Evaluating chemigation strategies for branched broomrape *(Phelipanche ramosa)* management in California processing tomato systems

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Introduction

Broomrapes (*Phelipanche spp*. syn. *Orobanche spp.*) are parasitic plants native to the Mediterranean region. Broomrape phenology makes management via conventional weed control practices very difficult, with the majority of its lifecycle occurring below the soil surface. Broomrape seeds germinate after receiving a chemical signal from a suitable host plant and quickly attach to the host roots via a modified root known as a haustorium. Broomrape is not yet common in California but detections of Egyptian (*Phelipanche aegyptiaca)* and branched broomrape (*Phelipanche ramosa)* have been made in processing tomato fields in recent years. Branched broomrape infestations have resulted in yield losses of up to 80% in tomatoes in Chile (Kogan 1994). Branched broomrape is a quarantine "A-listed" noxious weed and poses a significant threat to the California processing tomato industry for several reasons: 1) California's Mediterranean climate is similar to branched broomrape's native range, 2) broomrape's copious production of small, long-lived seed, 3) California agronomic practices (shared equipment, successive tomato crops, wide variety of host species cultivated) make seed dispersal highly likely, 4) broomrape's phenological development make it inaccessible to many conventional weed control practices, and 5) California's regulatory environment make soil fumigation difficult and herbicides unavailable. There is currently little information available for chemical control of broomrape in California tomato systems; however, management tactics developed in other countries may be similarly effective if they can be registered in California. This research was designed to evaluate the PICKIT decision support system developed in Israel for control of Egyptian broomrape as a potential management approach for branched broomrape in California processing tomato (Eizenberg and Goldwasser 2018). This system utilizes precision herbicide applications based on growing degree day accumulation after tomato transplanting to target specific broomrape life stages. Because the primary herbicides used in the PICKIT system, sulfosulfuron and imazapic, are not currently registered for this use in California, crop safety and efficacy data are needed to support a label expansion request.

Rotational Crop Study 2019/2020

Methods

In 2020, a rotational crop study was conducted to evaluate residual PICKIT herbicide effects on commonly rotated crops at the UC Davis Plant Science Research Field Facility. (**Table 1**) PICKIT treatments were applied to a tomato crop in 2019 to whole row plots. The tomato crop was mowed at commercial maturity, and minimal tillage was done. In spring of 2020, five crops were planted in randomly-assigned 30-foot subplots in each of the 2019 main plots using a split plot design. Phytotoxicity (percent plot affected), plant height (inches), and fresh biomass (kg) were recorded. Data were analyzed using ANOVA and Tukey-HSD tests in the agricolae package in R.

Table 1. 2019/20 Rotational crop study treatments.

Trt	Treatment Name	Rate (g ai/ha)	Application	GDD Appl.
1	Check	na	na	na
2	Sulfosulfuron 0.5X	18.75	PPI	na
3	Sulfosulfuron 1X	37.5	PPI	na
4	Sulfosulfuron 2X	70	PPI	na
5	Imazapic 1X	4.8	CHEMx5	400, 500, 600, 700, 800
6	Imazapic 2X	9.6	CHEMx5	400, 500, 600, 700, 800
7	Imazamox 2X	9.6	CHEMx5	400, 500, 600, 700, 800
8	Imazapyr 2X	9.6	CHEMx5	400, 500, 600, 700, 800
9	Imazethapyr 2X	9.6	CHEMx5	400, 500, 600, 700, 800

Table 2. Mean rotational crop weights in the season following herbicide treatments in tomato for management of branched broomrape. Numbers within a column that share the same letter are not significantly different at p=0.05.

	Corn	Safflower	Sunflower	Beans	Melon
Trt	Fresh biomass lbs/m				
1	12.4a	6.0a	14.9a	2.6a	6.1a
2	9.5ab	7.6a	14.3a	3.2a	3.3ab
3	3.0bc	7.6a	12.8a	2.8a	1.9ab
4	2.5c	6.1a	13.8a	2.7a	0.4b
5	10.9a	7.2a	12.9a	3.0a	4.8ab
6	11.1a	7.1a	12.5a	2.9a	4.6ab
7	15.0a	6.9a	13.5a	3.1a	5.7ab
8	10.5a	7.1a	13.4a	3.6a	4.9ab
9	11.5a	6.7a	13.7a	3.3a	5.0ab

Results

In the rotational crop study, corn planted 8 months after the 2019 0.5X, 1X, and 2X sulfosulfuron treatments experienced stunting and chlorosis (**Fig. 1, Table 2**). There were differences in melon biomass; however, the field was treated with a PRE that is not registered on melons and there was heavy bindweed pressure, which greatly affected melon growth.

Figure 1 . Corn planted in the following season after sulfosulfuron experienced significant stunting.

Efficacy Study 2020

Methods

In 2020, an efficacy trial was conducted in a commercial field near Woodland, CA reported to be infested with branched broomrape in 2019 (**Table 3**). PPI applications of sulfosulfuron were made on March 27, 2020 using a 3-nozzle boom at 30 GPA and mechanically incorporated to 3". Double row tomatoes ('BQ271') were mechanically transplanted on March 30, 2020 with plants spaced 12" apart within and between rows. Chemigation treatments were made using CO_2 to push a chemigation mix into a distribution manifold with valved connections at each plot (**Fig. 2).** Treatments were applied to 2 replicate plots at once with separate injection ports for replicates 1 and 2 and replicates 3 and 4 to reduce the system volume receiving herbicide-treated water. Herbicides were diluted in 11L of water and this solution was injected into the system over approximately 15 minutes, followed by 20 minutes of water to flush the distribution lines. Foliar imazapic treatments were made with a 2-nozzle boom at 30 GPA. Chemigation applications began on May 2 and concluded on May 29. Following initial broomrape observations on May 29, 2020, broomrape scouting was done 1-3 times weekly starting on June 1, 2020, and individual clusters were marked with a 24-inch wire construction flag (**Fig. 3, 4**), with different colors representing each week's emergence (**Fig. 4**). Final counts of broomrape clusters were recorded on July 30, 2020 at tomato maturity. Cumulative broomrape number were analyzed with a one-way analysis of variance and Tukey-HSD test in the agricolae package in R (**Fig. 5**). Broomrape emergence data was analyzed using a four-parameter log-logistic function (data not shown).

Table 3. PICKIT treatments for 2020 PICKIT efficacy study near Woodland, CA.

Trt	Treatment	Rate (g ai/ha)	Application	GDD Appl.*
A	Check*	--	na	
B	Check 2**	--	na	
C	Sulfosulfuron	37.5	PPI	
	Imazapic	4.8	CHEM x5	400, 500, 600, 700, 800
D	Sulfosulfuron	37.5	PPI	
	Imazapic	4.8	CHEM x2	400, 600
E	Imazapic	2.4	POSTx2	
F	Sulfosulfuron	37.5	PPI	
	Imazapic	9.6	CHEM x5	400, 500, 600, 700, 800
G	Sulfosulfuron	70	PPI	
	Imazapic	9.6	CHEM x2	400, 600
H	Imazapic	4.8	POSTx2	
I	Sulfosulfuron	37.5	PPI	
	Imazamox	4.8	CHEM x5	400, 500, 600, 700, 800
J	Sulfosulfuron	37.5	PPI	
	Imazapyr	4.8	CHEM x5	400, 500, 600, 700, 800
K	Sulfosulfuron	37.5	PPI	
	Imazethapyr	4.8	CHEM x5	400, 500, 600, 700, 800
L	Rimsulfuron	35	POST	

* PPI: preplant incorporated POST: post emergence CHEM: Chemigated. Cumulative Growing Degree Days (GDD) were calculated after tomato transplanting date by using the formula GDD = $\sum(\bar{T} - T_b)$, where $\bar{T}$ is mean daily temperature and T_b is the base temperature set at 10 °C (50 degrees Fahrenheit).
** Treatment 2 was a placeholder for a commercial standard PRE tank mix that was not applied in the 2020 experiment.
*** The entire experimental area was treated with the grower's preplant incorporated herbicide program of S-metolachlor (2pt/ac), pendimethalin (1pt/ac), metribuzin (1pt/ac), and diazinon (1gal/ac) and also with a post-transplant application of 2.5 oz /ac rimsulfuron.

Results

In the 2020 efficacy study, all PICKIT treatments had fewer average broomrape cluster numbers than the non-PICKIT treatments. Although fewer than the non-PICKIT treatments, all PICKIT treatments had some broomrape emergence and there were no differences among rates and treatment intensity (**Fig. 5**).

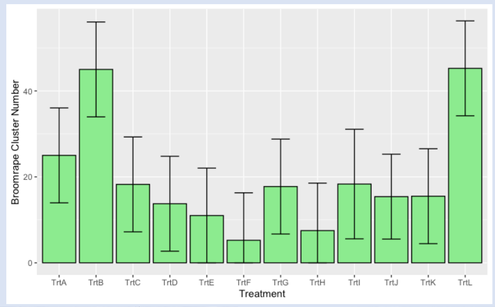

Figure 5. Broomrape cluster means at tomato maturity.

Figure 2. CO_2 injection system in efficacy study. The same system was used in the 2020 crop safety study.

Figure 3. Broomrape clusters from the same tomato plant at multiple development stages.

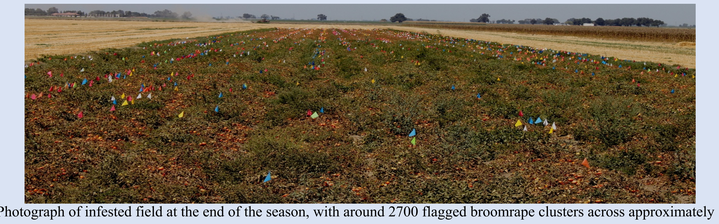

Figure 4. Photograph of infested field at the end of the season, with around 2700 flagged broomrape clusters across approximately 2 acres.

Crop Safety Studies 2019/2020

Methods

In 2019 and 2020, crop safety studies were conducted in an uninfested field at the UC Davis Plant Science Research Field Facility. (**Table 4**) PPI sulfosulfuron treatments were applied with a 3-nozzle boom at 30 GPA and mechanically incorporated to 3". Single line tomatoes ('Heinz 1662') were transplanted on 60" beds with 12" spacing with 40' plots. Two 5/8" drip lines with 0.16 gph emitters at 12" spacing were installed at 12" depth near the center of each bed, one a dedicated irrigation line and another set up to apply the experimental chemigation treatments in each plot.

In 2019, chemigation treatments were mixed in a 30-gallon tank and applied into a manifold and network of tubing to the field plots using an electric pump. Treatments were applied to four replicated plots at once with a total chemigation volume of 25.4 gallons per injection over the course of 1 hour. Following chemical injection 10 gallons of fresh water were used to flush the distribution lines. Foliar imazapic treatments were made with a 2-nozzle boom at 30 GPA.

In the 2020 crop safety trial, chemigation treatments were made using CO_2 following the same protocol used in the efficacy study (**Fig. 2).** Foliar imazapic treatments were made with a 2-nozzle boom at 30 GPA. Phytotoxicity (percent of plot affected), plant height (inch), and yield (kg tomatoes in 1 m^2 row) data were analyzed using ANOVA and Tukey-HSD tests in the agricolae package in R.

Table 4. 2019 and 2020 PICKIT crop safety trial treatment list.

Trt	Treatment Name	Rate g ai/ha	Application	GDD Appl.
1	Check			
2	Check 2**			
3	Sulfosulfuron	35	PPI	
	Imazapic	4.8	CHEM x5	400, 500, 600,700, 800
4	Sulfosulfuron	35	PPI	
	Imazapic	4.8	CHEM x2	400, 600
5	Imazapic	2.4	POST	
6	Sulfosulfuron	70	PPI	
	Imazapic	9.6	CHEM x5	400, 500, 600, 700, 800
7	Sulfosulfuron	70	PPI	
	Imazapic	9.6	CHEM x2	400, 600
8	Imazapic	4.8	POST	

** Treatment 2 was a placeholder for a commercial standard PRE tank mix that was not applied in the 2020 experiment.
*** The entire field was treated with 32 fl oz/ac S-metolachlor and 16 fl oz/ac trifluralin.

Table 5. Crop safety yield data from 2019 and 2020 (kg/m^2 row). Numbers within a column that share the same letter are not significantly different at p=0.05.

	Planting 1	Planting 2	Planting 3
Trt	Harvest 4-Sep-19	Harvest 19-Sep-19	Harvest 4-Sep-20
1	20.2a	20.2a	20.3a
2	24.3a	24.3a	17.5a
3	21.1a	21.1a	17.7a
4	16.8a	16.8a	21.3a
5	17.9a	17.9a	19.0a
6	21.1a	21.1a	19.9a
7	21.1a	21.1a	19.6a
8	20.1a	20.1a	17.0a

Results

There were no significant differences in phytotoxicity, height, or yield among treatments in the 2019 or 2020 crop safety trials (**Table 5** and data not shown).

Discussion and Future Research

After two field seasons, the PICKIT decision support system seems to have reasonable crop safety on California processing tomatoes, but control of branched broomrape was less than anticipated. The chemigation herbicides did not have significant effects on most rotational crops planted 8 months after application in 2019; however, sulfosulfuron caused significant injury to corn, which will have to be taken into account by growers if any of these programs are registered in the future.

Future research will focus on imazamox as the primary chemigation herbicide in place of imazapic due to the difficult registration pathway for that herbicide in California. A modified efficacy study protocol focused on imazamox will be implemented by cooperators in Chile during winter 2021 and repeated in California in the summer of 2021. The PICKIT system based its growing degree day model on Egyptian broomrape, which differs in development timing from branched broomrape. Future studies will investigate the effects alternative application timings. A fumigation study will be conducted in Spring of 2021 to examine quarantine eradication methods.

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