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Fresh market spinach has one primary herbicide, cycloate, which does not control all weeds. Previous studies demonstrated that cycloate PRE followed by (fb) phenmedipham at the four-leaf spinach stage is a safe and effective treatment. However, this treatment is not useful for the main growing season of fresh spinach due to its short crop cycle and the 21-d preharvest interval requirement of phenmedipham. This study evaluates the potential to use the combination of cycloate PRE fb phenmedipham on two-leaf spinach. Greenhouse and field studies were conducted in 2014 using three spinach varieties with low ('Nordic' and 'Sardinia') and high ('Regal') tolerance to phenmedipham. Greenhouse studies revealed that phenmedipham at 90 g ai ha^{-1} was safe to Regal when applied at the two-leaf stage. Sardinia was more susceptible to phenmedipham injury under high (310 W m^{-2}) light conditions than low (258 W m^{-2}) light conditions. Impact of time of day on phenmedipham safety was evaluated in the field: day-long exposure to high light intensity following morning applications vs. evening applications fb exposure to low light intensity. Injury estimations taken 3 d after treatment (DAT) were lower for evening than for morning applications. Nonetheless, injury 11 DAT and spinach yield evaluations found no differences between morning and evening applications. Subsequently, cycloate (1,700 g ha^{-1}) PRE fb phenmedipham (90 and 180 g ha^{-1}) applied in the evening at the two-leaf stage was evaluated. A reference treatment was cycloate PRE fb phenmedipham (270 g ha^{-1}) at the four-leaf stage. Treatments with cycloate fb two-leaf phenmedipham at 90 and 180 g ha^{-1} were safe to spinach and improved weed control compared to cycloate alone. Cycloate fb 180 g ha^{-1} phenmedipham at the two-leaf stage reduced weed biomass by 88% compared to cycloate alone. This level of weed control was similar to the reference treatment. Results here show that phenmedipham applied at the two-leaf stage is safe to fresh market spinach and it has the potential to be used during most of the fresh spinach growing season.

Nomenclature: Cycloate; phenmedipham; spinach, *Spinacia oleracea* L. 'Nordic', 'Regal', 'Sardinia'.

Key words: Evening application, morning application, sequential phenmedipham application, time of day, two-leaf application.

El mercado de espinaca fresca tiene un sólo herbicida primario, cycloate, el cual no controla a todas las malezas. Estudios previos demostraron que cycloate PRE seguido por (fb) phenmedipham en el estadio de cuatro hojas de la espinaca es un tratamiento seguro y efectivo. Sin embargo, este tratamiento no es útil para la principal temporada de crecimiento de la espinaca fresca, debido a su corto ciclo de producción, y al requisito para phenmedipham de un intervalo de aplicación de 21 d antes de la cosecha. Este estudio evalúa el potencial para el uso de la combinación de cycloate PRE fb phenmedipham en espinaca con dos hojas. Estudios de invernadero y estudios de campo fueron realizados en 2014 usando tres variedades de espinacas con baja ('Nordic' y 'Sardinia') y alta ('Regal') tolerancia a phenmedipham. Los estudios de invernadero revelaron que phenmedipham a 90 g ai ha^{-1} fue seguro en Regal cuando se aplicó en el estadio de dos hojas. Sardinia fue más susceptible al daño del phenmedipham en condiciones de luz alta (310 W m^{-2}) que en condiciones de luz baja (258 W m^{-2}). El impacto del momento durante el día de la aplicación en la seguridad de phenmedipham fue evaluado en el campo: exposición durante todo el día a alta intensidad de luz seguida de aplicaciones en la mañana vs. aplicaciones al atardecer fb de exposición a baja intensidad de luz. Las estimaciones de daño tomadas 3 d después del tratamiento (DAT) fueron menores para aplicaciones al atardecer que en la mañana. Sin embargo, las evaluaciones del daño 11 DAT y el rendimiento de la espinaca no fueron diferentes entre las aplicaciones en la mañana y al atardecer. Subsecuentemente, se evaluó la aplicación de cycloate (1,700 g ha^{-1}) PRE fb phenmedipham (90 y 180 g ha^{-1}) al atardecer en el estadio de dos hojas. Un tratamiento de referencia fue cycloate PRE fb phenmedipham (270 g ha^{-1}) en el estadio de cuatro hojas. Los

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tratamientos con cycloate fb phenmedipham en el estadio de dos hojas a 90 y 180 g ha^{-1} fueron seguros en la espinaca y mejoraron el control de malezas al compararse con cycloate solo. Cycloate fb 180 g ha^{-1} de phenmedipham en el estadio de dos hojas redujo la biomasa de las malezas en 88% al compararse con cycloate solo. Este nivel de control de malezas fue similar al tratamiento de referencia. Estos resultados muestran que phenmedipham aplicado en el estadio de dos hojas es seguro para la producción de espinaca para mercado fresco y tiene el potencial de ser usado durante la mayoría de la temporada de crecimiento de espinaca fresca.

Fresh market spinach is an important vegetable crop in many parts of the world due to its high nutritional value (Correll et al. 2011). California grows 66% of the nation's total fresh spinach and the Salinas Valley on the central coast is a major production area (USDA 2013). The mild temperatures with the relatively low seasonal fluctuations allow spinach production all year (Fennimore et al. 2001). However, most fresh spinach is grown from March to September, its main growing season (Smith et al. 2015).

In California, there is no POST herbicide for fresh spinach, and cycloate PRE is the primary herbicide, used on about 50% of the acreage (CADPR 2013; Fennimore and Doohan 2008; USDA 2013). Cycloate applications often result in partial control of typical Salinas Valley broadleaf weeds such as burning nettle (*Urtica urens* L.), common purslane (*Portulaca oleracea* L.), and common chickweed [*Stellaria media* (L.) Vill.], and under high weed densities many weeds escape control (Fennimore et al. 2001; Lati et al. 2015; Smith et al. 2015). Furthermore, fresh spinach in California is usually planted at high densities, which makes mechanical cultivation between spinach rows impossible (Fennimore et al. 2001). For these reasons, growers depend on hand-weeding to produce a marketable crop, and this weeding tactic is the most expensive one (Slaughter et al. 2008; Takele 2013).

Phenmedipham is a photosystem II (PS II) inhibitor that is applied POST for the control of annual broadleaf weeds and some grasses (Davies et al. 1990; WSSA 2014). It is registered for use on spinach grown for processing or seed, and for sugar beet (*Beta vulgaris* L.), but not for fresh spinach. Phenmedipham may cause temporary injury, and the short growth cycle of fresh market spinach during the main growing season, as short as 33 d, does not always allow sufficient time for recovery from injury (Anonymous 2015; Smith et al. 2015). Recently, Lati et al. (2015) demonstrated that sequential applications of cycloate (1,700 g ai ha^{-1}) PRE fb phenmedipham (270 g ha^{-1}) at the four-leaf stage was safe for fresh spinach, and reduced weed density by 87% compared to cycloate alone. However, this treatment is not feasible for fresh spinach main's growing season due to a 21-d preharvest interval (PHI) requirement on phenmedipham label. The crop reaches the four-leaf stage and harvest at approximately 17 and 33 d after seeding, respectively. The 21-d PHI means a 5-d delay at harvest timing, a significant time for this short-cycle crop (Anonymous 2015; Koike et al. 2011; Lati et al. 2015).

Phenmedipham must be applied at the earliest growth stage possible that is safe to spinach. Previous work has shown that time of day affects the injury level of PS II inhibitors. Phytotoxicity is less during cool temperatures and low light conditions than under strong sunlight (Abbaspoor and Streibig 2007). Starke and Renner (1996) found that sugar beet injury after night application of phenmedipham was lower than after morning applications, but we are not aware of similar evaluations in fresh spinach. Previous greenhouse studies found that fresh spinach at the two-leaf stage application was more sensitive to phenmedipham at 270 g ha^{-1} than at the four-leaf stage (Lati et al. 2015). Nonetheless, the previous work did not evaluate the safety and efficacy of cycloate PRE fb phenmedipham applied at the two-leaf spinach stage. Therefore, the objectives of this study were to (1) determine if cycloate PRE fb phenmedipham POST on two-leaf fresh spinach is safe and effective, and (2) determine if evening application of phenmedipham is a possible method of reducing injury to spinach compared to morning application.

Material and Methods

Three spinach varieties were used for greenhouse and field studies: 'Sardinia', 'Nordic', and 'Regal'. These varieties were chosen based on differing levels of tolerance to phenmedipham. Regal has high

Table 1. Critical dates and environmental conditions in the greenhouse and field experiments: location, planting, phenmedipham application, crop injury estimates, weed density and yield (fresh weight) evaluation dates, average light and temperature conditions measured after phenmedipham treatment. All experiments were conducted during 2014. Days after spinach seeding are in parentheses.

Experiment	Location	Planting	Application	Crop injury estimations		Weed evaluations	Yield evaluations	Light[a,b]	Temperature[a,c]
				1st	2nd			$W\ m^{-2}$	C
1	Greenhouse	June 4	June 25	—	—	—	July 4 (10)	310	16.6
2	Greenhouse	July 11	August 3	—	—	—	August 13 (10)	258	17.9
3	Spence	April 24	May 12	May 15 (21)	May 23 (29)	—	June 2 (39)	320	16.0
4	Spence	May 1	May 19	May 23 (22)	June 2 (32)	—	June 12 (42)	246	14.7
5	Hartnell	June 30	July 11	July 21 (15)	—	August 7 (33)	August 7 (33)	327	18.1
6	Hartnell	July 31	August 11	August 22 (17)	—	September 9 (36)	September 9 (36)	285	17.6

[a] Values were recorded from the California Irrigation Management Information System weather station network using data from the south Salinas station, which is located less than 1 km from the test site (CIMIS 2015).

[b] Values are an average of 5 d after phenmedipham application.

[c] Values are average of all days between phenmedipham application and spinach harvest.

tolerance, 550 g ha^{-1} at the four-leaf stage, whereas Sardinia and Nordic are more sensitive, 270 g ha^{-1} at the four-leaf stage (Lati et al. 2015). To characterize any interactions between environmental conditions and crop injury or biomass reduction in the greenhouse and field studies, average temperatures and light values were recorded from the California Irrigation Management Information System weather station network using data from the south Salinas station, which is located less than 1 km from the test site (CIMIS 2015). Table 1 lists the critical dates for the experiments, including location, planting, phenmedipham application, crop injury evaluation, weed density measurement, and harvesting dates, as well as the average temperature and light conditions.

Greenhouse Study. Experiments 1 and 2 were conducted to provide preliminary data about the tolerance of fresh spinach to cycloate PRE fb phenmedipham POST at the two-leaf stage. Pots (8 cm diam) were filled with sandy loam soil (2.1% organic matter and pH 7.0) and seeded with three seeds of Regal and Sardinia separately. Cycloate (Ro-Neet®, Helm Agro US, Tournament Dr., Memphis, TN, 38125) was applied PRE at 1,700 g ha^{-1} and activated with 50 ml water immediately after treatment. Pots were thinned to one spinach plant per pot 7 d after spinach emergence, and kept outside the greenhouse under direct sunlight conditions throughout the study. Phenmedipham (Spin-Aid®, Engage Agro, Prescott, AZ, 86303) at 90 and 180 g ha^{-1} was applied at the two-leaf stage. The control pots were treated with cycloate PRE at 1,700 g ha^{-1}. Herbicides were applied with a CO_2-pressurized backpack sprayer equipped with 8002VS flat fan nozzles (Tee Jet Technologies, Wheaton, IL, 60189) calibrated to deliver 337 L ha^{-1} at 290 kPa. Ten days after phenmedipham application the aboveground biomass of all plants was harvested and dry weights determined by drying at 80 C for 6 d. The experiment was conducted twice, and arranged in a complete randomized design with five replicates.

Statistical Analysis. For Regal there were no experiment by treatment interactions, and therefore, data were pooled. Plant dry weights were subjected to ANOVA, and mean separation was performed using Fisher's protected LSD ($\alpha \leq 0.05$). One-way ANOVA was conducted to determine the effects of

Table 2. The effect of cycloate 1,700 g ai ha^{-1} PRE followed by phenmedipham applied at 90 and 180 g ai ha^{-1} at two-leaf stage on Regal and Sardinia dry weight in experiments 1 and 2.

	Dry weight[a]		
		Sardinia	
Phemedipham rate	Regal	Experiment 1	Experiment 2
g ai ha^{-1}	g $plant^{-1}$		
0	0.55 a	54 a	56 a
90	0.50 a	31 b	44 b
180	0.37 b	13 c	29 c

[a] Means in a column with the same letter are not significantly different according to Fisher's protected LSD at $\alpha < 0.05$.

phenmedipham rate on Regal and Sardinia dry weight using PROC GLM (version 9.3, SAS Institute Inc., Cary, NC).

Field Studies. Experiments were conducted during 2014 at Spence U.S. Department of Agriculture and Hartnell field stations near Salinas, CA. Soil type at the Hartnell station is an Antioch sandy loam soil, fine, smectitic, thermic Typic Natrixeralf (53% sand, 32% silt, and 15% clay) with a pH of 7.0 and organic matter content of 2.1%. Soil type at the Spence station is a Chualar loam, fine-loamy, mixed, thermic Typic Argixeroll (79% sand, 14% silt, and 7% clay) with a pH of 7.2 and organic matter content of 1%. All plantings were grown on 1-m-wide raised beds with two seed lines 30 cm apart per bed. One seed line was planted with Nordic (experiments 3 and 4) or Sardinia (experiments 5 and 6) and the other with Regal (experiments 3 through 6). A tractor-mounted planter (Stanhay Webb Ltd., Grantham, U.K.) was used for seeding, and overhead sprinkler irrigation and other common spinach cultural practices were used (LeStrange et al. 2013). Herbicides were applied to the bed top with a CO_2-pressurized backpack sprayer as described in the previous section. Plot size was one bed wide by 6 m long. Crop injury estimates were recorded on a scale of 0 (no injury) to 100 (plant death). Treatments with minor growth inhibition and phytotoxicity symptoms (injury estimate < 20%) were considered safe. Spinach yield (fresh weight) was determined by harvesting a 3-m sample area from each seed line. Experiments were conducted twice. Experiments were arranged in a randomized complete block design with five replications.

Experiments 3 and 4 were conducted to determine if evening phenmedipham applications under low light conditions caused less spinach injury than morning applications under high light conditions. Phenmedipham 550 g ha^{-1} was applied to four-leaf stage spinach at two timings: morning (9:00 A.M.) and evening (6:00 P.M.). Estimation of crop injury and yield were recorded as described above. Experiments included a nontreated hand-weeded control.

Experiments 5 and 6 were conducted to evaluate the safety and effectiveness of sequential applications of cycloate fb evening phenmedipham application at the two-leaf spinach stage. Treatments included: cycloate PRE at 1,700 g ha^{-1} fb phenmedipham POST at 90 and 180 g ha^{-1} at the two-leaf stage and, cycloate PRE at 1,700 g ha^{-1} fb phenmedipham POST at 270 g ha^{-1} at the four-leaf stage. The four-leaf stage application using higher phenmedipham rate, 270 g ha^{-1}, was a reference for a spinach-safe cycloate and phenmedipham treatment (Lati et al. 2015). All phenmedipham applications were made in evening (6:00 P.M.). Crop visual injury and yield were recorded as described above. Weed control was evaluated by harvesting aboveground biomass within a 3,900-cm^2 sample area in each plot.

Statistical Analysis. Where there was no experiment by treatment interaction, data were pooled; otherwise data from each experiment were analyzed separately. For the time-of-day study, factorial analysis was conducted to determine the interaction between time of day and variety on spinach injury estimates and yield. For the cycloate fb phenmedipham study, injury estimates, weed biomass, and yield data were subjected to ANOVA using PROC GLM in SAS and means were separated by Fisher's protected LSD at $\alpha \leq 0.05$.

Result and Discussion

Greenhouse Study. Spinach tolerance to phenmedipham varied among rates and varieties. Regal was more tolerant to phenmedipham than Sardinia. Regal treated with phenmedipham at 90 g ha^{-1} resulted in dry weight similar to the nontreated, 0.55 and 0.5 g $plant^{-1}$, respectively (Table 2). Regal treated with phenmedipham at 180 g ha^{-1} resulted in 31% reduction ($P = 0.003$) in dry weight compared to the nontreated control. Sardinia

Table 3. Injury estimate and yield (fresh weight) of Regal and Nordic resulting from phenmedipham 550 g ai ha^{-1} applied at 9:00 A.M. and 6:00 P.M. in experiments 3 and 4.

Application time	Injury estimate[a,b]				
	Experiment 3		Experiment 4		
	3 DAT[d]	11 DAT	4 DAT	11 DAT	Yield[a,c]
	%				g $plant^{-1}$
Nordic					
9:00 A.M.	65 a	24 a	42 a	16 a	17
6:00 P.M.	23 b	14 ab	16 b	7 ab	18
Regal					
9:00 A.M.	60 a	16 ab	22 ab	8 ab	74
6:00 P.M.	14 b	2 b	8 b	1 b	76
ANOVA					
Variety	0.044	0.043	0.046	0.002	0.001
Time	< 0.001	0.066	0.016	0.0483	0.303
Variety × time	0.469	0.422	0.600	0.300	0.521

[a] Means in a column with the same letter are not significantly different according to Fisher's protected LSD at $P < 0.05$.

[b] Injury estimates were taken 3 and 11 (experiment 3) and 4 and 11 (experiment 4) DAT with 0% = no injury and 100% = dead plants.

[c] Yields were measured 21 (experiment 3) and 24 (experiment 4) DAT.

[d] Abbreviation: DAT, days after treatment.

treated with phenmedipham at both rates had lower dry weights than the control (Table 2). These results demonstrate that phenmedipham applied to Regal at the two-leaf stage can be safe, but biomass reduction may occur in sensitive varieties.

Dry weights of Sardinia were not consistent between experiments. Dry weight of Sardinia treated with phenmedipham at 90 g ha^{-1} was reduced by 42 and 21% in experiments 1 and 2, respectively (Table 2). Table 1 shows that light intensity after phenmedipham treatment was 20% higher in experiment 1 than in experiment 2, while temperature was 7% lower. Sardinia dry weights were lower in experiment 1 than in experiment 2, possibly in response to the higher light intensity in experiment 1 than in experiment 2, 310 and 258 W m^{-2}, respectively (Table 1). This suggests that the tolerance level of fresh spinach to phenmedipham is affected by light intensity, and under higher light conditions spinach injury will probably be higher. Similar results were reported for other PS II inhibitors, bromoxynil and atrazine; the phytotoxicity effects of these herbicides are related to the formation of reactive oxygen species, which are promoted under high light intensities (Brain et al. 2012; Fufezan et al. 2002; Hess 2000). These results suggest that evening and night phenmedipham applications might be a strategy to reduce spinach injury.

Time of Day. The first set of field experiments evaluated the impact of time of day of phenmedipham application on fresh spinach crop safety. Therefore, as a test case, the high (550 g ha^{-1}) phenmedipham rate was used to verify crop safety. Injury levels in experiment 3 were higher than in experiment 4 (Table 3), and can be attributed to the higher light intensity measured in experiment 3, rather than the higher temperatures (Table 1). The variety factor P values indicate that Regal was more tolerant to phenmedipham than Nordic. Nonetheless, there were no variety by time interactions, demonstrating that the impact of time of day was similar between both varieties (Table 3). At the first injury evaluation, spinach treated with phenmedipham in the evening had less injury than when applied in the morning regardless of variety (Table 3). The largest difference in injury between morning and evening applications were observed for Regal 3 DAT in experiment 3, where injury estimations for the evening and morning applications were 60 and 14%, respectively (Table 3). Differences in injury level between morning and evening applications diminished by 11 DAT as the plants partially recovered. At the time of harvest, 39 and 42 d after seeding for experiments 3 and 4, respectively, there were no differences between evening and morning applications for Regal and Nordic (Table 3).

We concluded that applying phenmedipham in the evening was safer than morning. Because spinach leaves are directly consumed, growers are concerned about their visual appearance and color, so biomass is only part of the consideration. Any means that can avoid visual injuries increase the odds that the phemedipham treatment is viable. It is likely that the low light intensity in the immediate hours after phenmedipham treatment allows better and faster recovery from the herbicide and less injury to the spinach (Fufezan et al. 2002).

Cycloate fb Phenmedipham. In these experiments, cycloate PRE fb hand-weeding was the commercial

Table 4. Spinach injury estimates and yield (fresh weight) in experiments 5 and 6, resulting from cycloate 1,700 g ai ha^{-1} PRE followed by different phenmedipham rates applied in the evening (6:00 P.M.) at different rates and growth stages.

Treatment	Phenmedipham rate	Growth stage	Injury[a,b]		Yield[a,c]			
					Experiment 5		Experiment 6	
			Regal	Sardinia	Regal	Sardinia	Regal	Sardinia
	g ai ha^{-1}	Leaf no.			g m^{-2}			
Cycloate[d]	0		1	1 c	1,330	1,380	1,710	2,040
Cycloate fb hand-weeding[e,f]	0		1	1 c	1,310	1,590	1,950	2,160
Cycloate fb phenmedipham	90	2	2	4 bc	1,520	1,620	1,910	2,340
Cycloate fb phenmedipham	180	2	9	10 a	1,400	2,260	1,950	2,140
Cycloate fb phenmedipham	270	4	3	2 bc	1,350	1,730	2,040	2,070

[a] Means in a column with the same letter are not significantly different according to Fisher's protected LSD at $\alpha < 0.05$.

[b] Injury estimates were taken 4 (experiment 5) and 7 (experiment 6) days after last phenmedipham treatment on a scale of 0 to 100%, with 0% = no injury and 100% = dead plants.

[c] Yields were measured 22 (experiment 5) and 25 (experiment 6) days after last phenmedipham treatment.

[d] This treatment was used as the nonweeded control.

[e] Abbreviation: fb, followed by.

[f] This treatment was the commercial standard.

standard and cycloate PRE without hand-weeding was the control. The two-leaf stage phenmedipham applications treatments were safe for spinach when evaluated 4 DAT (experiment 5) and 7 DAT (experiment 6), and resulted in $\leq$ 10% injury on both varieties (Table 4). Correspondingly, spinach yield from all two-leaf–stage phenmedipham treatments were similar to cycloate fb hand-weeding, which indicates that these treatments did not significantly injure spinach (Table 4).

The primary weeds by percentage of population in experiments 5 and 6 were 45% common purslane, 25% burning nettle, 10% nettleleaf goosefoot (*Chenopodium murale* L.), and 10% little mallow (*Malva parviflora* L.). Weed control was significantly improved by both two-leaf–stage phenmedipham treatments compared to cycloate PRE alone. Relative to the control, all weed species were affected by phenmedipham; application to two-leaf spinach at 180 g ha^{-1} reduced the weed biomass in experiment 5 from 1,678 to 216 g m^{-2}, an 87% reduction compared to the control, (Table 5). This level of weed control was similar to the four-leaf phenmedipham application at 270 g ha^{-1}, which proved to be an effective treatment in previous study (Lati et al. 2015).

Phenmedipham is not registered for use on fresh market spinach. However, results from this study indicate that cycloate PRE fb phenmedipham POST (90 or 180 g ha^{-1}) should be considered as a treatment for fresh spinach that is applied in the evening to two-leaf spinach. We conclude that the phenmedipham-based program tested here was safe for fresh spinach, and resulted in better weed control than cycloate alone. The sequential use of herbicides with two different modes of action provided effective weed control even at the low 90 g ha^{-1} phenmedipham rate (Table 5). The smaller weeds were likely more sensitive to phenmedipham at the two-leaf spinach stage than at the four-leaf stage, and phenmedipham at 90 and 180 g ha^{-1} was effective on all weed species in our experiments. Herbicides are just one component in the commonly used weed management systems of vegetables; weeds that escape control from the herbicide are removed by cultivation and hand-weeding. In addition, spinach is rotated with lettuce (*Lactuca sativa* L. var.), broccoli (*Brassica oleracea* L.), and celery [*Apium graveolens* L. var. *dulce* (Mill.) Pers.] which all have different weed control programs than spinach. For these reasons, using reduced rate herbicides in this unique production system lessens the chance for herbicide-resistant weeds (Fennimore et al. 2014).

Fresh spinach growers need POST herbicides to reduce hand-weeding costs and dependency on labor (Fennimore et al. 2001). For that reason, cycloate PRE fb the two-leaf phenmedipham

Table 5. The effects of cycloate PRE (1,700 g ai ha^{-1}) followed by different phenmedipham rates applied in the evening (6:00 P.M.) at different rates and growth stages on weed biomass and compared to cycloate in experiments 5 and 6.

Treatment	Phenmedipham rate	Growth stage	Weed biomass[a,b]			
			Experiment 5		Experiment 6	
	g ai ha^{-1}	Leaf no.	g m^{-2}	% reduction[c]	g m^{-2}	% reduction[c]
Cycloate[d]	0	—	1,678 a	—	778 a	—
Cycloate fb hand weeding[e,f]	0	—	10 c	99	20 c	97
Cycloate fb phenmedipham	90	2	476 b	71	244 b	68
Cycloate fb phenmedipham	180	2	216 bc	87	92 bc	88
Cycloate fb phenmedipham	270	4	169 bc	89	252 b	67

[a] Means in a column with the same letter are not significantly different according to Fisher's protected LSD at $\alpha \leq 0.05$.

[b] Weed biomass was evaluated 22 (experiment 5) and 25 (experiment 6) days after last phenmedipham treatment. The primary weeds in experiments 5 and 6 were common purslane (45%), burning nettle (25%), nettleleaf goosefoot (10%) and little mallow (10%).

[c] Reduction compared to cycloate alone.

[d] This treatment was used as the nonweeded control.

[e] Abbreviation: fb, followed by.

[f] This treatment was the commercial standard.

treatments can be useful even though this control program does not provide complete weed control. During the main growing season, fresh spinach reaches the two-leaf and harvest stages at approximately 12 and 33 d after seeding, respectively (Table 1). Therefore, the two-leaf phenmedipham application will allow compliance with the 21-d PHI required by the label; it will not cause delay in harvest timing (Lati et al. 2015).

Stewart et al. (2009) and Stopps et al. (2013) evaluated the impact of time of day on the efficacy of other PS II herbicides (bentazon, atrazine, bromoxynil) and found it to vary among weed species; the control of velvetleaf (*Abutilon theophrasti* Medik.) treated with atrazine varied by 58% in the different application timings, whereas the control of redroot pigweed (*Amaranthus retroflexus* L.) with atrazine was not affected. Stewart et al. (2009) and Stopps et al. (2013) evaluated different weeds from our study and in experiments 5 and 6 only evening application was evaluated. Nonetheless, control of common purslane and burning nettle in this study were similar to results obtained by morning phenmedipham application (Lati et al. 2015). Further research is needed to evaluate the efficacy of this system on other weed species and in commercial spinach plantings. However, this study offers for the first time a POST herbicide tool for fresh spinach production that is safe and effective, and can be used throughout the growing season. Based on our findings here, we suggest that fresh market spinach can be added to the phenmedipham label with caveats for rates, 90 and 180 g ha^{-1}, applied in the evening.

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