TITLE: Breaking bindweed: Deciphering the complex interactions among weed, water, herbicide and crop to improve *Convolvulus arvensis* control in processing tomato.

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SUMMARY:

Field bindweed (*Convolvulus arvensis*) is a deep-rooted perennial that is difficult to control once it has become established. Since 2013, we have been engaged in research to evaluate the management of field bindweed in processing tomatoes. Results from our trials suggest:

1. Soil-applied trifluralin (PPI), rimsulfuron (PRE), and sulfentrazone (PPI) can suppress field bindweed vines; *S*-metolachlor has not been shown to be effective against perennial plants.

2. Sub-surface, layered applications of trifluralin can be effective at suppressing field bindweed, although crop injury may occur depending on transplant root ball placement.

3. With respect to POST herbicide applications, glyphosate can control field bindweed (i.e. reduce vine number, vine cover (length, biomass)) for up to six weeks; rimsulfuron and carfentrazone provide almost no suppression of perennial vines.

INTRODUCTION:

Processing tomato production in California has changed, dramatically, over the last half-century. Improved cultivars, conversion from seeded to transplanted production, commercialization of the mechanical harvester, and the steady adoption of drip irrigation have helped to expand the size and economic value of the industry (Mitchell et al. 2012). In 2013, California led the nation in the production of processing tomatoes in terms of hectares planted and harvested (105,000 ha), total yield (10 million metric tons), and total value of production ($918 million). Processing tomatoes are a significant component of the agricultural value chain in the Central Valley, where the majority of production occurs; in 2013, Fresno, Kings, Merced, San Joaquin, Stanislaus, and Yolo Counties each produced tomato crops valued at more than $100 million.

Field bindweed (*Convolvulus arvensis* L.), a deep-rooted and drought tolerant perennial, (DeGennaro and Weller 1984; Frazier 1943a, 1943b, 1943c; Sharma and Singh 2007; Shrestha et al. 2007; Swan and Chancellor 1976; Weaver and Riley 1982; Wiese and Lavake 1986; Yerkes and Weller 1996) is a significant concern of the processing tomato industry in California. If allowed to compete with tomatoes during canopy establishment, field bindweed can significantly reduce both fruit number and quality (Lanini and Miyao 1989). Furthermore, field bindweed vines can become physically entwined with tomato plants, which, in turn, can reduce harvest efficiency (Mitich 1991).

Although bindweed seedlings are relatively easy to manage using physical and chemical control strategies, established plants with extensive root systems are relatively tolerant to most management practices. For example, perennial bindweed control with tillage and cultivation is made more difficult by the weed's significant below-ground nutrient reserves and regenerative capacity (Derscheid et al. 1970; Frazier 1943a, 1943b, 1943c; Swan 1980; Swan and Chancellor 1976; Weaver and Riley 1982). Infrequent mechanical cultivation may also facilitate plant spread by dispersing root fragments as opposed to exhausting stored energy. Suppression of established bindweed using chemical tools may be equally challenging, especially in crops like processing tomato, where effective herbicide options are limited.

PRE-PLANT INCORPORATED/PRE-EMERGENCE HERBICIDE EFFICACY:

Between 2013 and 2015, multiple field studies were conducted to evaluate the efficacy of pre-plant incorporated (PPI) and pre-emergence (PRE) herbicides on the suppression of field bindweed. All trials were conducted at the University of California, Davis, research farm (38 32'N, 121 47'W), where the soil is a fine, silty loam (Yolo series, 37% sand, 41% silt, 22% clay; 1.5-3% OM; pH 6.7-7.2) (Haar et al. 2002). The fields used in this study were known to be heavily infested with field bindweed (Lanini and Sosnoskie, personal observations). Tomatoes were transplanted between April and June and were sprinkler-irrigated with 1 inch of water immediately after planting to facilitate crop establishment. Furrow irrigation was used, thereafter, to maximize weed pressure in the study (Sutton et al. 2006). All herbicides were applied using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet

Technologies, Wheaton, IL) spaced 16-20 in apart and calibrated to deliver 20-30 GPA. All herbicides were applied to the soil surface 1 day before transplanting; trifluralin, *S*-metolachlor, and sulfentrazone were mechanically incorporated immediately thereafter. Field bindweed cover (defined as the percent (%) of the plot area that was occupied by field bindweed) was assessed until tomato canopy closure began to occur.

Field bindweed cover at 4 weeks after transplanting (WAT), as observed in multiple herbicide trials, is displayed in Figure 1. Results suggest that trifluralin (as Treflan at 32 oz/A) applied PPI, rimsulfuron (as Matrix at 4 oz/A) applied PRE, and sulfentrazone (as Zeus at 3.2, 4.5 or 6 oz/A) applied PPI were effective at suppressing field bindweed at 4 WAT. Field bindweed cover ranged from 11-76% in the untreated checks (mean = 51% cover). Cover in the *S*-metolachlor (as Dual Magnum at 27 oz/A) treatments (mean = 51% cover) did not differ, substantially, from the controls. Mean field bindweed vine cover in the trifluralin, rimsulfuron, and sulfentrazone treatments ranged from 4-35% cover. Mean cover, averaged over trials was 16% for trifluralin, 10% for rimsulfuron, and between 4 and 17% for sulfentrazone, depending on rate.

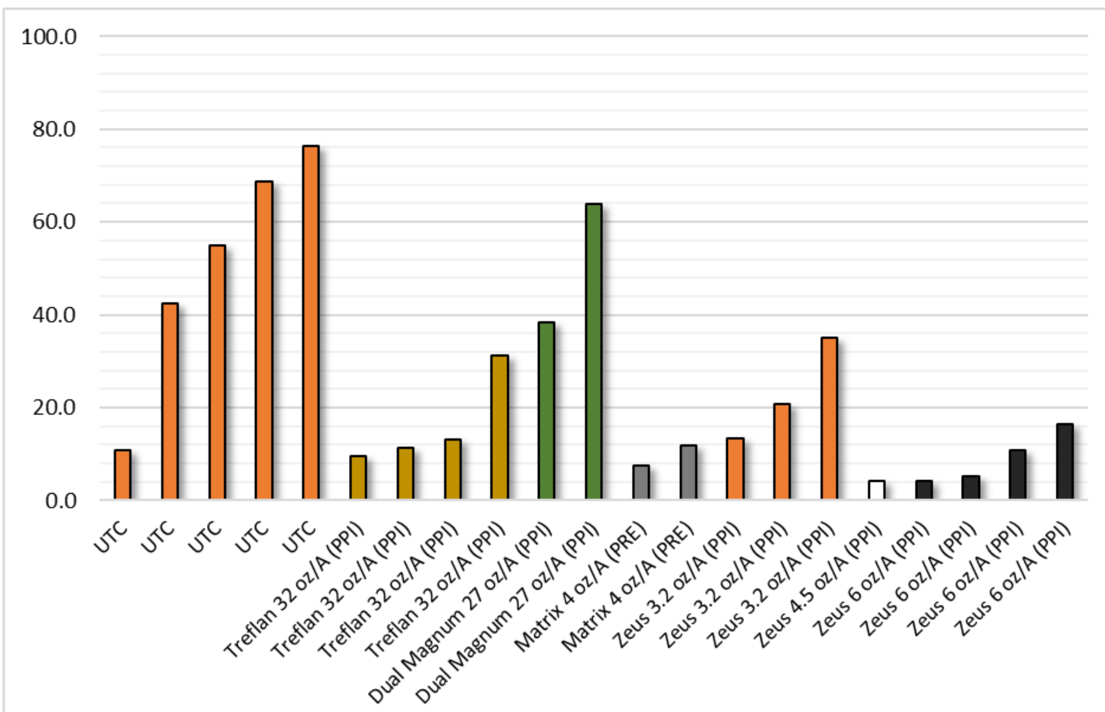

Figure 1. Bindweed cover (% of plot area covered by bindweed vines) in response to pre-emergence incorporated (PPI) and pre-emergence (PRE) herbicides at 4 WAT. Trials were conducted between 2013 and 2015. Each bar within a treatment class (i.e. UTC, Treflan), etc…) represents the mean observation from an individual trial.

SUB-SURFACE LAYERED (SSL) APPLICATIONS OF TRIFLURALIN FOR THE SUPPRESSION OF FIELD BINDWEED:

The successful control of deep-rooted perennials, such as field bindweed, is dependent upon herbicides reaching latent root and shoot buds. The majority of root/rhizome biomass for field bindweed is located within the top 2 feet of the soil profile, although some vertical roots can reach depths of more than 10 feet. Treflan and other residual herbicides registered for use in processing tomatoes are usually incorporated into the top 2-3 inches of the soil profile; because of their shallow placement, these herbicides may not suppress bindweed vines that are emerging from deeply buried rhizomes.

In response to concerns that (traditional) incorporation strategies were diluting the herbicides and distributing them unevenly throughout the bed, Carlson et al. (1980) suggested applying the herbicidal products in a thin, concentrated, horizontal layer below the typically treated zone, instead. Sub-surface applications of alachlor in both dry and lima beans were able to suppress yellow nutsedge (*Cyperus esculentus*) for up to 6 weeks, thereby 'reducing the weed's early competitive potential'.

In 2015, we undertook a similar study in processing tomatoes. This trial was conducted at the University of California, Davis, research farm, which was described previously. Specifically, our research was focused on describing how sub-surface layered (SSL) (to a depth of 4-6 inches) applications of trifluralin (as Treflan at 2 pt/A) interacted with surface applied herbicides ((trifluralin, *S*-metolachlor (as Dual Magnum at 27 oz/A) and sulfentrazone (as Zeus at 3 oz/A)) with respect to field bindweed control. SSL applications of trifluralin were made using horizontal spray blades (each with a spray width of 6 inches) one day prior to transplanting. Trifluralin was applied as either a banded or a broadcast application; the application rig was calibrated to deliver 40 GPA. A banded blade application received trifluralin only to the outer-most 6 inches of each bed (i.e. the bed shoulders); a broadcast application received trifluralin 4-6 inches deep across the entire width of the bed. Each type of SSL trifluralin application was repeated three times. For the purpose of comparison, three beds were left 'untreated' or 'blank' in that they did not receive any SSL trifluralin.

Surface applied, and then mechanically incorporated, residual herbicides, plus a non-treated check, were overlaid on top of the SSL treatments. All surface herbicides were applied using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet Technologies, Wheaton, IL) spaced 16-20 inches apart and calibrated to deliver 20-30 GPA. Field bindweed cover (defined as the percent (%) of the plot area that was occupied by field bindweed) and percent crop injury were assessed until tomato canopy closure began to occur.

Field bindweed cover was greatest in the plots that did not receive a SSL trifluralin application (none), followed by the banded treatment (band), across all of the surface applied, PPI herbicides (Table 1). Field bindweed cover was lowest when SSL trifluralin was applied as a broadcast application across the entire width of the bed at a depth of 4-6 inches. When averaged over all surface herbicide treatments, bindweed cover in the broadcast-treated plots was 7, 18, 36, and 12% at 1 (19 June), 2 (28 June), 3 (3 July), and 4 (10 July) WAT, respectively. Conversely, mean bindweed cover ranged from 10-11, 33-24, 49-50, and 26-31% at 1, 2, 3, and 4 WAT, respectively, in the banded and non-treated plots. When averaged over all SSL treatments, bindweed cover was the greatest in the untreated check (UTC) (16-66%) and the *S*-metolachlor treatment (10-47%). As was observed, previously, trifluralin and sulfentrazone were more effective at suppressing field bindweed cover (5-34%), relative to the control plots.

		Percent (%) Weed Cover			
SSL	PPI/PRE	19-Jun	28-Jun	3-Jul	10-Jul
Band	UTC	20	63	77	51
	Treflan	7	22	35	12
	Dual Mag	11	33	53	29
	Zeus	4	12	30	13
Broadcast	UTC	11	32	48	25
	Treflan	6	17	33	7
	Dual Mag	6	16	37	13
	Zeus	4	9	27	5
None	UTC	17	55	73	55
	Treflan	4	21	35	11
	Dual Mag	12	47	51	38
	Zeus	6	15	43	21
Main effects - SSL	Band	11	33	49	26
	Broadcast	7	18	36	12
	None	10	34	50	31
Main effects - PPI/PRE	UTC	16	50	66	44
	Treflan	6	20	34	10
	Dual Mag	10	32	47	27
	Zeus	5	12	33	13

Table 1. Bindweed cover in response to sub-surface layered (SSL) Treflan and surface applied (PPI) herbicides. SSL Treflan was applied using a set of 6-inch-wide spray blades positioned at a depth of 4-6 inches below the bed-top; a banded blade application received trifluralin only to the outer-most 6 inches of each bed, a broadcast application received trifluralin to the entire width of the bed, and a blank application received no sub-surface treatment of trifluralin. All herbicide applications were made 1 day before tomato transplanting. Herbicides: Treflan = trifluralin, Dual Mag = Dual Magnum = S-metolachlor, Zeus = sulfentrazone.

		Percent (%) Crop Injury			
SSL	PPI/PRE	19-Jun	28-Jun	3-Jul	10-Jul
Band	UTC	0	2	8	17
	Treflan	13	20	17	17
	Dual Mag	17	33	25	28
	Zeus	17	35	22	27
Broadcast	UTC	2	13	13	22
	Treflan	20	32	27	33
	Dual Mag	17	23	22	28
	Zeus	25	47	30	35
None	UTC	0	0	0	0
	Treflan	0	7	15	17
	Dual Mag	0	7	13	15
	Zeus	5	28	18	17
Main effects - SSL	Band	12	23	18	22
	Broadcast	16	29	23	30
	None	1	10	12	12
Main effects - PPI/PRE	UTC	1	5	7	13
	Treflan	11	19	19	22
	Dual Mag	11	21	20	24
	Zeus	16	37	23	26

Table 2. Tomato injury in response to sub-surface layered (SSL) Treflan and surface applied (PPI) herbicides. SSL Treflan was applied using a set of 6-inch-wide spray blades positioned at a depth of 4-6 inches below the bed-top; a banded blade application received trifluralin only to the outer-most 6 inches of each bed, a broadcast application received trifluralin to the entire width of the bed, and a blank application received no sub-surface treatment of trifluralin. All herbicide applications were made 1 day before tomato transplanting. Herbicides: Treflan = trifluralin, Dual Mag = Dual Magnum = S-metolachlor, Zeus = sulfentrazone.

Crop injury was greatest when SSL trifluralin was applied as a broadcast application across the entire width of the bed at a depth of 4-6 inches (Table 2). When averaged over all surface herbicide treatments, crop injury in the broadcast-treated plots was 16, 29, 23, and 30% at 1 (19 June), 2 (28 June), 3 (3 July), and 4 (10 July) WAT, respectively. Conversely, crop injury for the banded SSL application and the non-treated control at 1, 2, 3, and 4 WAT was 12 and 1%, 23 and 10%, 18 and 12%, 22 and 12%, respectively. When averaged over all SSL treatments, tomato injury was the lowest in the untreated check (UTC) (1-13%); crop injury in the trifluralin, *S*-metolachlor, and sulfentrazone treatments ranged from 11-37%. The extensive injury observed in this trial is likely due to the fact that the transplants were relatively short in height and root-balls could not be positioned below the treated zone.

The aforementioned trial was expanded in 2016. SSL applications (at a depth of 4-6 inches) of trifluralin (as Treflan at 32 oz/A) were made at approximately 21 days before transplanting (DBT) (application on 28 April, 2016) or else at 2 DBT (application on 17 May, 2016) using horizontal spray blades that were 6 inches wide. The timing component was included in this study to see if advance SSL applications of trifluralin could suppress bindweed without causing crop injury. SSL trifluralin was applied to either the entire width of the bed (broadcast) or else banded along the shoulders. The rig was calibrated to deliver the spray solution at a rate of 40 GPA. To determine if the cutting action of the blades affected bindweed development, independent of the trifluralin spray, the broadcast and banded treatments were repeated without a concomitant herbicide application. A non-treated (no SSL trifluralin, no soil disturbance due to blade movement through the soil) was also included in the trial. Surface applied residual herbicides (trifluralin as Treflan at 32 oz/A and trifluralin plus *S*-metolachlor as Dual Magnum at 27 oz/A), plus a non-treated check, were overlaid on top of the SSL treatments. All surface herbicides were applied using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet Technologies, Wheaton, IL) spaced 16-20 in apart and calibrated to deliver 20-30 GPA. Herbicides were mechanically incorporated (PPI) after application. Field bindweed cover (defined as the percent (%) of the plot area that was occupied by field bindweed), bindweed density, and percent crop injury were assessed until canopy closure began to occur.

Results from preliminary analyses suggest that bindweed cover was affected by the interaction between the SSL trifluralin and surface applied, PPI herbicide applications (Figure 2). The plots that did not receive SSL trifluralin applied nor any surface applied, PPI herbicides (No SSL, UTC) had the highest weed cover (15-66%) on 8, 14. and 22 June, 2016, compared to all other treatments. Bindweed cover in plots that did receive trifluralin applied SSL but did not receive surface applied, PPI herbicides (SSL, UTC) ranged from 4-42%. Bindweed cover in the plots treated with surface applied, PPI trifluralin and trifluralin plus *S*-metolachlor did not exceed 13% on any observation date, regardless of the SSL treatment.

With respect to vine density, field bindweed was affected by the application of SSL trifluralin and the use of surface-applied and incorporated herbicides (Table 3), but not the interaction between them. Perennial vine density was reduced in the SSL trifluralin treatment (2, 4, 4 vines/m^2) as compared to the no SSL treatment (4, 7, 5 vines/m^2). Perennial vine density was also lower in the trifluralin and trifluralin plus *S*-metolachlor treated plots (2-3 vines/m^2) as compared to the untreated check (6-12 vines/m^2). Broadleaf weed density was affected by the use of surface-applied and incorporated herbicides (Table 3). Broadleaf weed density was lower in the trifluralin and trifluralin plus *S*-metolachlor treated plots (1-3 vines/m^2) as compared to the untreated check (6-12 vines/m^2). Results from preliminary statistical analyses indicate that field bindweed cover and density and broadleaf weed density were not affected by the timing of the SSL applications (2 or 21 DBT) nor by the arrangement of the spray blades/placement of the SSL trifluralin application (banded or broadcast).

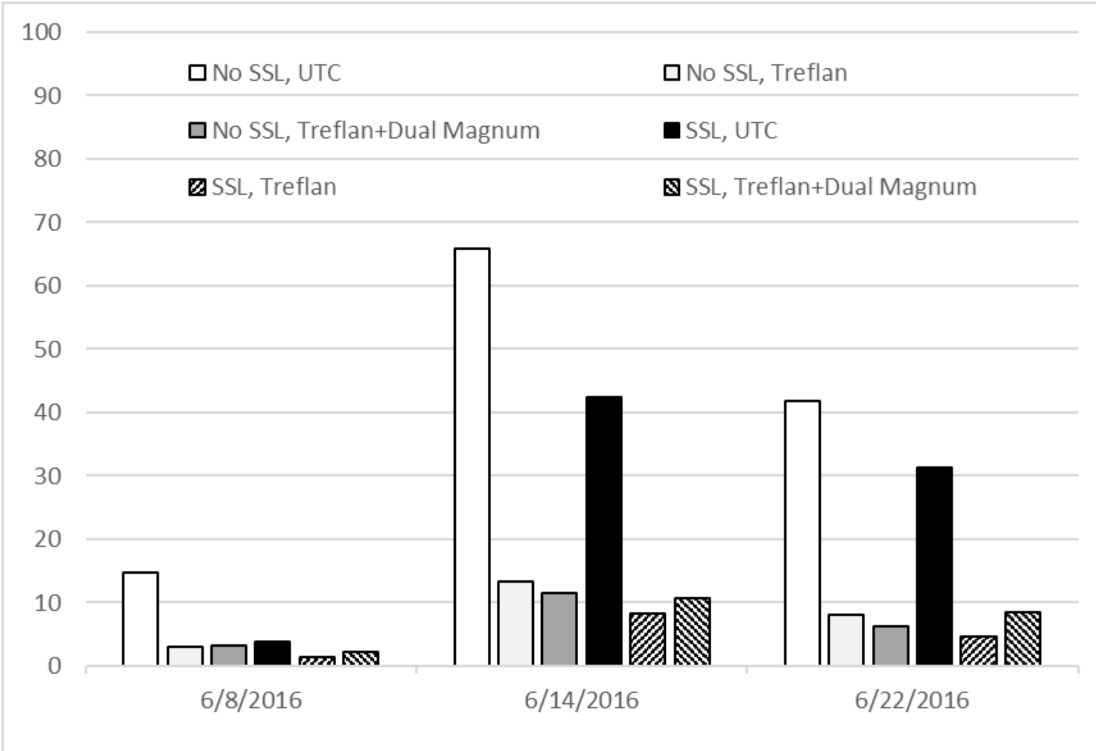

Figure 2. Bindweed cover (% of plot area covered by bindweed vines) in response to sub-surface layered (SSL) Treflan and pre-plant (PPI) herbicides. All PPI herbicide applications were made 1 day before tomato transplanting. Data are averaged over SSL application dates (2 and 21 DBT) and blade arrangements (banded and broadcast). Herbicides: Treflan = trifluralin, Dual Mag = Dual Magnum = S-metolachlor, Zeus = sulfentrazone, UTC = untreated.

	6/8/2016		6/14/2016		6/22/2016	
	Vines	Broadleaf weeds	Vines	Broadleaf weeds	Vines	Broadleaf weeds
	numbers per m^2					
SSL						
No SSL Treflan	4.0	na	6.7	na	5.0	na
SSL Treflan	1.6	na	4.4	na	3.9	na
Surface applied, PPI						
UTC	5.8	11.5	11.7	10.9	8.8	7.9
Treflan	1.6	0.5	2.9	2.0	2.3	1.6
Treflan+Dual Magnum	1.8	1.7	2.8	2.4	2.6	1.6

Table 3. Bindweed density (number of bindweed vines/m^2) in response to sub-surface layered (SSL) Treflan and pre-plant incorporated (PPI) herbicides. Broadleaf weed density (number of broadleaf weeds/m^2) in response to PPI herbicides. All PPI herbicide applications were made 1 day before tomato transplanting. Data are averaged over SSL application dates (2 and 21 DBT) and blade arrangements (banded and broadcast). Herbicides: Treflan = trifluralin, Dual Mag = Dual Magnum = S-metolachlor, Zeus = sulfentrazone, UTC = untreated.

	Percent (%) Crop Injury		
	6/8/2016	6/14/2016	6/22/2016
Days before transplanting			
2	3.1	5.4	4.9
21	1.7	3.5	6.7
Surface applied, PPI			
UTC	0.6	1.1	5.3
Treflan	3.3	5.9	5.7
Treflan + Dual Magnum	3.4	6.5	6.4

Table 4. Processing tomato injury in response to the timing of sub-surface layered (SSL) Treflan applications and the type of surface applied, pre-plant incorporated (PPI) herbicides. All surface herbicide applications were made 1 day before tomato transplanting. Data are averaged over arrangement of the spray blades/placement of the SSL trifluralin application. Herbicides: Treflan = trifluralin, Dual Mag = Dual Magnum = S-metolachlor, UTC = untreated.

	Percent (%) Crop Injury		
	6/8/2016	6/14/2016	6/22/2016
Band no SSL	2.0	4.1	5.9
Band plus SSL	2.3	4.0	5.5
Broadcast no SSL	1.8	3.5	4.3
Broadcast plus SSL	4.1	7.3	7.4
Untreated (no blades, no SSL)	2.1	3.5	6.0

Table 5. Processing tomato injury in response to the arrangement of the spray blades/placement of the sub-surface layered (SSL) Treflan application. Data are averaged over SSL application dates and surface applied, pre-plant incorporated (PPI) herbicides. Herbicides: Treflan = trifluralin.

Processing tomato injury was influenced by the timing of the SSL trifluralin applications and the type of PPI herbicides applied (Table 4). With the exception of the 22 June observation date, crop injury was greatest where SSL trifluralin was applied closer to planting (i.e. 2 DBT vs 21 DBT). With respect to the PPI herbicides, injury to processing tomatoes was greater in the trifluralin and trifluralin plus *S*-metolachlor treatments on 8 and 14 June as compared to the untreated check (UTC).

Processing tomato injury was also influenced by the arrangement of the spray blades/placement of the SSL trifluralin application (banded or broadcast) (Figure 5). The greatest amount of injury (4-7%) was observed when trifluralin was applied broadcast, at a depth of 4-6 inches across the width of the entire bed. Crop injury in the untreated check (no blade, no SSL), the banded SSL application of trifluralin, and the treatments that included only the movement of the spray blades through the soil (with no application of trifluralin) ranged from 2-6%. All plots were hand-weeded in July, and the tomatoes allowed to grow without competitive interference for the remainder of the season. Mature fruits were harvested on 18 August, 2016. The mean yield across all plots equaled 28 lbs/10 ft^2. No differences were observed with respect to the type and timing of SSL applications nor the use of PPI herbicides.

POST-EMERGENCE HERBICIDE EFFICACY:

Post-emergence herbicides (applied as a pre-plant burn down, for post-harvest field cleanup, or used in-crop) can be important tools for managing field bindweed infestations. In 2013 and 2014, we conducted two trials at the University of California, Davis, research farm to evaluate the efficacy of glyphosate (as Roundup Powermax), rimsulfuron (as Matrix), and carfentrazone (as Shark) for the control of vigorously growing field bindweed vines. All herbicides were applied post-emergence (POST) using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet Technologies, Wheaton, IL) spaced 16-20 in apart and calibrated to deliver 30 GPA. Adjuvants were used according to label recommendations. Control of field bindweed was rated for 3-5 weeks after application.

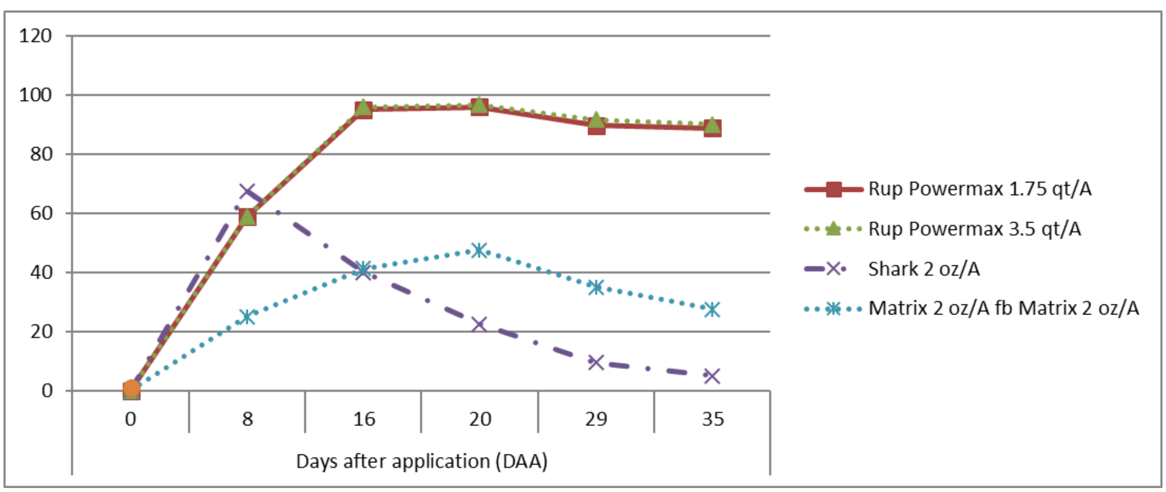

Figure 3. Bindweed control (%) in response to post-emergence applied herbicides (in field, 2013) for up to 35 days (or 5 weeks) after herbicide application (DAA). Herbicides: Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron.

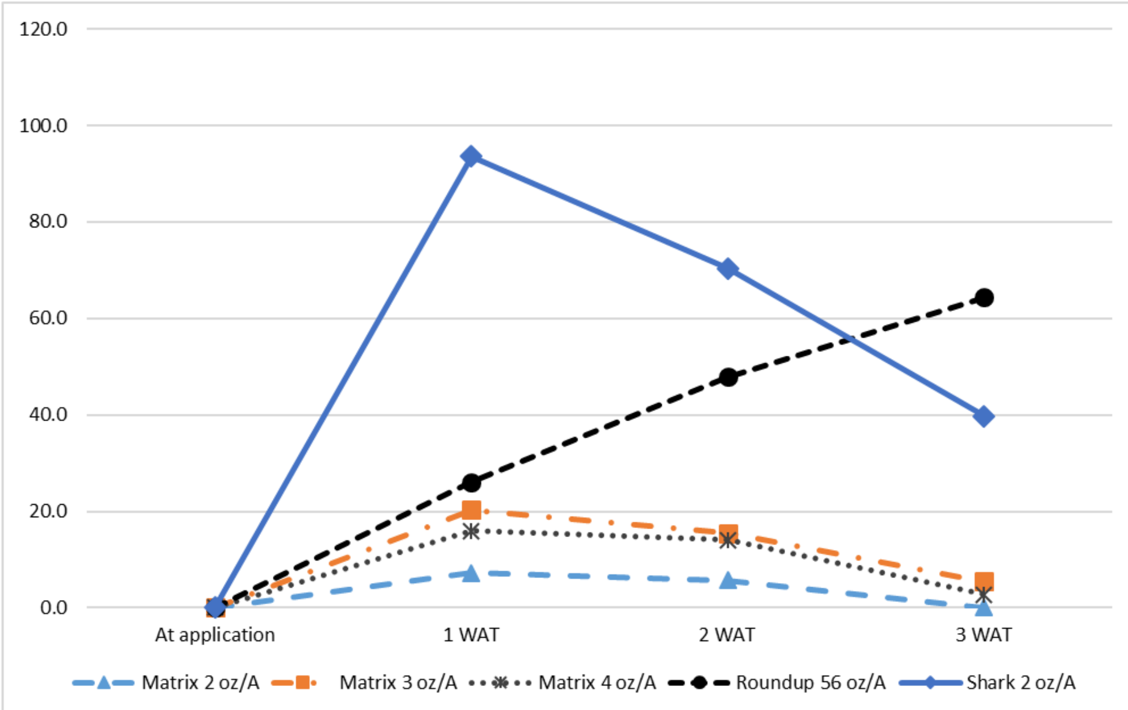

Figure 4. Bindweed control (%) in response to post-emergence applied herbicides (in field, 2014) at application and at 1, 2, and 3 weeks after treatment (WAT). Herbicides: Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron.

Results presented in Figures 3 and 4 show that POST herbicide applications of rimsulfuron and carfentrazone were largely ineffective at controlling field bindweed. In the 2013 trial, Field bindweed control with rimsulfuron did not exceed 50%; in 2014, rimsulfuron was unable to provide more than 20% control at any observation date. Carfentrazone will burn down aboveground bindweed vines, giving the appearance of effective management, although regrowth can rapidly occur. In our research trials, carfentrazone controlled field bindweed 60 and 95% at 1 WAT; however, within 3-5 WAT, control fell to 5 and 40%. Glyphosate is slower to demonstrate activity, although its suppressive ability may persist for a longer period of time.

A similar study was conducted in 2016 (Table 6), except that estimates of bindweed cover, plant vigor (on a scale of 1-5, where 1 = poor and 5 = excellent) and the percentage (%) of vines that were producing flowers were determined instead of control. The untreated check plots produced more cover (40-73%) at 1, 3, and 5 WAT as compared to the glyphosate (23-50%) and rimsulfuron (32-43%) treated plots; the higher rate of glyphosate was more effective at suppressing bindweed (25-25% cover) than the lower rate (23-50%). Bindweed vigor in the untreated plots ranged between 3 and 3.5 at every observation date. The vigor ratings for the glyphosate and rimsulfuron treatments ranged from 3-4 at 1 WAT to 1-2.2 at 5 WAT. Reductions in vigor were associated with chlorosis and necrosis of leaf and stem tissue. Field bindweed flowering was also affected by POST herbicide treatments. Few vines exhibited any flowers, regardless of treatment on 18 May. On 1 June and 14 June, 42 and 50% of the vines untreated check plots were flowering; conversely, less than 7% of the vines in the glyphosate or rimsulfuron treatments were flowering at the same observation periods.

	Percent (%) Cover		
Herbicide	18-May	1-Jun	14-Jun
UTC	40.0	61.7	73.3
Roundup Powermax 1 qt/A	38.3	50.0	23.3
Roundup Powermax 2 qt/A	25.0	31.7	26.7
Matrix 2 oz/A	31.7	40.0	43.3

	Plant Vigor (1=poor, 5=Excellent)		
Herbicide	18-May	1-Jun	14-Jun
UTC	3.5	3.5	3.3
Roundup Powermax 1 qt/A	4.0	1.3	1.0
Roundup Powermax 2 qt/A	2.7	1.3	1.7
Matrix 2 oz/A	2.8	1.7	2.2

	Percent (%) Flowering		
Herbicide	18-May	1-Jun	14-Jun
UTC	2.0	41.7	50.0
Roundup Powermax 1 qt/A	2.0	5.0	0.0
Roundup Powermax 2 qt/A	0.0	6.0	1.3
Matrix 2 oz/A	3.7	4.3	6.7

Table 6. Field bindweed cover (percent (%) of plot area covered with vines), plant vigor, and percent (%) of vines with flowers in response to post-emergence (POST) herbicide applications at approximately 1 (18 May, 3 (1 June), and 5 (14 June) weeks after treatment (WAT). Roundup Powermax = glyphosate, Matrix = rimsulfuron, UTC = untreated.

A comparable trial was also conducted in the greenhouse (Tables 7, 8, 9). Results show that bindweed injury, growth, and biomass accumulation were more affected by glyphosate than by rimsulfuron and carfentrazone. The injury observed in the rimsulfuron and carfentrazone treatments was more severe than what had been witnessed, previously in field trials. This is likely due to the fact that the field bindweed plants used in the greenhouse had been grown from exhumed rhizomes and did not possess the ample storage reserves that large, field-grown patches are expected to have. As has been described, previously, the highest rate of glyphosate was the most effective treatment for injuring field bindweed and suppressing plant growth.

Herbicide	Rate	11/6/2015 (0 Days after treatment)		12/3/2015 (28 Days after treatment)	
		Number Vines > 4"	Length (cm) Longest Vine	Number Vines > 4"	Length (cm) Longest Vine
UTC	na	5.5 a	42.5 a	19.0 a	51.6 a
Roundup Pmax	1 qt/A	7.0 a	39.1 a	6.3 ab	24.9 ab
Roundup Pmax	2 qt/A	6.3 a	38.9 a	1.3 c	13.6 b
Matrix	2 oz/A	8.0 a	35.9 a	16.5 a	35.1 ab
Shark	2 oz/A	8.3 a	40.5 a	1.5 bc	23.4 ab
	Significance	*NS*	*NS*	$P < 0.05$	$P < 0.05$

Field bindweed plants were grown from 10 cm long, fall-exhumed rhizomes planted in 5 in pots.
All plants were grown in the same heated greenhouse.
Herbicide were applied at 30 GPA using a cabinet sprayer.
Each treatment was replicated 4X.

Table 7. Number of field bindweed vines greater than 4 inches in length and length in cm of the longest vines at the time of application and at 28 days after treatment (DAT) in response to post-emergence (POST) herbicide applications. Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron, UTC = untreated.

Herbicide	Rate	Percent (%) Injury				
		3 DAT	7 DAT	14 DAT	21 DAT	28 DAT
UTC	na	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Roundup Pmax	1 qt/A	2.5 a	6.3 bc	23.8 c	60.0 c	68.8 cd
Roundup Pmax	2 qt/A	2.5 a	12.5 d	71.3 d	92.5 d	95.0 d
Matrix	2 oz/A	1.3 a	4.0 cd	12.5 b	17.5 b	12.5 b
Shark	2 oz/A	91.3 b	95.0 e	91.3 e	85.0 d	80.0 cd
	Significance	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$	$P < 0.05$

Field bindweed plants were grown from 10 cm long, fall-exhumed rhizomes planted in 5 in pots.
All plants were grown in the same heated greenhouse.
Herbicide were applied at 30 GPA using a cabinet sprayer.
Each treatment was replicated 4X.

Table 8. Field bindweed injury at 3, 7, 14, 21 and 28 days after treatment (DAT) in response to post-emergence (POST) herbicide applications. Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron, UTC = untreated.

Herbicide	Rate	12/3/2015 (28 Days after treatment) Aboveground Biomass (g)	Belowground Biomass (g)
UTC	na	17.7 a	21.4 a
Roundup Pmax	1 qt/A	6.5 bc	6.5 abc
Roundup Pmax	2 qt/A	1.5 d	3.0 c
Matrix	2 oz/A	13.0 b	12.1 abc
Shark	2 oz/A	2.1 bc	5.1 bc
	Significance	*P* < 0.05	*P* < 0.05

Field bindweed plants were grown from 10 cm long, fall-exhumed rhizomes planted in 5 in pots.
All plants were grown in the same heated greenhouse.
Herbicide were applied at 30 GPA using a cabinet sprayer.
Each treatment was replicated 4X.

Table 9. Above and below ground field bindweed biomass at 28 days after treatment (DAT) in response to post-emergence (POST) herbicide applications. Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron, UTC = untreated.

It is important to recognize that the timing of herbicide applications can significantly affect weed control performance. For example, numerous growers, commercial applicators, and university personnel have reported that the performance of several herbicides (i.e. glyphosate, glufosinate, paraquat) may fluctuate with respect to application time of day (diurnally). Waltz et al. (2004), Mohr et al. (2007) and Sellers et al. (2003) reported that glyphosate and glufosinate are more injurious to weeds when applied early to mid-day, as opposed to in the evening. Conversely, the activity of some photosystem inhibitors, such as paraquat, may be improved at night because the herbicide can be translocated prior to light activation (Slade and Bell 1966). Possible factors influencing herbicide performance include: circadian changes in leaf angle that affect herbicide interception; differences in humidity and temperature that may affect herbicide absorption and translocation; the presence of dew, which can reduce herbicide retention; and physiological processes that may be affected by lack of sunlight.

In 2016, we conducted trial to evaluate if the herbicidal efficacy glyphosate (as Roundup Powermax at 1 and 2 qt/A), rimsulfuron (as Matrix at 2 oz/A), carfentrazone (as Shark at 2 oz/A), and paraquat (as Gramoxone Inteon at 3 pt/A) varied with the time of day the herbicides were applied. Herbicides were applied to vigorously growing bindweed vines on 29 June, 2016, at five different times during the day: sunrise, 2 hours after sunrise, mid-day, 2 hours before sunset, and at sunset. All herbicides were applied using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet Technologies, Wheaton, IL) spaced 16-20 in apart and calibrated to deliver 30 GPA. Field bindweed cover (percent of the plot area covered with field bindweed vines) was rated for 5 weeks after the treatments were applied (WAT).

	Percent (%) Field Bindweed Cover					
Herbicide and Rate	6/29/2016	7/7/2016	7/14/2016	7/21/2016	7/28/2016	8/4/2016
UTC	69	66	72	62	56	37
Matrix 2 oz/A	71	65	66	55	53	36
Roundup 1 qt/A	73	67	19	8	5	5
Roundup 2 qt/A	71	62	7	3	3	2
Shark 2 oz/A	70	4	9	21	37	45
Gramoxone Inteon 3 pt/A	66	4	10	21	42	42
P- Values						
Herbicide	NS	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Timing	NS	NS	NS	NS	NS	NS
Herbicide * Timing	NS	NS	NS	NS	NS	NS

Herbicides applied at 30 GPA on 6/30/2016
Timings included: sunrise, 2 hrs after sunrise, midday, 2 hrs before sunset, sunset
Bindweed cover decreased over time in the UTC, Matrix treatments due to powdery mildew
Regrowth in the plots treated with contact herbicides was vigorous, largely mildew free

Table 9. Field bindweed cover for up to 5 weeks after treatment (WAT), which occurred on 29 June, 2016, in response to post-emergence (POST) herbicide applications made at sunrise, 2 hours after sunrise, midday, 2 hours before sunset, and sunset. Herbicides: Roundup Powermax = glyphosate, Shark = carfentrazone, Matrix = rimsulfuron, Gramoxone Inteon = paraquat, UTC = untreated.

Results from the diurnal timing trial (Table 9) indicated that herbicide, alone, had a significant effect on bindweed cover; the timing of herbicide applications and the interaction between herbicide and the time of day when the herbicides were applied were not significant. Although the carfentrazone and the paraquat treatments worked rapidly (field bindweed cover was reduced by more than 90% at 1 WAT), the vines regrew vigorously; cover at 5 WAT was 45 and 42%, which was similar to what was observed for the untreated check (37%). Glyphosate, while slower acting due to its systemic nature, was significantly better at reducing field bindweed cover at 5 WAT (2 and 5%) relative to the untreated check. In this trial, rimsulfuron did not reduce field bindweed cover, relative to the control, at any point in time. Bindweed cover in the untreated check and the rimsulfuron treatment decreased over time due to the development of powdery mildew, which resulted in leaf loss. Interestingly, the bindweed regrowth in the carfentrazone and paraquat treatments was robust and did not show signs of infection during the course of this study.

CONCLUSIONS:

California leads the nation in the production of processing tomatoes with respect to acres planted and harvested, yield per acre, total production, and total value of production. In 2012, California growers harvested approximately 300,000 acres of processing tomatoes, worth an estimated $1.4 billion, with Fresno, Kings, Merced, San Joaquin, Stanislaus and Yolo Counties each producing crops valued at more than $100 million.

Historically, processing tomato production has been heavily dependent on pre-plant, inter-crop tillage operations and in-crop cultivation for weed control (Mitchell et al. 2012; Shrestha et al. 2007; Sutton et al. 2006). While effective at managing many weed species, especially during the seedling stage, frequent mechanical disturbances can negatively impact human and environmental health by increasing dust production and greenhouse gas emissions, and by reducing soil quality (Reicosky et al. 1997; Mitchell et al. 2012). Physical weed suppression programs are also accompanied by significant financial costs with respect to labor, fuel, and equipment purchase and maintenance (Mitchell et al. 2012). As a result, California tomato growers have been steadily transitioning towards minimum-tillage production systems.

The adoption of reduced-tillage programs in processing tomatoes has been facilitated by growers' decisions to switch from furrow- to sub-surface drip-irrigation (Mitchell et al. 2012). Because drip-irrigation limits soil surface wetting, the density and biomass of many small-seeded, annual, broadleaf weed species, such as common lambsquarters (*Chenopodium album* L.), pigweeds (*Amaranthus* spp.), and black nightshade (*Solanum nigrum* L.), can be significantly reduced relative to furrow irrigation systems (Shrestha et al. 2007; Sutton et al. 2006). Consequently, weed management practices for drip-systems may be less dependent on physical control measures, such as cultivation and hand-weeding (Mitchell et al. 2012; Shrestha et al. 2007; Sutton et al. 2006).

The use of drip-irrigation and minimum-tillage can, however, create an environment where field bindweed (*Convolvulus arvensis* L.), a deep-rooted and drought tolerant perennial, can survive, grow, and compete with crops (Sharma and Singh 2007; Shrestha et al. 2007; Wiese and Lavake 1986). With respect to processing tomatoes, interspecific interference for up to eight weeks after transplanting (WAT) can significantly reduce fruit number and quality. Furthermore, field bindweed vines can become physically entwined in the crop canopies, which, in turn, can reduce crop harvest efficiency (Mitich 1991). The purpose of our research over the last four years has been to evaluate currently recommended and novel weed control practices for the suppression of field bindweed. Our results have shown:

Trifluralin, rimsulfuron (PRE), and sulfentrazone have some activity (for up to 4 to seeks weeks) against perennial bindweed vines, while *S*-metolachlor does not. Trifluralin, rimsulfuron, and *S*-metolachlor are labeled for use in tomatoes for the residual control of emerging weeds (http://ipm.ucanr.edu/PMG/r783700311.html). Sulfentrazone has/has had a supplemental label (as Zeus) allowing for its use in transplanted tomatoes for the suppression of yellow nutsedge. Always check current manufacturers labels to ensure that an effective and legal application is being made before applying any herbicides. In addition to perennial bindweed suppression, rimsulfuron is effective against most nightshade species, pigweeds, and lambsquarters; trifluralin will control many annual grasses as well as some broadleaf weed species. *S*-metolachlor, while not effective against bindweed, can suppress nutsedge and nightshades.

Most soil-applied herbicides require 0.5 to 1 inch of precipitation or irrigation for activation. Furthermore, water needs to be distributed evenly to ensure adequate coverage and maximum control. Although drip-irrigation can reduce labor costs, prevent some disease development, improve water use efficiency, and reduce surface wetting, which reduces weed seed germination, it may not be effective at activating many residual herbicides. Growers with significant field bindweed problems should be mindful of how their irrigation protocols may affect herbicide performance. Results from trials not discussed in this report have shown that the activities of rimsulfuron and sulfentrazone against field bindweed were significantly improved when sprinkler irrigation was used for herbicide activation.

The application of trifluralin, sub-surface, using a spray blade is currently labeled for bindweed control in grapes in California. According to the Treflan HFP label: "Treflan HFP can be applied using a specially equipped spray blade for the control of field bindweed in grapes and in plantings of almond, apricot, grapefruit, lemon, nectarine, orange, peach, pecan, tangelo, tangerine, and walnut trees. Destroy existing weeds with soil tillage before applying Treflan HFP to prevent interference with operation of the spray blade. Application requires a spray blade capable of operation at 4 to 6 inches below the soil surface. Equip the blade with nozzles located under the blade and directed so as to allow spray to be trapped in a thin layer as the blade is pulled through the soil. Use a nozzle spacing sufficient to insure application of a uniform horizontal layer. Apply Treflan HFP in 40 to 80 gallons of water per acre. Operate blade at a depth of 4 to 6 inches. Some soils may develop cracks as they dry after rainfall or irrigation. Field bindweed may emerge if the cracks extend through the layer of Treflan HFP. Prevent or eliminate cracks by shallow discing or other tillage. Avoid deep tillage which disturbs the subsurface layer. Cultivation or tillage also aids the control of germinating seeds."

Although SSL applications of trifluralin appear to be effective at suppression bindweed in processing tomatoes, this strategy is not labeled for use in this crop. Crop injury is a significant concern when transplant root-balls are not positioned below the treated zones (as was observed in 2015). Carryover effects on rotation crops were not investigated in these trials and is a significant concern.

Rimsulfuron is labeled for POST use in processing tomatoes (http://ipm.ucanr.edu/PMG/r783700311.html) although its efficacy as a POST herbicide, with respect to field bindweed control, is poor. As was discussed, previously, rimsulfuron applied PRE may suppress the emergence of field bindweed vines. Paraquat and carfentrazone are both labeled for the control of emerged weeds prior to transplanting, although perennial weed control will not be long lasting as both products are contact herbicides and will do little more than burn off any above ground foliage. Glyphosate, was the most effective POST product for suppressing field bindweed growth across all trials; it is labeled for use as a pre-plant burn down. One of the tenets of integrated pest management is to start off clean and remain clean to prevent weed interference in the current and future crops. Growers with significant bindweed problems should strive to ensure effective burn down of existing vines prior to crop planting and following harvest; the management of bindweed in rotation crops and following rotation crop harvest is also encouraged.

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