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Field Bindweed (*Convolvulus arvensis*) Control in Early and Late-Planted Processing Tomatoes

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Field bindweed is a deep-rooted and drought-tolerant perennial that can be difficult to control once it has become established in specialty crops. Field studies were conducted in 2013 and 2014 to evaluate the efficacy of currently registered preplant (PP), PPI, PRE, and POST herbicides for field bindweed management in both early and late-planted processing tomatoes. Results show that bindweed cover in PPI/PRE programs (trifluralin, alone or in combination with rimsulfuron; *S*-metolachlor; or sulfentrazone) was reduced > 50% in early planted tomatoes, relative to the no PPI/PRE herbicide treatment (0 to 31% cover at up to 6 wk after transplanting [WAT]). Similar trends were observed with respect to field bindweed density. PP applications of glyphosate to emerged bindweed in late-planted tomatoes, coupled with PPI/PRE herbicide applications, reduced weed cover (1 to 13% at up to 6 WAT) by more than one-half when compared with plots treated with residual herbicides alone (1 to 43% at up to 6 WAT); perennial vine density was also reduced > 50%. PP herbicide burndown applications and the use of residual products can significantly improve the suppression of field bindweed in processing tomato systems. The emergence and vigor of bindweed vines may differ with respect to the timing of transplant operations and should be considered when developing management strategies

Nomenclature: Carfentrazone; glyphosate; rimsulfuron; *S*-metolachlor; sulfentrazone; trifluralin; field bindweed, *Convolvulus arvensis* L.; tomato, *Lycopersicum esculentum* L.

Key words: Perennial weeds, specialty crops, weed control.

Convolvulus arvensis es una maleza perenne con sistema radical profundo y tolerante a la sequía que puede ser difícil de controlar una vez que se ha establecido en cultivos hortícolas. En 2013 y 2014, ser realizaron estudios de campo para evaluar la eficacia de herbicidas actualmente registrados para aplicaciones en presiembra (PP), PPI, PRE, y POST para el manejo de *C. arvensis* en tomate para procesamiento, plantado temprano y tarde. Los resultados muestran que la cobertura de *C. arvensis* en programas PPI/PRE (trifluralin, solo o en combinación con rimsulfuron; *S*-metolachlor; o sulfentrazone) se redujo >50%, en tomates plantados temprano, en relación con tratamientos sin herbicidas PPI/PRE (0 a 31% de cobertura hasta 6 semanas después del trasplante [WAT]). Se observaron tendencias similares con respecto a la densidad de *C. arvensis*. Las aplicaciones PP de glyphosate a plantas emergidas de *C. arvensis* en tomates plantados tarde, aunadas a aplicaciones de herbicidas PPI/PRE, redujeron la cobertura de la maleza (1 a 13% hasta 6 WAT) en más de la mitad cuando se comparó con parcelas tratadas con sólo los herbicidas residuales (1 a 43% hasta 6 WAT). La densidad de la enredadera también se redujo >50%. Las aplicaciones de quema con herbicidas PP y el uso de productos residuales puede significar la mejora en la supresión de *C. arvensis* en sistemas de producción de tomate para procesamiento. La emergencia y el vigor de las enredaderas de *C. arvensis* podría diferir según el momento de las operaciones de trasplante, y esto debería ser considerado cuando se desarrollan las estrategias de manejo.

Processing tomato production in California has changed dramatically during the past 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 hectares planted and harvested (105,000 ha), total yield (10 million metric tons), and total value of production ($918 million) (NASS 2015). Tomatoes are a significant component of the agricultural value chain in the Central Valley, where most of the production occurs; in 2013, Fresno, Kings, Merced, San Joaquin, Stanislaus, and Yolo counties each produced tomato crops valued at more than $100 million (NASS 2015).

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Field bindweed, a deep-rooted and drought-tolerant perennial (DeGennaro and Weller 1984; Sharma and Singh 2007; Shrestha et al. 2007; Wiese and Lavake 1986; Yerkes and Weller 1996), is a significant concern of processing tomato growers. If allowed to compete with tomatoes during the period of canopy establishment (which can occur for up to 8 wk after transplanting), 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 belowground nutrient reserves and regenerative capacity (Derscheid et al. 1970; Frazier 1943a–c; 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.

Tomato growers in California have some flexibility with respect to the timing of crop planting so as to fulfill precontracted processing needs throughout the production season. As part of an integrated pest management (IPM) approach for managing weeds, growers may alter planting dates among various fields to take advantage of differences in weed germination and emergence and allow for nonselective weed-control opportunities before or after the tomato crop. The objective of this study was to evaluate the interactive effects among PP burndown, PPI, PRE, and POST herbicide applications for the control of field bindweed in early and late-planted processing tomato.

Materials and Methods

Field trials were established in 2013 and 2014 at the University of California, Davis, Plant Sciences Field Station (38.32′N, 121.47′W). This region has a Mediterranean climate, characterized by hot, dry summers and relatively wet winters. Soil at the site is a fine, silty loam (Yolo series, 37% sand, 41% silt, 22% clay; 1.5 to 3% organic matter; pH 6.7 to 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).

The study sites were planted to wheat (*Triticum aestivum* L.) during the preceding growing seasons. After wheat harvest, the entire area was subsoiled, disked, and planed to eliminate residue and to create a uniform surface before the establishment of tomato beds. PP fertilizer applications of 8.4 kg ha^{-1} each of nitrogen, PO_5, and KO_2 were made 3 to 5 d before transplanting. The experiment was conducted twice each year (providing for an early planting and a late-planting) so as to describe field bindweed control over a range of cropping dates available to growers to meet season-long processing needs. The early plantings were established on April 11 and 15 in 2013 and 2014, respectively; the late-season plantings occurred on June 4 and 10. Tomato seedlings (15 to 20 cm tall; 'Halley Bos 3155') were transplanted 0.31 m apart in single row in the middle of raised beds that were on 1.52 m centers; the only exception was the early planting in 2013, when cultivar 'AB2' was used. Tomato transplants were sprinkler-irrigated with 25 mm water immediately after planting to facilitate crop establishment. Furrow irrigation was used thereafter to maximize weed pressure in the study (Sutton et al. 2006). Irrigation, fertilization, and insect/disease management schedules followed guidelines developed by University of California Cooperative Extension Service (Hartz et al. 2008).

The herbicide treatment combinations used to determine how PP burndown and PPI/PRE products affect field bindweed control in early and late-planted processing tomato crops are presented in Table 1; POST and shielded (SHIELD) applications of rimsulfuron and carfentrazone, respectively, were also included in the trial. Treatments were arranged in a randomized complete block design with three replications. Each plot was two planted beds wide (3 m) and 7.6 m long. With respect to the PP treatments, plots received either an application of glyphosate (2.1 kg ae ha^{-1}, Roundup Powermax, Monsanto Company) to emerged vines 7 to 10 d before final bed-shaping, or they were left untreated. Trifluralin (1.1 kg ai

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Table 1. Preplant (PP) burndown, PPI, PRE, POST, and shielded (SHIELD) herbicide combinations applied in 2013 and 2014 processing tomato trials near Davis, CA.[a]

Treatment	PP[b]	PPI/PRE	POST/SHIELD
1	Glyphosate	None	None
2	Glyphosate	Trifluralin	Rimsulfuron
3	Glyphosate	Trifluralin + *S*-metolachlor	Rimsulfuron
4	Glyphosate	Trifluralin fb rimsulfuron	Rimsulfuron
5	Glyphosate	Trifluralin + sulfentrazone	Rimsulfuron
6	Glyphosate	Trifluralin	Carfentrazone
7	Glyphosate	Trifluralin + *S*-metolachlor	Carfentrazone
8	Glyphosate	Trifluralin fb rimsulfuron	Carfentrazone
9	Glyphosate	Trifluralin + sulfentrazone	Carfentrazone
10	None	None	None
11	None	Trifluralin	Rimsulfuron
12	None	Trifluralin + *S*-metolachlor	Rimsulfuron
13	None	Trifluralin fb rimsulfuron	Rimsulfuron
14	None	Trifluralin + sulfentrazone	Rimsulfuron
15	None	Trifluralin	Carfentrazone
16	None	Trifluralin + *S*-metolachlor	Carfentrazone
17	None	Trifluralin fb rimsulfuron	Carfentrazone
18	None	Trifluralin + sulfentrazone	Carfentrazone

[a] Abbreviation: +, tank mix; fb, followed by.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

ha^{-1}, Treflan HFP, Dow AgroSciences LLC), *S*-metolachlor (1.8 kg ai ha^{-1}, Dual Magnum, Syngenta Crop Protection LLC), and sulfentrazone (0.1 kg ai ha^{-1}, Zeus Herbicide, FMC Corporation Agricultural Products Group) were broadcast-applied directly to the soil surface 24 h before transplanting and physically incorporated (PPI) into the top 5 to 7 cm with a powered rototiller and bed shaper. In treatments 4, 8, 13, and 17, rimsulfuron (0.03 kg ai ha^{-1}, Matrix SG, DuPont Crop Protection) was applied to the bed tops immediately following mechanical incorporation but before transplanting. POST applications of rimsulfuron (0.03 kg ha^{-1}) and SHIELD applications of carfentrazone (0.03 kg ai ha^{-1}, Shark EW, FMC Corporation Agricultural Products Group) were made 3 to 4 wk after transplanting (WAT) but before tomato canopy closure. With the exception of carfentrazone, all materials were applied using a CO_2-pressurized backpack sprayer equipped with three 8002VS flat-fan nozzles (TeeJet Technologies) spaced 50 cm apart and calibrated to deliver 187 L ha^{-1}. Carfentrazone was applied to the bed shoulders using a single nozzle (8002VS) wand enclosed in a plastic shield to minimize herbicide contact with crop foliage. All treatments included label-recommended adjuvants.

Field bindweed cover and vine density were assessed, weekly, for up to 6 WAT when canopy closure began to occur. Cover was defined as the percentage of the plot area that was occupied by field bindweed. With respect to density, all seedling and perennial vines were counted in 1-m^2 quadrats in each row of each plot; seedling and perennial bindweed vines were counted separately. Crop injury estimates, rated on a scale of 0 (no injury) to 100% (complete plant death) for up to 4 WAT. Tomatoes were hand-harvested approximately 17 to 20 WAT. Fruit yield was determined by collecting and weighing all marketable tomatoes within 1-m-long sections of row in the center of each plot.

Continuous data were log transformed, and the percentage data were arcsine–square root transformed to improve normality and homogeneity of variance. Data were analyzed using the MIXED procedure in SAS (SAS Institute Inc.), where treatment was considered a fixed effect and year and repetition were considered as random. Because of the large number of multiple pairwise assessments, statistical differences among the most pertinent treatments/treatment groups with respect to bindweed cover and density, crop injury, and fruit yield were evaluated using contrast statements. This includes comparing all of the PPI/PRE

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Table 2. Field bindweed cover in early planted tomatoes in response to PPI/PRE applied herbicides when averaged over POST/SHIELD treatments.[a]

	1 WAT	2 WAT	4 WAT	6 WAT
Treatments[b]	% cover			
No PPI/PRE	3.8	6.5	10.2	30.8
Trifluralin	< 1	< 1	3.4	9.8
Trifluralin + *S*-metolachlor	0	< 1	2.5	10.0
trifluralin fb rimsulfuron	0	< 1	1.2	9.8
Trifluralin + sulfentrazone	< 1	< 1	1.6	7.7
Contrasts				
No PPI/PRE vs. PPI/PRE	*	*	*	*
Trifluralin vs. trifluralin + *S*-metolachlor	NS	NS	NS	NS
Trifluralin vs. trifluralin fb rimsulfuron	NS	NS	*	NS
Trifluralin vs. trifluralin + sulfentrazone	NS	NS	*	NS

[a] Abbreviations: +, tank mix; *, $P \leq 0.05$; fb, followed by, NS, not significant.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

treatments to the no PPI/PRE checks; comparing trifluralin applied singly to trifluralin plus *S*-metolachlor, trifluralin followed by rimsulfuron, and trifluralin plus sulfentrazone; and comparing each of the PPI/PRE herbicide treatments to themselves with and without the inclusion of a PP glyphosate burndown. The early and late-planted tomato data were analyzed separately because of differences in field bindweed establishment and pressure at the time of burndown applications.

Results and Discussion

In both 2013 and 2014, no seedling or perennial field bindweed vines emerged before transplanting in the early planted tomatoes; therefore, the PP glyphosate treatment was not applied. The PPI/PRE-treated plots differed ($P \leq 0.05$) with respect to bindweed cover from the no PPI/PRE check for up to 6 WAT. However, there were few differences ($P \geq 0.05$) in apparent weed suppression among the herbicide treatments (Table 2). Field bindweed cover in the no PPI/PRE check was 4, 7, and 10% at 1, 2, and 4 WAT; bindweed cover in the PPI/PRE-treated plots did not exceed 3% for the same period of observation. By 6 WAT, field bindweed cover averaged 31% in the no PPI/PRE plots, whereas weed cover in the trifluralin, trifluralin plus *S*-metolachlor, trifluralin followed by rimsulfuron, and trifluralin plus sulfentrazone treatments ranged from 8 to 10%.

Field bindweed density in the herbicide-treated plots was reduced relative to the no PPI/PRE check (Table 3). Perennial bindweed densities ranged from 3 to 13 vines m^{-2} in the no PPI/PRE plots and 0 to 3 vines m^{-2} in the PPI/PRE treatments at 1 to 4 WAT. With the exception of trifluralin followed by rimsulfuron at 4 WAT, the inclusion of additional herbicides to a trifluralin program did not reduce field bindweed density relative to trifluralin applied alone.

Mean field bindweed seedling densities ranged from < 1 to 8 vines m^{-2} in the no PPI/PRE system at 1 to 4 WAT; seedling numbers did not exceed 1 vine m^{-2} in any of the PPI/PRE herbicide treatments at any sampling date. There were no differences between the rimsulfuron (POST) and carfentrazone (SHIELD) treatments in bindweed cover and vine density (data not shown).

Perennial bindweed vines emerged and were flowering when the late-planted trials were established; initial mean bindweed cover exceeded 50% in all plots for both years. In the absence of a PP glyphosate burndown and PPI/PRE herbicides, bindweed cover was 8, 22, 46, and 41% at 1, 2, 4, and 6 WAT, respectively (Table 4). Conversely, the use of a PP glyphosate application reduced weed cover to 4, 16, 28, and 38% for the same observation dates in the no PPI/PRE check plots. When glyphosate was used as a PP burndown, weed cover in the trifluralin, trifluralin plus *S*-metolachlor, trifluralin followed by rimsulfuron, and trifluralin plus sulfentrazone treatments ranged from < 1% at 1 WAT to 13% at 6 WAT. When

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Table 3. Field bindweed perennial vine density in early planted tomatoes in response to PPI/PRE applied herbicides when averaged over POST/SHIELD treatments.[a]

	1 WAT	2 WAT	4 WAT
Treatments[b]	No. m^{-2}		
No PPI/PRE	2.7	6.3	12.5
Trifluralin	< 1	< 1	3.2
Trifluralin + *S*-metolachlor	0	< 1	2.3
Trifluralin fb rimsulfuron	0	< 1	1.7
Trifluralin + sulfentrazone	< 1	< 1	1.9
Contrasts			
No PPI/PRE vs. PPI/PRE	*	*	*
Trifluralin vs. trifluralin + *S*-metolachlor	NS	NS	NS
Trifluralin vs. trifluralin fb rimsulfuron	NS	NS	*
Trifluralin vs. trifluralin + sulfentrazone	NS	NS	NS

[a] Abbreviations: +, tank mix; *, $P \leq 0.05$; fb, followed by, NS, not significant.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

a PP glyphosate burndown was not employed, field bindweed cover in the PPI/PRE-treated plots ranged from 1 to 5% at 1 WAT, 3 to 11% at 2 WAT, 12 to 26% at 4 WAT, and 30 to 43% at 6 WAT.

The use of glyphosate PP reduced perennial bindweed vine density across all PPI/PRE treatments, including the no PPI/PRE check in the late-planted tomatoes (Table 5). Perennial bindweed densities at 1 to 4 WAT ranged from 1 to 8 vines m^{-2} in the no PPI/PRE check plots when glyphosate was applied as a PP burndown. In the absence of a PP application, bindweed densities in the no PPI/PRE treatment ranged from 6 to 15 vines m^{-2}. In the trifluralin, trifluralin plus *S*-metolachlor, trifluralin followed by rimsulfuron, and trifluralin plus sulfentrazone treatments, vine densities did not exceed 2 vines m^{-2} when glyphosate was applied PP; when glyphosate was not part of the greater herbicide program, perennial

Table 4. Field bindweed cover in late-planted tomatoes in response to a preplant (PP) burndown with glyphosate and PPI/PRE applied herbicides when averaged over POST/SHIELD treatments.[a]

	1 WAT	2 WAT	4 WAT	6 WAT
Treatments[b]	% cover			
No PPI/PRE, no PP	8.2	22.0	45.5	40.8
Trifluralin with PP	4.7	10.7	26.2	42.5
Trifluralin + *S*-metolachlor, no PP	2.6	7.1	21.6	30.0
Trifluralin fb rimsulfuron, no PP	1.0	3.2	15.3	36.8
Trifluralin + sulfentrazone, no PP	2.1	4.9	12.2	36.3
No PPI/PRE with PP	3.5	16.2	27.8	38.3
Trifluralin with PP	< 1	3.3	5.6	9.9
Trifluralin + *S*-metolachlor with PP	< 1	2.3	2.6	13.3
Trifluralin fb rimsulfuron with PP	< 1	1.7	1.2	10.6
Trifluralin + sulfentrazone with PP	< 1	1.8	5.1	11.0
Contrasts				
No PPI/PRE, no PP vs. with PP	*	*	*	NS
Trifluralin, no PP, vs. with PP	*	*	*	*
Trifluralin + *S*-metolachlor, no PP vs. with PP	*	*	*	*
Trifluralin fb rimsulfuron, no PP vs. with PP	*	*	*	*
Trifluralin + sulfentrazone, no PP vs. with PP	*	*	*	*

[a] Abbreviations: +, tank mix; *, $P \leq 0.05$; fb, followed by, NS, not significant.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

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Table 5. Field bindweed perennial vine density in late-planted tomatoes in response to a preplant (PP) burndown with glyphosate and PPI/PRE applied herbicides when averaged over POST/SHIELD treatments.[a]

	1 WAT	2 WAT	4 WAT
Treatments[b]		No. m^{-2}	
No PPI/PRE, no PP	5.7	10.8	15.4
Trifluralin with PP	3.4	7.9	10.4
Trifluralin + *S*-metolachlor, no PP	2.1	5.8	8.7
Trifluralin fb rimsulfuron, no PP	< 1	2.2	4.8
Trifluralin + sulfentrazone, no PP	1.5	4.5	5.4
No PPI/PRE with PP	1.2	8.8	7.8
Trifluralin with PP	< 1	1.7	2.2
Trifluralin + *S*-metolachlor with PP	< 1	2.0	1.9
Trifluralin fb rimsulfuron with PP	0	1.1	1.0
Trifluralin + sulfentrazone with PP	< 1	1.4	1.9
Contrasts			
No PPI/PRE, no PP vs. with PP	*	*	*
Trifluralin, no PP, vs. with PP	*	*	*
Trifluralin + *S*-metolachlor, no PP vs. with PP	*	*	*
Trifluralin fb rimsulfuron, no PP vs. with PP	NS	*	*
Trifluralin + sulfentrazone, no PP vs. with PP	*	*	*

[a] Abbreviations: +, tank mix; *, $P \leq 0.05$; fb, followed by, NS, not significant.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

bindweed densities ranged from < 1 to 10 vines m^{-2} from 1 to 4 WAT.

When averaged over PP treatments, the addition of rimsulfuron or sulfentrazone to a trifluralin program reduced field bindweed cover and density in late-planted tomatoes 1 to 4 WAT. Percentage of bindweed cover ranged from 3 to 16% in the trifluralin-only treatment; in the trifluralin followed by rimsulfuron and trifluralin plus sulfentrazone treatments, bindweed cover ranged from < 1 to 9% at 1 to 4 WAT. Perennial vine density ranged from 2 to 6 vines m^{-2} at 1 to 4 WAT. In the trifluralin followed by rimsulfuron and trifluralin plus sulfentrazone treatments, bindweed density ranged from < 1 to 4 vines m^{-2} at 1 to 4 WAT.

Field bindweed seedling density in late-planted tomatoes was also affected by the use of residual herbicides. Seedling numbers in the no PPI/PRE treatment ranged from three to five plants per square meter at 1 to 4 WAT, whereas seedling numbers in the trifluralin and trifluralin plus *S*-metolachlor, rimsulfuron, and sulfentrazone programs did not exceed two plants per square meter. There were no differences between the rimsulfuron (POST) and carfentrazone (SHIELD) treatments in weed cover and perennial or seedling field bindweed densities (data not shown).

Crop injury in response to PPI/PRE herbicide use was statistically similar and transient across all treatments. With the exception of the no PPI/PRE treatment, in which the tomatoes were uninjured, crop injury did not exceed 15%. Maximum crop injury peaked at 1 to 2 WAT and then subsided. Although PP glyphosate applications suppressed bindweed cover and reduced in-crop vine densities, tomato yield was not influenced by its use. Tomato yields were affected by the use of PPI/PRE herbicides for both early and late-planted tomatoes (Table 6). Crop yields did not exceed 9.5 kg m row^{-1} in the no PPI/PRE program; where PPI/PRE herbicides were applied, yields ranged from 11.7 to 13.3 kg m row^{-1}. The trifluralin plus *S*-metolachlor, rimsulfuron, or sulfentrazone programs did not differ from trifluralin, used singly, in crop yield, for either planting period. Although the differences were not statistically significant, tomato yields tended to be numerically greater when rimsulfuron was applied POST as compared with carfentrazone SHIELD (13.5 vs. 12.0 kg m row^{-1} in the early planted; 12.6 vs. 11.4 kg m row^{-1} in the late-planted tomatoes). Despite using a shield to reduce spray drift, visually assessed injury in the carfentrazone treatment (up to 20%) was at least two times greater than the damage observed in the

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Table 6. Tomato yield in response to PPI/PRE applied herbicides when averaged over preplant (PP) glyphosate and POST/SHIELD treatments.[a]

	Early	Late
Treatments[b]	—kg m row^{-1}—	
No PPI/PRE	8.9	9.5
Trifluralin	12.7	11.9
Trifluralin + *S*-metolachlor	13.3	11.9
Trifluralin + rimsulfuron	12.3	12.7
Trifluralin + sulfentrazone	12.7	11.7
Contrasts[b]		
No PPI/PRE vs. PPI/PRE	*	*
Trifluralin vs. trifluralin + *S*-metolachlor	NS	NS
Trifluralin vs. trifluralin fb rimsulfuron	NS	NS
Trifluralin vs. trifluralin + sulfentrazone	NS	NS

[a] Abbreviations: +, tank mix; *, $P \leq 0.05$; fb, followed by, NS, not significant.

[b] Herbicides were applied at the following rates: glyphosate, 2.1 kg ae ha^{-1} (PP); trifluralin, 1.12 kg ha^{-1} (PPI); *S*-metolachlor, 1.8 kg ha^{-1} (PPI); sulfentrazone, 0.1 kg ha^{-1} (PPI); rimsulfuron, 0.03 kg ha^{-1} (PRE, POST); carfentrazone, 0.03 kg ha^{-1} (SHIELD).

rimsulfuron-treated plots (up to 10%) at 2 to 3 wk after application.

To maintain crop yields, maximize harvest efficiency, and preserve tomato quality, California growers may invest substantial resources into weed management (Harr et al. 2002; Shrestha et al. 2007; Sutton et al. 2006). Historically, processing tomato production has been heavily dependent on PP, intercrop tillage operations and in-crop cultivation for weed control (Mitchell et al. 2012). Although effective at managing many weed species, frequent mechanical disturbances can increase dust production and greenhouse gas emissions and reduce soil quality and are accompanied by significant financial costs in labor, fuel, and equipment purchases and maintenance (Clausnitzer and Singer 1997; Mitchell et al. 2012; Reicosky et al. 1997; Sauerbeck 2001; Six et al. 1999). The switch from furrow to subsurface drip-irrigation in processing tomatoes, which was primarily driven by improved water-use efficiency and nutrient management, greater field accessibility, and increased yields, has also affected weed-management practices in processing tomatoes (Mitchell et al. 2012). Because drip-irrigation limits soil surface wetting, the density and biomass of many small-seeded, 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). As a consequence, weed-management practices for drip-systems can 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). Because of its perennial nature and extensive root system, field bindweed may be less affected by a switch to drip-irrigated systems. Reduced tillage and infrequent cultivation may also facilitate the establishment and spread of field bindweed in these systems.

Results from our studies suggest opportunities for suppressing bindweed in processing tomatoes with an IPM approach to manipulate planting dates or to take advantage of selective and semiselective herbicides. Field bindweed vines and seedlings may emerge after early planted (March and April) tomatoes are already established in the Sacramento Valley, whereas late-planted (May and June) crops may be forced to compete with actively growing vines. In the case of the latter, using a glyphosate PP burndown may be effective at suppressing bindweed competition when tomato transplants are becoming established compared with PP tillage, alone. The timing of glyphosate applications is critical, however, to ensure effective management because plant growth stage at the time of application can significantly affect weed control success (Dall'Armellina and Zimdahl 1989; Knezevic et al. 2009; Westra et al. 1992; Wiese and Lavake 1986). Maximum suppression of field bindweed with glyphosate is most readily achieved when the vines are actively blooming, as they were in our study; this timing corresponds to the greatest movement of carbohydrates from shoots to roots, as well as root metabolic activity (Frazier 1943a–c; Weaver and Riley 1982).

Previous research has shown that trifluralin can control johnsongrass [*Sorghum halepense* (L.) Pers.], a perennial grass that reproduces from rhizomes and seeds, by inhibiting lateral root development (Millhollon 1978; Standifer and Thomas 1965). It is presumed that the same is occurring with field bindweed, although no studies have been undertaken, to our knowledge, to describe the observed suppression in such specific terms. Regardless of planting date, trifluralin effectively suppressed both seedling and perennialized field bindweed. The use

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of sulfentrazone PPI or rimsulfuron PRE in partnership with trifluralin may improve field bindweed control under certain conditions; in our study, these herbicide additions were most beneficial in late-planted tomatoes when emerged bindweed was not treated with glyphosate before crop planting. Furthermore, these herbicides, as well as *S*-metolachlor, are effective against other problematic species, such as small-seeded broadleaves and nutsedges (*Cyperus* spp.), which are also of significant concern to California specialty-crop growers (Adcock et al. 2008; Clewis et al. 2007; Felix and Newberry 2012).

If bindweed is a problem in a field or part of a field, growers should consider whether altering their planting date could assist their weed-management efforts. If field bindweed has emerged at the time of planting, the inclusion of a PP burndown application with a nonselective herbicide, such as glyphosate, will be beneficial in perennial bindweed control efforts. The effect of field bindweed in processing tomato may be further reduced with the inclusion of PPI/PRE herbicides that can suppress field bindweed during the crop establishment phase (Lanini and Miyao 1989). Subsequent canopy development, in turn, can reduce light levels reaching the soil surface, adversely affecting bindweed leaf and flower development, seed production, and carbohydrate storage (Dall'Armellina and Zimdahl 1989; Mitich 1991; Weaver and Riley 1982). Although results from these studies suggest that PP and PPI/PRE herbicide applications can be effective at suppressing field bindweed in processing tomatoes, continued management of established populations will also require management efforts outside of the tomato production season when bindweed vines may be more sensitive to physical disturbance (e.g., tillage) and in crops that have more effective and selective herbicides for this weed (e.g., cereals).

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