152-cm-wide beds on May 1, 2010. Herbicides were applied 31 DAS on tomatoes at the four- to five-leaf stage that were parasitized by young twining 15- to 20-cm-long dodder. Herbicides were applied using a handheld CO_2 backpack sprayer delivering 336 L ha^{-1} (8004 flat fan nozzle at 206 kPa). The field was furrow irrigated. Dodder development was determined by measuring the length of individual dodder plants, parallel to the crop row at 0, 14, 56, and 70 DAT, and tomato development was assessed by measuring the height of three plants per plot at 0, 14, 56, and 70 DAT. Tomato fruit were hand-harvested on September 4, 2010, from a 2-m center section of each plot and separated into red, green, or rot (unmarketable) fruit, and yields were estimated for each treatment.

Statistical Analysis. The IS and CA greenhouse experiments were conducted in a randomized complete block design with five (IS) and four (CA) replications of each treatment. Tomato and dodder fresh weight (CA and IS) and tomato fruit (IS only) fresh weight were subjected to analysis of variance performed by SAS (version 8.2), and means separated according to the protected LSD test ($P \leq 0.05$).

Field studies utilized a randomized complete block design with five replications per treatment. Results were subjected to analysis of variance performed by SAS (version 8.2), and

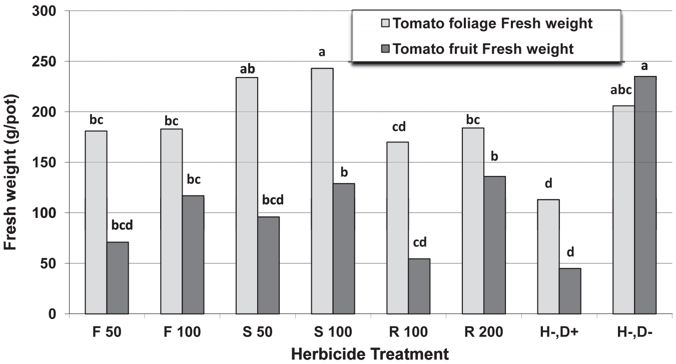

Figure 2. Tomato foliage and fruit fresh weight following herbicide treatments of dodder- parasitized plants in the Israel greenhouse experiment at 75 d after treatment. F 50, flazasulfuron 50 g ai ha^{-1}; F 100, flazasulfuron 100 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; R 100, rimsulfuron 100 g ai ha^{-1}; R 200, rimsulfuron 200 g ai ha^{-1}; H–,D+, nontreated dodder-parasitized control; H–,D–, nontreated, no dodder control. Bars of each variable topped with the same letter are not significantly different according to Fischer's protected LSD test at P $\leq$ 0.05.

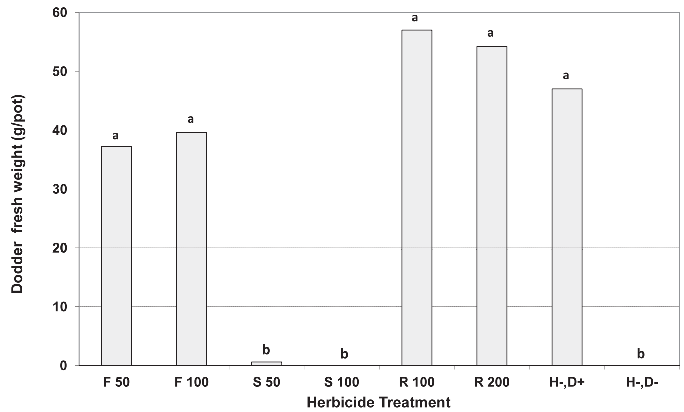

Figure 3. Dodder fresh weight in the herbicide treatments at the end of the Israel greenhouse experiment 75 d after herbicide treatment. F 50, flazasulfuron 50 g ai ha^{-1}; F 100, flazasulfuron 100 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; R 100, rimsulfuron 100 g ai ha^{-1}; R 200, rimsulfuron 200 g ai ha^{-1}; H–,D+, nontreated, dodder-parasitized control; H–,D–, nontreated, no dodder control. Bars topped with the same letter are not significantly different according to Fischer's Protected LSD test at P $\leq$ 0.05.

means were separated according to the protected LSD test (P $\leq$ 0.05).

Results and Discussion

Greenhouse Studies. *IS Greenhouse Experiment.* Herbicide treatments, excluding the low rates of rimsulfuron and sulfosulfuron, initially caused an approximately 40% reduction in tomato growth compared to the nontreated control in the absence of dodder. Tomato growth in all treatments recovered by 37 DAT and was similar to the nontreated control plants (data not shown). Sulfosulfuron or rimsulfuron applied at the low rates caused 12% or less tomato injury. When no dodder was present, the mean nontreated tomato foliage fresh weight at 75 DAT was 206 g pot^{-1} and tomato fruit fresh weight was 235 g pot^{-1}. Herbicide treatments applied to dodder-parasitized tomatoes (H+,D+) initially caused plant growth retardation relative to dodder infected tomatoes that were not treated (H–,D+). Tomatoes gradually recovered from the herbicide injury, and at 59 DAT all treatments achieved 90 to 100% growth of the nonparasitized control (H–,D–), excluding both flazasulfuron treatments. Tomato plants recovered from the flazasulfuron damage, but dodder was not controlled and caused 20 to 40% growth retardation from 37 DAT throughout the end of the experiment (Figure 2). Dodder suppressed tomato growth about 60% in this experiment, compared to the nonparasitized control (H–,D–) (Figure 2). Dodder caused a gradual decline in tomato growth in the parasitized control, with a 40% reduction in growth at the time of the application of the herbicide treatments, to a 62% reduction at the end of the experiment. This damage to tomato plants resulted in a fivefold reduction in tomato fruit fresh weight compared to the nonparasitized control (H–,D–) (Figure 2).

Flazasulfuron (50 or 100 g ha^{-1}) and rimsulfuron (100 or 200 g ha^{-1}) initially suppressed dodder, but dodder growth resumed 20 to 30 DAT, and dodder fresh weight following treatment with these herbicides was not different from the nontreated control (H–,D+) starting at 59 DAT through the end of the experiment 75 DAT. Sulfosulfuron at either 50 or 100 g ha^{-1} controlled dodder throughout the experiment (Figure 3).

Herbicide applied to dodder-parasitized tomato plants (H+,D+) resulted in an increase in tomato plant biomass and fruit yield at harvest compared to the parasitized control (H–,D+). Compared to the nontreated nonparasitized control (H–,D–), herbicide treatments generally reduced the negative effect of dodder on tomato plant biomass, but fruit yield was reduced (Figure 2).

Sulfosulfuron at 100 g ha^{-1} completely controlled dodder on tomato plants, and only a trace of dodder was measured at

Table 1. 'Halley 3155' tomato and dodder fresh weight following herbicide treatment in the California greenhouse experiment at 35 d after treatment.

Treatment[a]	Tomato fresh weight	Dodder fresh weight
	g pot^{-1}[b,c]	
H 70	4.94 c	1.01 bc
H 100	6.65 c	1.01 bc
R 150	3.17 c	3.20 ab
R 250	3.64 c	4.06 a
S 100	13.94 b	0.06 c
H−,D+ control	0.45 c	1.56 abc
H−,D− control	22.56 a	0.00 c

[a] Abbreviations: H 70, halosulfuron 70 g ai ha^{-1}; H 100, halosulfuron 100 g ai ha^{-1}; R 150, rimsulfuron 150 g ai ha^{-1}; R 250, rimsulfuron 250 g ai ha^{-1}; S 25, sulfosulfuron 25 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; H–,D+ control, no herbicide, dodder infested; H–,D– control, no herbicide, no dodder.

[b] Mean values of five replications.

[c] Means within a column followed by the same letter are not significantly different according to Fischer's Protected LSD test at P $\leq$ 0.05.

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Table 2. Effect of herbicide treatments on field dodder control and tomato ('Lipton U-91') growth and yield in the Fresno County 2002 field study.

Treatment[a]	Tomato growth reduction[b] 12 DAT	Tomato growth reduction[b] 70 DAT	Dodder control[c] 70 DAT	Tomato yield Green	Tomato yield Red	Tomato yield Rot
	%[d]		%[d]	ton ha^{-1}		
H 70	9 bc[e]	7 ab	41 bc	2.6	111.2	4.3
R 150	15 ab	11 a	21 c	1.5	104.5	5.5
S 25	13 ab	5 ab	73 ab	2.8	111.0	12.1
S 50	12 abc	12 a	80 ab	4.6	120.6	9.5
S 100	18 a	12 a	95 a	4.0	100.0	4.4
H–,D+ control	6 c	1 b	0 c	3.0	103.4	8.5

[a] Abbreviations: H 70, halosulfuron 70 g ai ha^{-1}; R 150, rimsulfuron 150 g ai ha^{-1}; S 25, sulfosulfuron 25 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; H–,D+ control, no herbicide, dodder infested.

[b] Tomato growth reduction was assessed on a 0 to 100% scale: 0% representing healthy vigorous plants and 100% representing dead plants.

[c] Dodder control was estimated on a scale of 0 to 100 %, 0% describing healthy, vigorous dodder and 100% representing complete dodder control.

[d] Mean values of five replications.

[e] Means within a column followed by the same letter are not significantly different according to Fischer's protected LSD test at $P \leq 0.05$.

74 DAT when 50 g ha^{-1} was applied. Rimsulfuron and flazasulfuron did not significantly reduce dodder fresh weight on parasitized tomato plants (Figure 3).

California Greenhouse Experiments. Dodder reduced tomato growth (H–,D+) more than 50-fold compared to nonparasitized controls (H–,D–) (Table 1). Sulfosulfuron (100 g ai ha^{-1}) reduced dodder growth, resulting in a 25-fold increase in tomato foliage fresh weight at 35 DAT, compared to the parasitized control (H–,D+). However, sulfosulfuron treated tomato fresh weight was only 60% of the nonparasitized control (H–,D–). Dodder reduced tomato growth prior to the sulfosulfuron treatment, and the herbicide treatment may have also caused some reduction in tomato growth. Halosulfuron (70 or 100 g ha^{-1}) and rimsulfuron (100 or 150 g ha^{-1}) did not reduce dodder fresh weight.

Field Studies. *Fresno County 2002 Experiment.* Dodder covered 48% of the tomato plants at 70 DAT in the nontreated control plots (H–,D+) (data not shown). Sulfosulfuron applied at 25, 50, or 100 g ha^{-1} improved dodder control to 73, 80, and 95%, respectively (Table 2). Rimsulfuron applied at 150 g ha^{-1} or halosulfuron applied at 70 g ai ha^{-1} did not improve dodder control compared to untreated tomatoes (H–,D+). Tomato growth reduction was least with the halosulfuron treatment, while sulfosulfuron at 100 g ha^{-1} caused some reduction in tomato growth. The differences observed among treatments in dodder control and crop injury did not affect tomato yield. Dodder had been growing on tomatoes for several weeks prior to treatment and may have reduced tomato growth prior to treatment. In spite of no yield improvement associated with sulfosulfuron treatment, the reduction in dodder growth resulted in less dodder seed being produced.

Yolo County 2008 Field Experiment 1. Dodder was well established at the time of treatment (Table 3). However by 5 DAT, most treatments were already suppressing dodder growth, and by 12 DAT, all treatments were suppressing dodder, compared to the untreated control (H–,D+). All treatments continued suppressing dodder growth, compared to the control plots (H–,D+) through 29 DAT. By 64 DAT, dodder suppression declined in the plots treated with fomesafen, rimsulfuron, and the low rate of imazosulfuron. Red tomato yields were significantly reduced by imazethapyr and imazamox but unaffected by other treatments (Table 4).

Yolo County 2010 Field Experiment 2. Tomato and dodder growth throughout the experiment is presented in Table 5.

Table 3. Length of dodder shoots parasitizing tomatoes following herbicide treatment: 2008 Yolo County field site.

Treatment[a]	Length of dodder shoots 0 DAT[b]	5 DAT	12 DAT	20 DAT	29 DAT	34 DAT	64 DAT
	cm						
IZT 50	86[c]	109 cd[d]	109 de	107 ef	96 e	86 f	132 d
F 210	96	132 bc	178 b	259 b	290 b	350 ab	442 ab
IZS 210	109	137 abc	165 bc	208 bcd	238 bc	279 bc	437 ab
IZS 840	124	117 cd	142 bcde	203 bcd	229 bc	264 c	323 bc
R 35	86	132 bc	165 bc	236 bc	262 bc	287 bc	465 a
R 70	99	114 cd	137 bcde	190 cd	213 cd	254 cd	391 ab
S 50	114	117 cd	117 cde	127 ef	124 e	135 ef	249 cd
S 100	99	96 d	107 e	99 f	99 e	99 f	221 cd
IZM 35	102	119 bcd	158 bcd	160 de	158 de	180 de	323 bc
IZM 53	84	152 ab	175 b	201 cd	206 cd	188 de	224 cd
H–,D+ control	104	170 a	234 a	330 a	391 a	414 a	470 a

[a] Abbreviations: IZT, imazethapyr 50 g ai ha^{-1}; F 210, fomesafen 210 g ai ha^{-1}; IZS 210, imazosulfuron 210 g ai ha^{-1}; IZS 840, imazosulfuron 840 g ai ha^{-1}; R 35, rimsulfuron 35 g ai ha^{-1}; R 70, rimsulfuron 70 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; IZM 35, imazamox 35 g ai ha^{-1}; IZM 53, imazamox 53 g ai ha^{-1}; H–,D+ control, no herbicide, dodder infested.

[b] Days after treatment. Treatments were applied once on July 2, 2008.

[c] Mean values of five replications.

[d] Means within a column followed by the same letter are not significantly different according to Fischer's protected LSD test at $P \leq 0.05$.

Table 4. Tomato yield following herbicide treatment: 2008 Yolo County field site.

Treatment[a]	Tomato yield[b–d] Green	Red	Rot	Total
	ton ha^{-1}			
IZT 50	19.2 a	47.1 bc	3.2 cd	69.5 ab
F 210	6.4 b	83.2 a	7.2 ab	96.8 a
IZS 210	2.4 b	86.3 a	5.2 bc	94.0 a
IZS 840	4.6 b	75.5 ab	6.7 ab	86.9 a
R35	3.5 b	86.1 a	8.4 a	97.9 a
R 70	4.6 b	100.9 a	4.8 bc	110.4 a
S 50	4.6 b	87.4 a	4.8 bc	96.8 a
S 100	6.3 b	86.3 a	4.5 bcd	97.1 a
IZM 35	4.2 b	31.2 c	2.5 cd	37.9 b
IZM 53	2.8 b	33.3 c	1.5 d	37.7 b
H−,D+ control	2.3 b	86.0 a	5.5 abc	93.8 a

[a] Abbreviations: IZT, imazethapyr 50 g ai ha^{-1}; F 210, fomesafen 210 g ai ha^{-1}; IZS 210, imazosulfuron 210 g ai ha^{-1}; IZS 840, imazosulfuron 840 g ai ha^{-1}; R 35, rimsulfuron 35 g ai ha^{-1}; R 70, rimsulfuron 70 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; IZM 35, imazamox 35 g ai ha^{-1}; IZM 53, imazamox 53 g ai ha^{-1}; H–,D+ control, no herbicide, dodder infested.

[b] Tomatoes were harvested on September 17, 2008.

[c] Mean values of five replications.

[d] Means within a column followed by the same letter are not significantly different according to Fischer's protected LSD test at $P \leq 0.05$.

Herbicide treatments did not cause significant tomato injury as demonstrated by visual estimates of tomato health (data not shown) and tomato height measurements, while dodder in the untreated control (H–,D+) caused significant retardation of tomato growth at 70 DAT. At 14 DAT dodder growth was reduced threefold by all herbicide treatments compared to the untreated control (H–,D+), but by 70 DAT only the 50 g ha^{-1} sulfosulfuron treatment retarded dodder length. Regardless, rimsulfuron at 150 g ha^{-1} or sulfosulfuron at 50 or 100 g ha^{-1} increased tomato yields, demonstrating their positive effect on dodder control—these treatments increased red tomato yields twofold or more compared to the untreated control (H–,D+). Sulfosulfuron at 50 or 100 g ha^{-1} resulted in more than a 2.5-fold increase in red tomato yield compared to the untreated control (H–,D+).

Rimsulfuron did not provide consistent dodder control in the experiments presented herein. Mullen et al. (1998) reported that rimsulfuron applied at the tomato cotyledon stage controlled 95 to 100% dodder in an experiment conducted in a Sacramento County field. In contrast, dodder control with rimsulfuron in our studies was poor, possibly due to later application timing or a more severe dodder infestation. Sulfosulfuron at 100 g ha^{-1} selectively controlled dodder on tomato plants without significant damage to tomato plants in the IS greenhouse study. CA greenhouse and field experiments confirmed this observation. Sulfosulfuron is registered worldwide for PRE and POST control of grass and broadleaf weeds in wheat and turf at recommended application rates of 10 to 70 g ha^{-1} (Sensemen 2007). The other sulfonylurea herbicides tested in this study exhibited good tomato safety but did not provide effective dodder control. The tolerance of specific Solanaceae species to sulfosulfuron has not been studied, but is probably due to metabolism of the herbicide to nonphytotoxic products (Sensemen 2007).

In Israel, sulfosulfuron has proven to be highly efficient and selective for the control of the plant parasite Egyptian broomrape (*Phelipanche aegyptiaca* Pers.) in processing tomato (Eizenberg et al. 2004) and has recently been registered in Israel for Egyptian broomrape control in tomato. This parasitic plant taps into the host plant root phloem and xylem in a similar way to the parasitism of dodder on the tomato stems and leafs.

In the present study, sulfosulfuron at rates of 50 or 100 g ha^{-1} was the best herbicide treatment for the selective control of dodder on tomato in greenhouse and field experiments both in California and in Israel. Dodder management in processing tomato fields remains difficult and expensive. The integration of dodder-tolerant tomato varieties with the

Table 5. Effect of herbicide treatments on field dodder control and tomato ('Heinz 2401′) growth and yield in the 2010 Yolo County field study.[a]

Treatment	Tomato height[b] 14 DAT	56 DAT	70 DAT	Dodder length[c] 14 DAT	56 DAT	70 DAT	Tomato yield[d] Green	Red	Rot
	cm			cm			ton ha^{-1}		
H 70	21[e]	46	43 a[f]	9 b	120 ab	126 ab	6.7	46.5 ab	5.6 ab
R 150	28	48	44 a	11 b	116 abc	160 a	5.3	61.8 a	8.7 a
S 25	32	45	35 ab	11 b	88 bc	126 ab	4.4	55.0 ab	5.4 ab
S 50	30	39	36 ab	10 b	57 c	87 b	3.9	74.7 a	4.4 b
S 100	37	47	44 a	13 b	103 abc	117 ab	7.8	70.6 a	9.4 a
H−,D+ control	34	38	25 b	34 a	151 a	149 a	1.2	26.7 b	4.2 b

[a] Abbreviations: H 70, halosulfuron 70 g ai ha^{-1}; R 150, rimsulfuron 150 g ai ha^{-1}; S 25, sulfosulfuron 25 g ai ha^{-1}; S 50, sulfosulfuron 50 g ai ha^{-1}; S 100, sulfosulfuron 100 g ai ha^{-1}; H–,D+ control, no herbicide, dodder infested; DAT, days after treatment. Treatments were applied on June 2, 2010.

[b] Tomato height is an average of three plant measurements per plot.

[c] An individual dodder plant per plot was measured parallel to the crop row.

[d] Tomatoes were harvested on September 4, 2010.

[e] Mean values of five replications.

[f] Means within a column followed by the same letter are not significantly different according to Fischer's protected LSD test at $P \leq 0.05$.

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application of sulfosulfuron for effective and selective dodder control can reduce the detrimental impact of dodder in processing tomato fields and ensure effective and sustainable dodder control.

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