Project Title: Branched broomrape: doubling down on research for a critical California pest

Year of Project Initiation: 2021.

- 2021 California Tomato Research Institute project 2019-272 (Hanson)
- UC Davis sub-contracted to UC Davis Chile

Project Leader and any Co-PIs:

Principal Investigator:
Bradley D. Hanson, Extension Weed Specialist
290a Robbins Hall, University of California - Davis
Department of Plant Sciences, MS-4
One Shields Avenue
Davis, CA 95616
(530) 752-8115
bhanson@ucdavis.edu

Co-Investigator(s):
Mauricio Canoles & Juan Carlos Galaz
UC Davis Chile Life Sciences Innovation Center
Av. Santa María 2670, Torre B of. 206, Providencia
Santiago, Chile
https://chile.ucdavis.edu/en

1. Executive Summary:

Research on branched broomrape (*Phelipanche ramosa*, aka *Orobanche ramosa*) continues on several fronts. CTRI has funded basic biology and growth chamber research (PI, Mesgaran) and is pushing forward on soil fumigation research (and eradication efforts). With funding support from CTRI and the USDA-funded IR-4 Project, we conducted research in 2019 and 2020 to evaluate herbicide chemigation approaches originally developed for control of Egyptian broomrape in Israel (the "PICKIT" decision support system). The PICKIT system is based on PPI treatments of sulfosulfuron followed by chemigation applications of imazapic. Unfortunately, during 2020, it became apparent that imazapic is unlikely to be registered in California. For 2021, we shifted the IR-4 project focus to a related herbicide, imazamox (trade name Raptor) which has a more likely path to registration success. However, less is known about the efficacy of this herbicide for this use pattern on this pest species.

In 2021, CTRI funded a project that was conducted by collaborators at the UC Davis Chile Life Sciences Center near Santiago, Chile. Branched broomrape is more widespread in Chile compared to California the southern hemisphere location allowed an initial evaluation of the imazamox chemigation treatments ahead of the 2021 California experiments (which were not directly funded by CTRI). Like in California, the Chilean researchers conducted a replicated, small-plot field experiment to evaluate the crop safety and branched broomrape efficacy of herbicide programs modified from the Israeli PICKIT system. Local practice is to irrigate via surface drip tapes and this was also how the chemigation treatments were applied. For herbicides in this year's experiment, we settled on a fixed rate of PPI sulfosulfuron which was consistent with the Israeli program and our 2019-2020 protocols in California. However, the chemigated herbicide (applied up to 5 times per season) tested a range of rates of imazamox rather than imazapic.

The experiment in Chile as initiated later than ideal due to a misalignment of southern hemisphere planting dates and northern hemisphere funding decisions. Because of the late planting, the tomato crop suffered from heat early in the season and did not reach full fruit maturity before the local irrigation district stopped delivering water; thus crop performance data and instructive but not definitive. Imazamox treatments suppressed branched broomrape and performance was better when combined with PPI sulfosulfuron; and was similar to the imazapic reference treatment. However, crop safety with imazamox was not as good as with imazapic, especially at the highest rates (the putative 3x and 4x treatments) which caused substantial tomato injury and tended to reduce fruit yield.

The Chilean experimental results aligned with the California results from summer 2021. Both trials were planted later than ideal and had lower-than-expected branched broomrape emergence. Both experiments had adequate crop safety with PPI sulfosulfuron but unacceptable crop injury with the highest rates of chemigated imazamox. Lower rates of imazamox also caused moderate crop injury in Chile but less injury in the California experiments. In the Chilean experiment, the lower two rates of imazamox plus sulfosulfuron suppressed broomrape similarly to the imazapic reference treatment. Future research should focus on questions raised about planting dates, imazamox timing relative to planting date, and possible differences in tomato cultivar sensitivity to broomrape parasitism.

2. Introduction:

The parasitic broomrapes (*Orobanche* and *Phelipanche* spp.) are considered as one of the most disrupting weeds in many economically important crops. Lacking chlorophyll, broomrapes entirely survive on water and assimilates taken from the roots of their hosts and therefore can cause severe yield losses or, in case of heavy infestations, even total crop failure (Hershenhorn et al., 2009). Studies in Israel show that at high infestation levels (~100 shoots m^{-2}), Egyptian broomrape (*P. aegyptiaca*) can cause yield losses as high as 70 ton ha^{-1} in processing tomato. In a semi-commercial field in Israel, effective management of Egyptian broomrape (~95% control) increased the tomato yield by 40 ton ha^{-1} and the net revenue by $4,731 ha^{-1} (Eizenberg & Goldwasser, 2018).

Branched broomrape, and to a lesser extent Egyptian broomrape, are critical threats to California tomato industry. There is an urgent need to develop short- and long-term strategies for effective management, containment and eradication of broomrape. A decision support system, known as *PICKIT*, developed by Israeli scientists over the past 25 years, has proven effective for management of Egyptian broomrape in tomato (Eizenberg & Goldwasser, 2018). The *PICKIT* system uses a GDD-based phenological model to precisely time the application of PRE and POST herbicides. However, the adaptation of *PICKIT* in California tomato cropping system requires some modifications and further evaluations because: (1) the current *PICKIT* model has been optimized based on the growth and development of Egyptian broomrape and therefore needs to be re-calibrated for branched broomrape, (2) the herbicides found to be most effective in *PICKIT* (sulfosulfuron and imazapic: Eizenberg et al. 2012) have not been registered for use in tomato in California, and (3) differences in soil and climate conditions, crop variety, and management practices can affect the phenology of parasite and herbicide efficacy necessitating the reassessment of *PICKIT* under California tomato growing conditions.

In 2019 and 2020, a series of 5 field trials were conducted at UC Davis in a non-infested site to begin developing crop safety data to support eventual registration of sulfosulfuron and imazapic for this novel use pattern in California. In 2020, an infested site was identified in Yolo County and the grower hosted a PICKIT efficacy experiment. The efficacy trial included the imazapic programs identified as most effective by the Israeli researchers as well as initial evaluation of the related herbicides imazamox, imazethapyr, and imazapyr (Raptor, Pursuit, and Arsenal, respectively). In fall 2020, the registrant of the imidazolinone herbicides, BASF, indicated that there was not a viable path to registration of imazapic in California due to the lack of necessary environmental dissipation and ecotoxicological studies that would have to be done. In consultation with the registrant, the industry, and cooperators, we refocused the 2021 research on imazamox; however, considerable research will be needed to determine effective and safe treatment protocols.

Because the broomrape problem is at a relatively early stage in California and it is a quarantine pest, conducting this efficacy work in state is difficult due to low weed density and lack of cooperators. Additionally, this type of research often is an iterative process where improvements are made based on previous results which slows progress in an annual crop / annual parasitic weed problem such as broomrape in processing tomato. Thus, CTRI funded research that was subcontracted by UC Davis PI Hanson to collaborators at the UC Davis Chile Life Science Innovation Center in Chile to supplement and accelerate the ongoing California projects.

3. Main Goal and Objectives:

The goal of this research is to develop herbicide programs for management of branched broomrape in California processing tomato. While eradication efforts continue under different research and regulatory programs, we recognize that management approaches may also be needed to protect the important processing tomato industry in the state.

The specific objectives of the 2021 CTRI project was to:

- conduct an evaluation of sulfosulfuron PPI treatments supplemented with imazamox chemigation for control of branched broomrape in processing tomato in Chile during winter 2021
- Data from the experiment in Chile will inform treatment protocols for the experiments planned for spring/summer 2021 in California (not directly funded by CTRI)

4. **Methods:**

Cooperators and research staff at the UC Davis Chile Life Sciences Innovation Center conducted this research in partnership with UC Davis faculty and graduate student researchers. The UC Davis Chile group has been working on broomrape management in collaboration with the Israeli researchers for several years and have experience that mirrors the work in California. Like California, Chile is affected by branched broomrape (vs Egyptian broomrape like in Israel) and their production system and climate are similar to California. Also like California, the Chilean group sees registration challenges with imazapic and will, refocus on imazamox; thus there is mutual benefit to the northern and southern hemisphere approaches to accelerate our progress.

A field experiment was set up in a commercial tomato field with a cooperating grower. The geographical location of the experiment site was at 34°39'57.2"S 71°22'22.7"W. Due to relatively late approval of the project and subcontracting challenges, , the tomato crop was established 1.5 month later than the last commercial planting in the region, in the middle of the summer when temperatures were higher than ideal.

Research staff set up a randomized experiment to evaluate seven herbicide programs. Briefly, the field was prepared for tomato transplanting (Figure 1). Raised beds were 1.5 m wide by 35 m long; each 35 m bed was split into two 17 m- long plots (figure 4). PPI sulfosulfuron treatments were applied and mechanically incorporated into the beds prior to transplanting. After the sulfosulfuron application, a drip irrigation system was installed on the surface of the beds. The drip irrigation equipment in the field trials was ‘Netafim’ 16.2 mm diameter driplines with emitters 20 cm apart delivering 1.1 l/hr at 1 bar. (Fig 2).

Figure 1. Beds prepared for tomato transplanting.

Figure 2. drip tape installing by hand.

The tomato cultivar used in the experiment was HMX 7883, which was sown in seedling trays on December 12th 2020 and transplanted by hand on January 19th 2021 (Figures 3).

Figure 3. Plant of tomato variety HMX 7883 and hand planting in Chile on January 19, 2021

Chemigation treatments was applied at 400, 500, 600, 700, and 800 growing degree days after transplanting. Treatments are in the Table 1 and were designed to allow efficacy and crop safety evaluations of imazamox rates including the rates used in 2020 trial as well as several higher rates to determine margin of crop safety (treatments 8 and 9). Additionally, an imazapic treatment (treatment 7) and with sulfosulfuron (treatment 2) was included as a benchmark comparison to previous work in Israel, Chile, and California.

The herbicide chemigation treatments were applied using Venturi-type injectors, (Figure 5), which use a pressure difference between the water line and the stock tank to draw a concentrated solution into a faucet connect valve and mix it with water in the hose. In order to simultaneously inject the herbicides in all chemigation treatments, 5 parallel systems were installed, the first for the treatments 3 and 5, the second for the treatments 4 and 6, the third for the treatment 7, the fourth for the treatment 8 and the fifth for the treatment 9.

Table 1. List of treatments

Treatment number	**description**
1	Grower treatment (metribuzin and rimsulfuron).
2	37.5 g ai/ha sulfosulfuron (PPI) + 37.5 g ai/ha sprayed 3 times at 200, 400 and 600 GDD
3	9.6 g ai/ha imazamox (chemigated 5 times)
4	19.2 g ai/ha imazamox (chemigated 5 times)
5	37.5 g ai/ha sulfosulfuron (PPI) + 9.6 g ai/ha imazamox (chemigated 5 times)
6	37.5 g ai/ha sulfosulfuron (PPI) + 19.2 g ai/ha imazamox (chemigated 5 times)
7	37.5 g ai/ha sulfosulfuron (PPI) + 4.8 g ai/ha imazapic (chemigated 5 times)
8	37.5 g ai/ha sulfosulfuron (PPI) + 28.8 g ai/ha imazamox (chemigated 5 times)
9	37.5 g ai/ha sulfosulfuron (PPI) + 38.4 g ai/ha imazamox (chemigated 5 times)

The treatment distribution in the field is shown in Figure 4. Plots were 17 m long and beds were 1.5 m center-to-center planted with a single row of tomatoes.

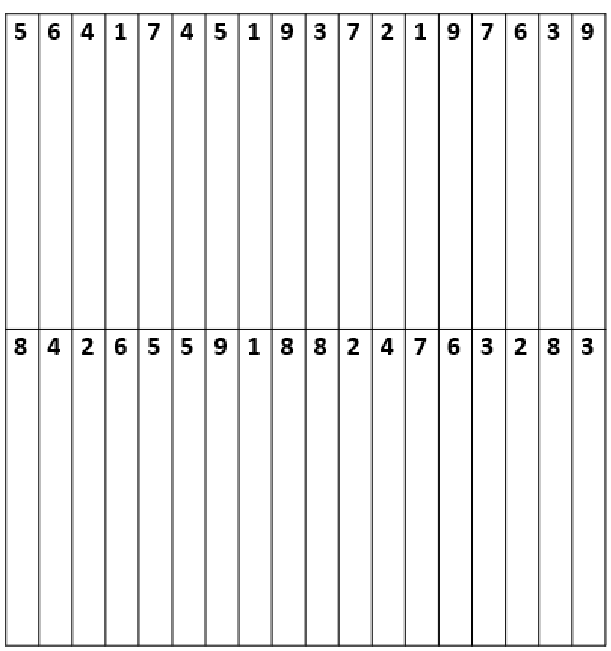

Figure 4. Treatment distribution

Figure 5. Venturi type injection system

Broomrape emergence was monitored in each plot with weekly field scouting and marking of emerged shoots. Broomrape clusters data are presented as number per 17-m bed. Spatial and temporal data analysis allowed comparison of treatment efficacy. Visual estimates of crop injury were made regularly and estimates of crop yields was made in each plot by harvesting all fruit in the center 5 m of each plot. Due to the lateness of the season the irrigation district stopped delivering water to the area; thus, the tomato fruits were harvested before reaching commercial maturity.

Foliar and PPI herbicide treatments were applied using a ‘Solo 434’ 18 liter high-pressure backpack motorized sprayer with a 1.5 m wide boom equipped with 3 ‘Spraying Systems’ Tee-Jet 110015 nozzles spaced 50 cm apart, delivering 200 l /ha.

Growing degree days (GDD) was calculated with the following formula:

$$GDD= (Tmax+Tmin/2)-10$$

The soil temperature, instead of air temperature, was used to calculate the GDD. Two HOBO data loggers (Figure 6) were installed at 10 cm depth in the experimental field. The loggers were programmed to record temperature hourly.

The table 2 presents the main activities conducted in the experimental site.

Table 2. Main activities conducted during the herbicide experiment in 2021

Activity	Date	Remarks
Soil preparation	Jan 6th	
Sulfosulfuron application at PPI	Jan 11th	37.5 g ai/ha
Tomato planting	Jan 19th	4.3 pl/m equivalent to 29,000 pl/ha
Sulfosulfuron 1st application (200 GDD)	Feb 2nd	37.5 g ai/ha, volume of water of 276 l/ha; 210 GDD
Herbicide chemigation + SS sprayed (400 GDD)	Feb 16th	380 GDD
Herbicide chemigation (500 GDD)	Feb 25th	513 GDD
Herbicide chemigation (600 GDD) + SS sprayed	Mar 5th	626 GDD
Herbicide chemigation (700 GDD)	Mar 11th	703 GDD
Herbicide chemigation (800 GDD)	Mar 19th	790 GDD
Experiment harvest	May 19th	

As the tomato crop was planted on January 19th, which is approximately 6 weeks later than the last commercial planting in the region, the temperature constantly decreased during the experiment, until day 119 after the planting (DAP), when the crop was harvested. Figure 7 shows the daily soil temperature fluctuation during the experiment and figure 8 shows the maximum and minimum soil temperatures in the same period.

Figure 6. Hobo data logger

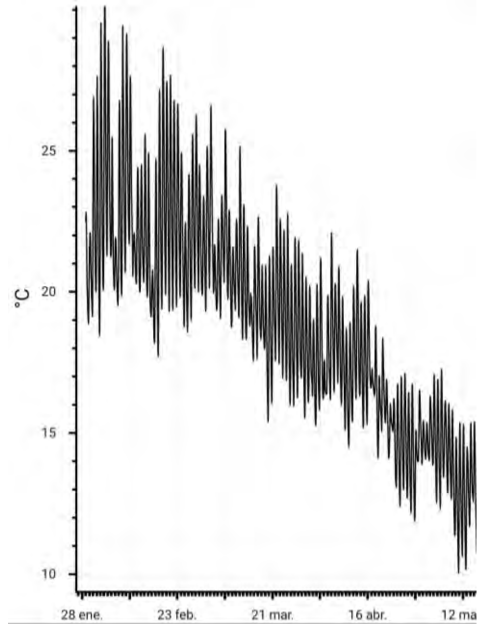

Figure 7. Hourly temperature

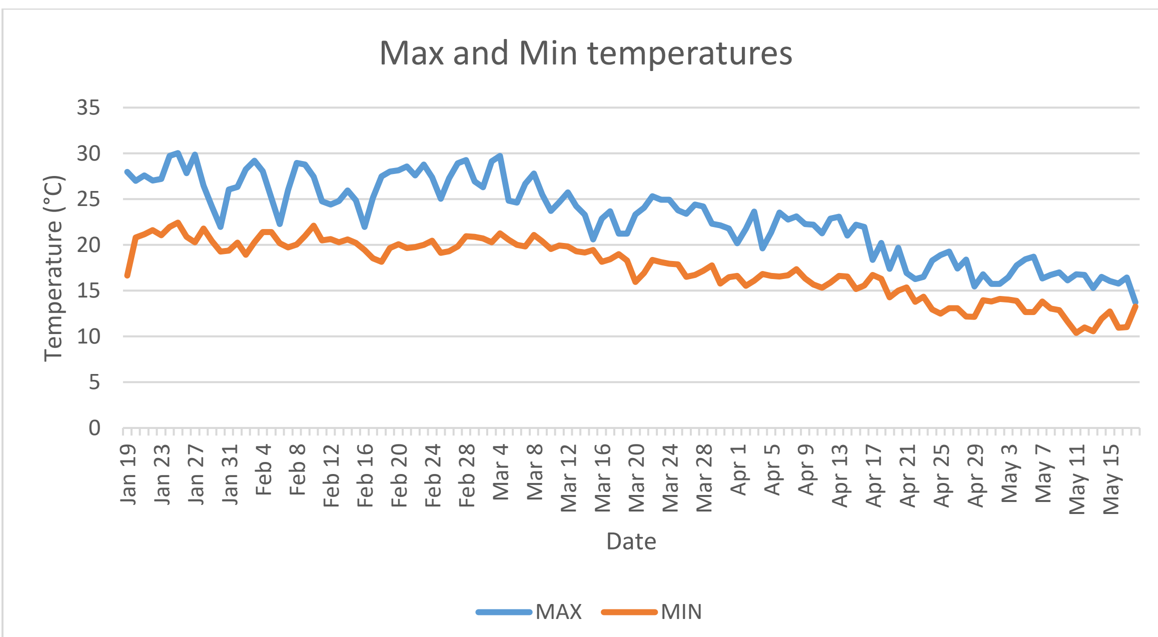

Figure 8. Max and min temperatures

5. Results

The results are presented in three parts, herbicide phytotoxicity on tomato plants, herbicides effects on broomrape shoots, yield results.

a. Herbicide phytotoxicity

After the chemigation, the tomato plants were observed weekly for visual phytotoxicity and mortality. The first signs of phytotoxicity started to appear at 715 GDD about 2 weeks after the first chemigation (52 days after transplanting). The plants exhibited small leaves, leaf and shoot malformation and stunt, as is showed in figure 9.

The plant vigor of the treatments can be seen in figures 11 to 16. Pictures show a severe damage in treatments 8 and 9, where some of the plants died, but most of the plants suffered significant stunting and malformation in the leaves and shoots. Treatments 4 and 6 (19.2 g ai/ha imazamox) suffered stunting but not much different than treatments 3 and 5 (9.6 g ai/ha imazamox). The treatments with best plant vigor were 1 (control), 2 (foliar sulfosulfuron) and 7 (chemigated imazapic). In figure 17 can be seen the difference in plant vigor on the treatments, from an aerial picture, taken at 923 GDD (72 DAP).

Over several days, some of the plants died and others plants turned to a purple color, as shown in figure 10.

 

Figure 9. Phytotoxicity effect on treatment 8 (left) and 9 (right) plants, at 715 GDD.

 

Figure 10. Tomato plants with some purple color in the leaves**.** Treatment 8, 923 GDD.

		
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9

Figure 11. Phytotoxicity on plants, Feb 25th (513 GDD), 37 DAP.

	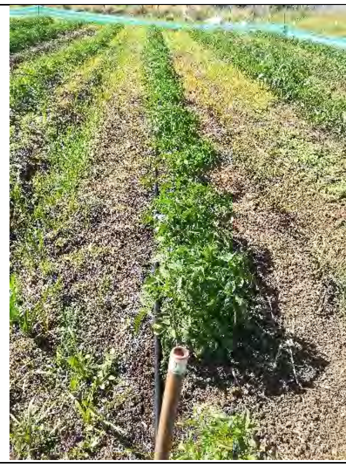	
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9

Figure 12. Phytotoxicity on plants, March 1st (569 GDD), 41 DAP.


Treatment 1


Treatment 2


Treatment 3


Treatment 4


Treatment 5


Treatment 6


Treatment 7


Treatment 8


Treatment 9

Figure 13. Phytotoxicity on plants, March 19th (790 GDD), 59 DAP

Figure 14. Phytotoxicity on plants, April 1st (923 GDD), 72 DAP.


Treatment 1


Treatment 2


Treatment 3


Treatment 4


Treatment 5


Treatment 6


Treatment 7


Treatment 8


Treatment 9

Figure 15. Phytotoxicity on plants, Apr 16th (1061 GDD), 87 DAP.

		
Treatment 1	Treatment 2	Treatment 3
		
Treatment 4	Treatment 5	Treatment 6
		
Treatment 7	Treatment 8	Treatment 9

Figure 16. Phytotoxicity on plants, Apr 29 (1138 GDD), 100 DAP

Figure 17. Aerial picture of the experiments 923 GDD, 72 DAP

b. Broomrape shoot count

The first broomrape emergence occurred at 715 GDD (Figure 18), which is later than in previous experiments. The last two season the broomrape shoot emergence started at 550 GDD. Maybe the late date of transplanting affected the emergence, the soil could have been too dry before the soil preparation, whereas, in a more timely spring planting, residual soil moisture from winter rain could have allowed the imbibition of broomrape seeds.

Figure 18. First broomrape emergence at 715 GDD, 52 DAP

The figure 19 shows the broomrape shoot count per week. The first week shoot emergence was observed only in the control treatment (Treatment 1), whereas in the second (780 GDD) there was also emergence in treatments 2 and 3, and in the third week (833 GDD) emergence was noted in treatments 6 and 7. Imazamox affected the emergence of broomrape, although caused toxicity on tomato plants, especially treatment 8 and 9 with 28.8 and 38.8 g a.i./ha. The lowest rate of imazamox (treatment 3) had emergence of broomrape, but the same dose following PPI sulfosulfuron (treatment 5) had much lower emergence.

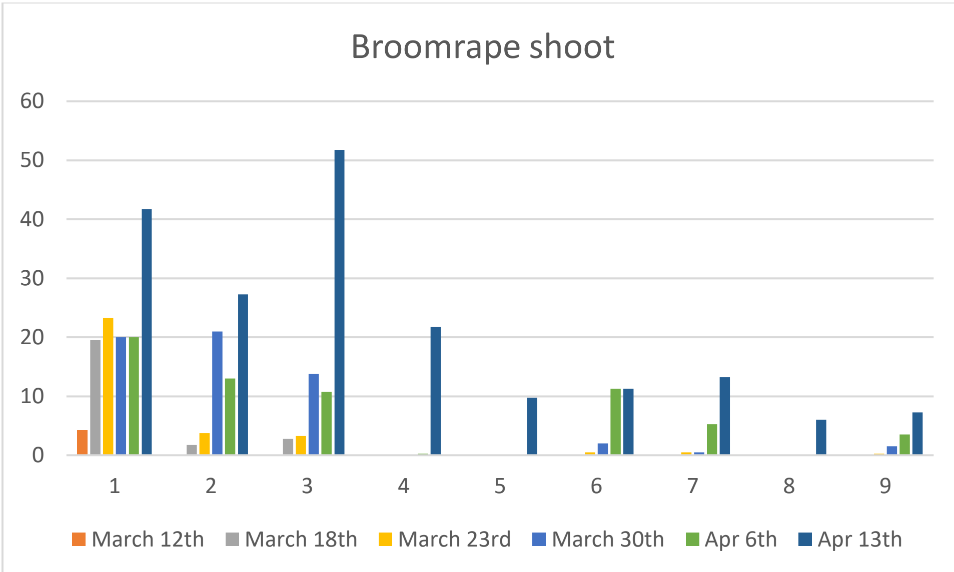

Figure 19. Broomrape shoot emergence per week (# of clusters per 17m plot)

c. Yield results

Because of the late planting date, the tomato crop faced high temperatures at the early stages and decreasing temperatures in later stages. The temperatures in the last month were too low for a good development of fruits (Figure 20). Also, the high relative humidity increased disease pressure. Because of these factors, fruit yield was in general low, but still provides a relative indicator of the impacts of herbicide toxicity and broomrape parasitism.

Figure 20. Left, green fruits, 1 month before harvest. At right, green fruits the day of harvest (May 19th)

Tomato fruit yield is shown in figure 21. The highest yield was in the treatment 2 with 43 t/ha and then the control treatment (37 t/ha). Treatment 7 (imazapic) reached only 28 t/ha, a more significant reduction than previously observed with this herbicide in Chile which used lower rates. Among the treatments with imazamox, treatment 5 (37.5 g ai/ha sulfosulfuron (PPI) + 9.6 g ai/ha imazamox (chemigated 5 times)) reached the highest yield

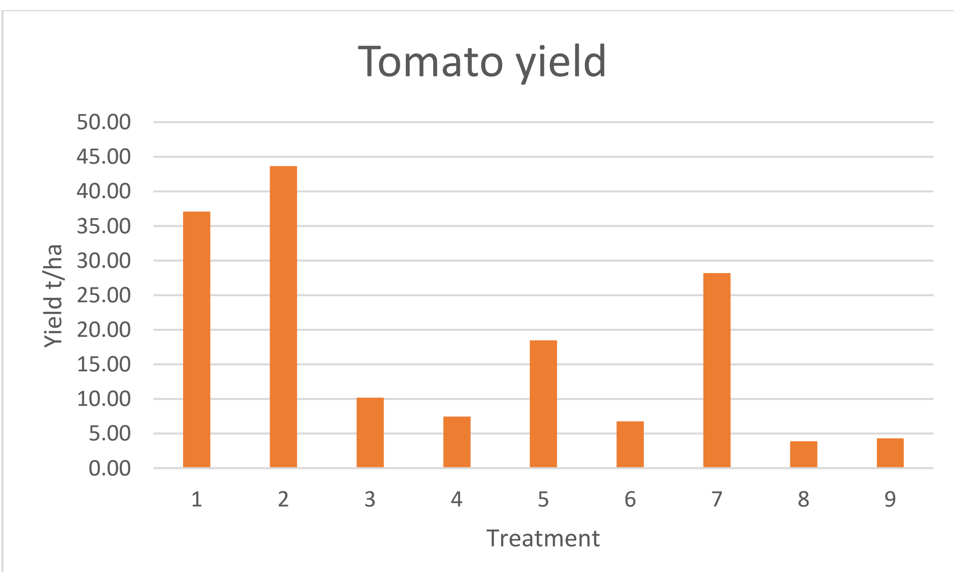

Figure 21. Average tomato yields.

6. Conclusions

- Imazamox has an effect on broomrape, diminishing the shoot emergence. However, the herbicide caused significant phytotoxicity on tomato plants, even at the lower doses.

- Due to the late transplant date, the tomato crop did not perform very well and yield data are instructive but may not be completely reliable.

- The effect of imazamox on broomrape was improved when sulfosulfuron was applied PPI.

- The herbicides imazapic and sulfosulfuron provided good control on broomrape, which is consistent with the Israeli PICKIT system and results in Chile during the past two seasons.