Evaluation of imazamox-based chemigation treatments for management of branched broomrape in California-grown processing tomato. Matt Fatino and Brad Hanson. University of California, Davis. (Part of IR-4 Project: IS00330 (2021))

Broomrape (*Phelipanche spp.* syn. *Orobanche spp.)* are parasitic weeds native to the Middle East. The biology of broomrape makes its control via conventional weed control practices very difficult. Broomrape seeds germinate after receiving a chemical signal from a suitable host plant and quickly attach to the host roots via a specialized structure known as a haustorium. The above ground portions of the plant lack chlorophyll and quickly produce a large amount of minute seed, which are highly persistent in the soil seedbank. Broomrape is not currently common in California but is an "A-listed" noxious weed and has been detected in several processing tomato fields in recent years.

Researchers in Israel developed decision support system and treatment protocols for management of Egyptian broomrape in tomato. The "PICKIT" decision support system relies on a thermal time model (Growing Degree Days) to predict broomrape phenological stages. Based on these predictions, ALS inhibitor herbicides are applied at very low rates at times intended to target specific broomrape life stages and attachment to the host crop. The Israeli protocol is based on imazapic as the in-season chemigation component; however, imazapic faces significant regulatory barriers in California and this trial focused on imazamox in place of imazapic. Two studies were conducted in 2021 at the UC Davis Department of Plant Sciences Field Research Facility near Davis, CA to evaluate the crop-safety of PPI sulfosulfuron plus imazamox chemigation treatments based on the PICKIT decision support system for control of branched broomrape (*Phelipanche ramosa)* in processing tomato.

Materials and Methods

The soil composition at the UC Davis site was 28.6% loamy alluvial sand and 71.4% Reiff very fine sandy loam. The site did not contain broomrape; this experiment focused on crop safety of imazamox and other herbicides used in the Israeli system that are not currently registered for use in tomato in the United States. Plots were 40 feet long on 60-inch beds with one plant line in the center of each bed. 'HM 58841' processing tomato transplants were planted at a 12-inch spacing. Each bed had two 7/8-inch drip lines buried 12 inches deep in the center of the bed with 0.16 GPH emitters spaced every 12 inches; one line ran the full length of the beds and was used for crop irrigation and the second line was terminated at the beginning and end of each plot and was used to apply the chemigation treatments. Chemigation plots were arranged in a randomized complete block design with four replications. PPI herbicides were applied using a backpack sprayer and three-nozzle boom delivering 30 GPA with TeeJet AIXR 11003 nozzles at 28 PSI. PPI treatments were mechanically incorporated to 3 inches after application. Tomatoes were mechanically transplanted with a single-row transplanter on April 28 and May 12, 2021. A redundant water delivery system was constructed to deliver irrigation water to the chemigation drip lines and drip herbicide injections were made using CO_2 to push a chemigation mix into individual plots. Herbicide solutions were mixed in 3 L bottles and injected into plots over

5-10 minutes, followed by one hour of irrigation to flush lines. Visual plant phytotoxicity (% vigor reduction, stunting, chlorosis) data were taken. Fruit was harvested from a 1-meter square section of row at commercial maturity on September 30 and October 7, 2021 (Table 1). Data were analyzed with a one-way analysis of variance followed by Tukey's HSD test in RStudio version 1.2.5033 using the agricolae package.

To evaluate the efficacy of an imazamox-based chemigation protocol, an efficacy study was conducted in a broomrape-infested commercial tomato field in Yolo County. The soil composition at this site was 25% sand, 42% silt, and 33% clay with 2.7% OM, 7.2 pH, and estimated CEC of 23.6 ($cmol_c$/kg of soil). This site was reported to be infested with broomrape in 2019 and had over 2700 confirmed broomrape clusters in the 2-acre site in 2020. Plots were 100-feet long on 60-inch beds with one plant line down the center of each bed. '9024 SVTM' processing tomato transplants were spaced at a 12-inch spacing within the row. Each bed had two drip lines in the center of the bed; one one-inch line buried at 12-inches was used for irrigation and one 7/8-inch line which was buried at 10.5-inches and terminated at the end of each plot was used for chemigation. Chemigation plots were arranged in a randomized complete block design with four replications. Two lateral 2" lay flat irrigation lines were place in between replications 1 and 2 and replications 3 and 4 to provide carrier water while injecting chemigation treatments at each plot. PPI herbicides were applied using a backpack sprayer and three-nozzle boom delivering 30 GPA with TeeJet AIXR 11003 nozzles at 28 PSI. PPI treatments were mechanically incorporated to 3 inches after application. Tomatoes were mechanically transplanted with a single-row transplanter on June 11, 2021. Drip herbicide injections were made using CO_2 to push a chemigation mix into individual plots. Herbicide solutions were mixed in 3 L bottles and injected into plots over 5-10 minutes, followed by one hour of irrigation to flush lines. Fruit was harvested from a 1-meter square section of row at commercial maturity on October 14, 2021 (Table 1). Data were analyzed with a one-way analysis of variance followed by Tukey's HSD test in RStudio version 1.2.5033 using the agricolae package.

Table 1. Growing degree targets and actual application dates in 2021 imazamox-based chemigation studies.

Application	**First Planting**	**Second Planting**	**Efficacy**
PPI	19-Apr	5-May	24-May
Transplant	28-Apr	12-May	11-Jun
400 GDD	20-May	4-Jun	1-Jul
500 GDD	27-May	9-Jun	7-Jul
600 GDD	2-Jun	15-Jun	12-Jul
700 GDD	7-Jun	22-Jun	16-Jul
800 GDD	10-Jun	24-Jun	20-Jul
900 GDD	16-Jun	29-Jun	24-Jul
1000 GDD			29-Jul
Harvest	30-Sep	7-Oct	14-Oct

Table 2. Treatments from two 2021 crop safety studies investigating chemigated imazamox on tomato crop safety near Davis, CA.

		Sulfosulfuron	**Imazamox**	**Imazapic**	
No.	**Treatment**		**Rate g ai/ha**		**Applications**
1	Grower Standard				na
2	Sulfosulfuron	37.5			PPI
3	Imazamox 1x		9.6		400, 500, 600, 700, 800
4	Imazamox 2x		9.6		400, 500, 600, 700, 800
5	Sulfosulfuron PPI /Imazapic 1x	37.5		4.8	400, 500, 600, 700, 800
6	Sulfosulfuron PPI/Imazamox 1x	37.5	9.6		400, 500, 600, 700, 800
7	Sulfosulfuron PPI/Imazamox 2x	37.5	19.2		400, 500, 600, 700, 800
8	Sulfosulfuron PPI/Imazamox 3x	37.5	28.8		400, 500, 600, 700, 800
9	Sulfosulfuron PPI/Imazamox 4x	37.5	38.4		400, 500, 600, 700, 800
10	Sulfosulfuron PPI/Imazamox 1x alternate timing	37.5	9.6		500, 600, 700, 800, 900

Table 3. Treatments from a study evaluating the efficacy of chemigated imazamox on branched broomrape control in an infested commercial tomato field in Yolo County, CA.

		Sulfosulfuron	**Imazamox**	**Imazapic**	
No.	**Treatment**		**Rate g ai/ha**		**Applications**
1	Grower standard				na
2	Rimsulfuron (25 g ai/ha)				400, 600, 800
3	Sulfosulfuron/Imazapic	37.5		4.8	400, 500, 600, 700, 800
4	Sulfosulfuron/Imazapic	37.5		4.8	500, 600, 700, 800, 900
5	Sulfosulfuron/Imazamox 1x	37.5	9.6		400, 500, 600, 700, 800
6	Sulfosulfuron/Imazamox 2x	37.5	19.2		400, 500, 600, 700, 800
7	Sulfosulfuron/Imazamox 3x	37.5	28.8		400, 500, 600, 700, 800
8	Sulfosulfuron/Imazamox 4x	37.5	38.4		400, 500, 600, 700, 800
9	Sulfosulfuron/Imazamox 1x alternate timing a	37.5	9.6		400, 500, 600, 700, 800, 900
10	Sulfosulfuron/Imazamox 1x alternate timing b	37.5	9.6		500, 600, 700, 800, 900
11	Actigard rate 1 (26.2 g ai/ha)				400, 500, 600, 700, 800, 900, 1000
12	Actigard rate 2 (52.4 g ai/ha)				400, 500, 600, 700, 800, 900, 1000

Table 4. Visual phytotoxicity on tomato from the first planting of an imazamox-based chemigation study near Davis, CA.

		Phytoxicity (% Vigor reduction, stunting, chlorosis)				
No.	**Treatment**	**6/17/21**	**6/29/21**	**7/8/21**	**7/19/21**	**7/27/21**
1	Grower Standard	0a	0a	0a	0a	0a
2	Sulfosulfuron	0a	0a	0a	0a	0a
3	Imazamox 1x	5a	0a	0a	0a	0a
4	Imazamox 2x	22.5a	17.5a	0a	0a	0a
5	Sulfosulfuron/Imazapic 1x	0a	0a	0a	0a	0a
6	Sulfosulfuron/Imazamox 1x	2.5a	0a	0a	0a	0a
7	Sulfosulfuron/Imazamox 2x	7.5a	7.5a	0a	0a	0a
8	Sulfosulfuron/Imazamox 3x	15a	7.5a	0a	0a	0a
9	Sulfosulfuron/Imazamox 4x	25a	22.5a	15a	7.5a	5a
10	Sulfosulfuron/Imazamox 1x alternate timing	2.5a	0a	0a	0a	0a

Means with the same letter within the same column are not significantly different according to Tukey's HSD test (alpha= 0.05).

Table 5. Tomato yield from two imazamox-based chemigation studies near Davis, CA.

No.	Treatment	Planting 1 Yield (kg/m^2)	Planting 2 Yield (kg/m^2)
1	Grower Standard	18.6a	17.9a
2	Sulfosulfuron	19.0a	21.3a
3	Imazamox 1x	18.1a	20.4a
4	Imazamox 2x	21.1a	16.6a
5	Sulfosulfuron/Imazapic 1x	21.7a	18.2a
6	Sulfosulfuron/Imazamox 1x	16.4a	16.7a
7	Sulfosulfuron/Imazamox 2x	20.5a	18.1a
8	Sulfosulfuron/Imazamox 3x	12.9a	14.1a
9	Sulfosulfuron/Imazamox 4x	19.1a	12.7a
10	Sulfosulfuron/Imazamox 1x alternate timing	19.7a	19.5a

Means with the same letter within the same column are not significantly different according to Tukey's HSD test (alpha= 0.05).

Table 6. Visual phytotoxicity on tomato from the second planting of an imazamox-based chemigation study near Davis, CA.

		Phytoxicity (% Vigor reduction, stunting, chlorosis)			
No.	**Treatment**	**6/29/21**	**7/8/21**	**7/19/21**	**7/27/21**
1	Grower Standard	0b	0a	0a	0a
2	Sulfosulfuron	0b	0a	0a	0a
3	Imazamox 1x	0b	0a	0a	0a
4	Imazamox 2x	17.5ab	20a	10a	7.5a
5	Sulfosulfuron/Imazapic 1x	10ab	2.5a	0a	0a
6	Sulfosulfuron/Imazamox 1x	0b	0a	0a	0a
7	Sulfosulfuron/Imazamox 2x	10ab	10a	5a	2.5a
8	Sulfosulfuron/Imazamox 3x	22.5ab	12.5a	5a	0a
9	Sulfosulfuron/Imazamox 4x	35a	30a	20a	12.5a
10	Sulfosulfuron/Imazamox 1x alternate timing	0b	0a	0a	0a

Means with the same letter within the same column are not significantly different according to Tukey's HSD test (alpha= 0.05).

Table 7. Tomato fruit yield from an imazamox-based chemigation efficacy study in Yolo County, CA.

No.	Treatment	Yield (kg/m^2)
1	Grower standard	11.8a
2	Rimsulfuron	11.8a
3	Sulfosulfuron/Imazapic	11.6a
4	Sulfosulfuron/Imazapic	10.5abc
5	Sulfosulfuron/Imazamox 1x	9.2abc
6	Sulfosulfuron/Imazamox 2x	6.2abc
7	Sulfosulfuron/Imazamox 3x	3.7c
8	Sulfosulfuron/Imazamox 4x	3.6c
9	Sulfosulfuron/Imazamox 1x alt timing a	4.6bc
10	Sulfosulfuron/Imazamox 1x alt timing b	9.3abc
11	Actigard rate 1	10.2abc
12	Actigard rate 2	10.7ab

Means with the same letter are not significantly different according to Tukey's HSD test (alpha= 0.05).

Results

There were early signs of visual injury in plots treated with the higher imazamox rates in both crop safety studies (Trts 4, 8, 9; Tables 4, 6). Noted symptoms included stunting, leggy stems, pale green and grey plants, and general vigor reduction. Midway through the season, the plants appeared to grow out of the most severe injury symptoms (Tables 4, 6). There were no significant differences in tomato yield in either study among treatments, although there was a trend in lower yield in the 28.8 and 38.4 g ai/ha rates of imazamox in the second planting (Table 5). There were significant differences in tomato yields among treatments in the efficacy study (Table 7). Treatments 7, 8, and 8 had lower tomato yields than treatments 1, 2, and 3 (Table 7). Visual injury symptoms were also observed at this site, with severe injury at the higher imazamox rates (data not shown). These symptoms were similar to those observed in the crop safety studies, though more severe, and persisted throughout the season. Chemigated rimsulfuron (Trt 2) and Actigard (acibenzolar-S-methyl, Trts 11 and 12) had similar tomato yields to the positive control (Trt 1) (Table 7).

Discussion

Early season tomato injury (stunting, vigor reduction, pale green/gray plants) was observed in the two Davis crop safety studies. The plants seemingly grew out of these symptoms later in the season. Anecdotally, reduction of injury symptoms seemed to coincide with fertigation events. The two studies on campus were very well fertilized and irrigated, while the efficacy study was less well fertilized and had some questions regarding irrigation efficacy possibly caused by less-than-ideal soil conditions when the drip tape was installed. These results lead to the hypothesis that well fertilized and irrigated plants are able to grow out of many of the visual injury symptoms, while herbicide injury on already-stressed plants may persist. More studies will need to be conducted to confirm this hypothesis and further refine imazamox rate structures. Future research will not include imazamox at 28.8 and 38.4 g ai/ha rates given the significant crop injury observed in the 2021 efficacy study.