Evaluation of Low-rate Herbicides to Supplement Methyl Bromide Alternative Fumigants to Control Weeds in Strawberry

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Summary. **Methyl bromide has been the foundation of chemical weed control in strawberry (*Fragaria ×ananassa*) in California for over 40 years. The impending phaseout of methyl bromide may leave strawberry producers dependent on less efficacious alternative fumigants for weed control. The use of herbicides to supplement fumigants is a potential weed control strategy for strawberry. A 2-year field study was conducted in California to evaluate 10 herbicides as possible supplements for methyl bromide alternative fumigants. Herbicides were applied immediately after transplanting (immediate posttransplant), and 3 weeks after transplanting (delayed posttransplant). Napropamide applied immediate posttransplant was included as a commercial standard. Immediate posttransplant treatments that were safe in strawberry include carfentrazone at 0.075 and 0.15 lb/acre (0.084 and 0.168 kg·ha^{-1}), flumioxazin at 0.063 lb/acre (0.071 kg·ha^{-1}) and sulfentrazone at 0.175 and 0.25 lb/acre (0.196 and 0.28 kg·ha^{-1}). Triflusulfuron at 0.016 lb/acre (0.017 kg·ha^{-1}) was the only delayed posttransplant treatment with acceptable selectivity. Among the selective herbicides applied immediate posttransplant, flumioxazin and napropamide provided the most consistent control of bur clover (*Medicago polymorpha*) and shepherd's purse (*Capsella bursa-pastoris*). Triflusulfuron applied delayed posttransplant did not significantly reduce bur clover densities, but did reduce shepherd's purse densities.**

Total U.S. strawberry production in 1999 was 757,750 tons (688,863 t), grown on 45,560 acres (18,696 ha) and valued at $1.1 billion (National Agricultural Statistics Service, 2000). The major production states include Arkansas, California, Florida, Louisiana, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Washington, and Wisconsin. California leads the U.S. in strawberry production, accounting for over half of the area planted, 84% of the tonnage and 80% of the value. About 65% of California strawberries are produced on the central coast and 35% in southern California (California Strawberry Commission, 1999). The high level of strawberry production in California has been made possible by a combination of improved cultivars, and control of soilborne pathogens and weeds by methyl bromide soil fumigation (Wilhelm and Paulus, 1980).

Methyl bromide has been the basis for pest management in California strawberry production for 40 years (Wilhelm and Paulus, 1980). Essentially all conventionally produced strawberries in California are grown in soil fumigated with methyl bromide plus chloropicrin. Methyl bromide provides consistent and effective control of soilborne diseases, nematodes and weeds, and is cost effective. The primary use of methyl bromide is as a preplant treatment for the control of soilborne pests of peppers, strawberry and tomato. Soil fumigation consumes 35 million lb (15.9 million kg) of methyl bromide each year; about 50% is used in California and 35% in Florida. Methyl bromide has been classified as an ozone-depleting substance, and under the provisions of the U.S. Clean Air Act and international treaty, methyl bromide use in the U.S. will be phased out by 2005 (Economic Research Service, 2000).

Methyl bromide alternative fumigants must control the same spectrum of soilborne pests that were previously controlled by methyl bromide. Alternative fumigants under consideration include: chloropicrin, metam sodium or a mixture of 1,3-dichloropropene (1,3-D) plus chloropicrin (Ajwa and Trout, 2000). Among the soilborne pathogens that are controlled by methyl bromide are *Verticillium dahliae*, *Phytophthora* sp., and *Pythium ultimum*. Several years of repeated experiments with strawberry on soil infested with *V. dahliae* demonstrated that chloropicrin treated plots yielded 77% to 117% of plots treated with methyl bromide plus chloropicrin (Duniway et al., 1999). Similarly, 1,3-D plus chloropicrin-treated plots yielded 88% to 105% of the methyl bromide plus chloropicrin standard. Chloropicrin provides some control of *Phytophthora* sp. and *P. ultimum*, but does not provide the level of control equivalent to methyl bromide (G. Browne and F. Martin, unpublished data). Recent work with alternative fumigants indicates they often provide less effective weed control than methyl bromide. Chloropicrin, 1,3-D plus chloropicrin mixture or metam sodium do not provide nutsedge (*Cyperus* sp.) control equivalent to methyl bromide in tomato (*Lycopersicum esculentum*) (Locascio et al., 1997). Field trials indicated that shank-applied 1,3-D plus chloropicrin at 410 lb/acre (460 kg·ha^{-1}) and chloropicrin alone at 300 lb/acre (337 kg·ha^{-1}) provided good control of common chickweed (*Stellaria media*) and shepherd's purse, but provided poor control of other weeds such as bur clover and little mallow (*Malva parviflora*) (Fennimore et al., 2000). The level of weed control provided by chloropicrin is generally less than that of methyl bromide as evidenced by repeated side-by-side comparisons of the two fumigants. Chloropicrin applied at 200 lb/acre (224 kg·ha^{-1}) has provided weed control equivalent to 37 to 65% of that provided by methyl bromide plus chloropicrin in a 67:33 ratio at 250 lb/acre (280 kg·ha^{-1}), and at 300 lb/acre chlo-

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ropicrin has provided weed control equivalent 20 to 97% of methyl bromide plus chloropicrin (S. Fennimore, unpublished results). Fumigants such as methyl iodide and propargyl bromide are currently being evaluated in strawberry nursery and fruit production fields and have not yet been fully characterized with regard to weed control (Fennimore et al., 2000).

Strawberries are extremely susceptible to crop losses due to weed competition, and weeds can harbor pathogens and insects deleterious to the crop; therefore, weeds must be carefully managed to maintain high production (Agamalian et al., 1994; Lange, 1985). The long growing season makes California strawberries particularly vulnerable to weed pests. Weed control in California strawberries has been accomplished through an effective combination of field selection, crop rotation, sanitation, hand weeding, mulching, preplant soil fumigation and occasionally, herbicides (California Strawberry Commission, 1999). Consequences of the methyl bromide phase out may include increased strawberry production costs due to increased hand weeding expense.

Because many of the alternative fumigants are generally not as effective on weeds as methyl bromide, the use of herbicides to provide supplemental weed control has been considered. Existing herbicide choices in strawberries are limited. Only four herbicides are currently registered for use in California strawberries: napropamide, DCPA, paraquat and sethoxydim. Napropamide is the only registered strawberry herbicide that may play a larger role in strawberry weed management in the future (California Strawberry Commission, 1999). However, issues such as restrictions on rotational crops may limit napropamide usage. For example, common rotational crops such as celery or lettuce cannot be planted within 12 months of a napropamide application (United Phosphorous, 1999). Use of napropamide in southern California would limit the choice of rotational crops since strawberry plantings there are maintained for about 8 months. DCPA is currently available for use in strawberry, but this herbicide does not control key weeds such as bur clover and little mallow (Agamalian et al., 1994). Paraquat is used primarily to control weeds in the furrow bottoms (California Strawberry Commission, 1999). Paraquat has no soil activity (Ahrens, 1994), therefore its role is limited to use as a postemergence directed spray application. Sethoxydim, a postemergence grass herbicide is used infrequently in California strawberries (California Dept. of Pesticide Regulation, 2000) since it does not control the major grass weed species, annual bluegrass (*Poa annua*) (Agamalian et al., 1994).

Pest management programs based on alternative fumigants must provide effective control of soilborne diseases, nematodes and weeds or grower profitability may suffer. If alternative fumigants do not control weeds effectively, then growers will be forced to remove them with expensive hand labor. We hypothesize that herbicides can be used to supplement alternative fumigants and improve the level and consistency of weed control. If herbicides are to perform a significant role in new strawberry weed management systems, more of them must be identified and registered. The objective of this study was to identify new potential strawberry herbicides for use as supplements to alternative fumigants such as chloropicrin and 1,3-D plus chloropicrin mixture for weed control in strawberry.

Materials and methods

TRIAL ESTABLISHMENT. Field studies were conducted during the 1998–99 and 1999–2000 growing seasons at the USDA Spence Research Farm near Salinas, California. The 1998–99 growing season will be referred to as 1999 and the 1999–2000 season will be referred to as 2000. The soil was a Chualar series loamy sand (fine-loamy, mixed, thermic Typic Argixeroll). The trial area was tilled, beds were formed, and chloropicrin was shank-injected at 140 lb/acre (157 $kg \cdot ha^{-1}$) on 31 Oct. 1998 and at 336 lb/acre (376 $kg \cdot ha^{-1}$) on 25 Oct. 1999. Beds were tarped with polyethylene at time of fumigation, which was removed after 14 d. Transplant dates were 18 Nov. 1998 and 9 Nov. 1999. Two strawberry rows were planted, with one row each of 'Selva' and 'Camarosa' per bed. The cultivars chosen for this study were representative of most strawberries planted in California. 'Selva', a day-neutral cultivar, has been a popular northern California cultivar; more than 4940 acres (2000 ha) were planted in 1997 (Hokanson and Finn, 2000). 'Camarosa', a short-day cultivar, is the most popular strawberry planted in southern California, at 6175 acres (2500 ha) in 1997. The trial area was sprinkler-irrigated for the first month after transplanting to establish the plants. From the second month until the completion of the study, subsurface drip irrigation was used to water the study area. Each plot was one 52 inch (1.3 m) bed wide by 15 ft (4.6 m) long. All treatments were replicated four times and arranged in a randomized complete-block design.

HERBICIDE TREATMENTS. The herbicides and rates tested in these trials were selected after consultation with herbicide manufacturers. Herbicides applications were made at two crop stages: immediate posttransplant (IPT), and delayed posttransplant (DPT). Immediate posttransplant applications were made immediately after transplanting and DPT applications were made 21 d after transplanting. The strawberry plants at the time of IPT application were newly planted dormant plants with few or no leaves, while at the time of the DPT application the strawberries had one to two sets of leaves. Herbicides evaluated and rates tested in lb/acre and $kg \cdot ha^{-1}$ are listed in Table 1. Eight herbicides plus the commercial standard, napropamide, were applied IPT, and nine herbicides were applied DPT. The herbicide rates used IPT were selected for preemergence weed control since no weeds were present at transplanting. Postemergence activity is desirable at the DPT timing since there may be some emerged weeds and preemergence activity is also desired since there is considerable potential for more weeds to emerge during the winter–spring period after the DPT application (S. Fennimore, unpublished results). All herbicides were applied at 40 gal/acre (374 $L \cdot ha^{-1}$) at a pressure of 40 lb/inch^2 (276 kPa) with a carbon dioxide-pressurized plot sprayer equipped with 80-02 VS nozzles. In 2000, cotyledon to two-leaf stage bur clover and cotyledon to six-leaf stage shepherd's purse were present at time of DPT application.

CROP AND WEED EVALUATIONS. Strawberry tolerance and herbicide efficacy were evaluated by assessing crop injury, and stand, and by measuring plant diameter, fresh weight and weed density. Crop injury and stand count were assessed at 30 (data not shown) and 47 d after transplanting (DAT) in 1999, and 42 (data not shown) and 50 DAT in 2000. Injury ratings were visual estimates of one or more injury symptoms such as chlorosis, necrosis, leaf cupping and stunting, relative to the untreated plants. A scale of 0 (no injury) to 10 (plant death) was used for the injury ratings. Greatest injury occurred at about 50 DAT, i.e., 50 d after the IPT application and 29 d after the DPT application. Stand was assessed by counting the number of live plants per 13 ft (4 m) of row (data not shown). Plant diameter was measured after the onset of vigorous spring growth, at 113 and 112 DAT in 1999 and 2000, respectively (data not shown), and at 153 and 161 DAT in 1999 and 2000, respectively. Two plant diameter measurements were taken per plant, one measurement perpendicular to the bed and the other parallel. Five plants of each cultivar were measured per plot, for a total of 10 measurements. Above ground strawberry biomass production was measured as fresh weight at 181 DAT in 1999 and 183 DAT in 2000. Strawberry plants were cut off at the soil line, and then weighed immediately to measure biomass. Weed density counts by species were taken 4 Jan. and 24 Feb. (47, 98 DAT) 1999 and 2 and 28 Feb. (85, 111 DAT) 2000. Individual weed species were counted in a 6.0-ft^2 (0.56-m^2) quadrat within each plot in 1999 and over the entire 41.1-ft^2 (3.82-m^2) bed top area of each plot in 2000.

Statistical analysis. All data were subjected to analysis of variance, and Fisher's LSD was used for mean comparison. Analysis of variance for the data from 1999 and 2000 resulted in significant year by treatment interactions for all attributes. All attributes were presented individually within each cropping cycle. Weed densities were low in 1999 and are not reported.

Results and discussion

Crop tolerance to IPT herbicide applications. The criteria for an acceptable herbicide treatment was a crop injury <2.0, and no significant plant diameter or fresh weight reduction. Visual injury symptoms such as leaf malformation and chlorosis became more obvious as the plants grew, and were very obvious by 50 DAT. The plant diameter and biomass measurements indicated whether individual treatments resulted in normal plant growth. Acceptable IPT treatments in 'Selva' include carfentrazone at 0.075 and 0.15 lb/acre (0.084 and 0.168 kg·ha^{-1}) flumioxazin at 0.063 and 0.125 lb/acre (0.071 and 0.14 kg·ha^{-1}), napropamide at 4.0 lb/acre (4.48 kg·ha^{-1}), and sulfentrazone at 0.175 and 0.25 lb/acre (0.196 and 0.28 kg·ha^{-1}) (Table 2). Crop injury symptoms in the 0.15 lb/acre carfentrazone and 0.125 lb/acre flumioxazin treatments in 1999 were significantly greater than the untreated check, but this rating was not different from that of the industry standard napropamide at 4.0 lb/acre. Similarly, IPT treatments in 'Camarosa' that resulted in crop injury ratings <2.0 and no significant plant diameter or fresh weight reduction compared to the untreated included: carfentrazone at 0.075 and 0.15 lb/acre, napropamide at 4.0 lb/acre and sulfentrazone at 0.175 and 0.25 lb/acre (Table 3). IPT applications of carfentrazone, napropamide and sulfentrazone were selective in both cultivars. Flumioxazin resulted in moderate injury on 'Camarosa' in 1999 but not 2000. The differential responses of both strawberry cultivars to herbicides over the 2 years may have resulted from high rainfall in November 1998 and cooler than normal weather in Winter 1998–99.

Herbicide treatments that resulted in unacceptable injury, plant diameter or fresh weight reduction on 'Selva' and 'Camarosa' were cloransulam, halosulfuron, rimsulfuron and SAN 582. Due to the severity of injury, no further strawberry work is recommended for these compounds. Isoxaben at 0.5 lb/acre (0.56 kg·ha^{-1}) slightly reduced 'Selva' fresh weight,

Table 1. Herbicides evaluated for selectivity in strawberry at two application timings; immediately after transplanting (immediate posttransplant) and 3 weeks after transplanting (delayed posttransplant).

Immediate posttransplant				Delayed posttransplant			
		Rate				Rate	
Common name	Formulation	(lb/acre)	(kg·ha^{-1})	Common name	Formulation	(lb/acre)	(kg·ha^{-1})
Carfentrazone	40% DF[z]	0.075	0.084	Carfentrazone	40% DF	0.010	0.011
Carfentrazone	40% DF	0.150	0.168	Carfentrazone	40% DF	0.030	0.033
Cloransulam	84% DF	0.016	0.018	Cloransulam	84% DF	0.008	0.009
Cloransulam	84% DF	0.031	0.035	Cloransulam	84% DF	0.016	0.018
Flumioxazin	50% WP[y]	0.063	0.071	Halosulfuron	75% DF	0.032	0.036
Flumioxazin	50% WP	0.125	0.140	Halosulfuron	75% DF	0.047	0.053
Halosulfuron	75% DF	0.032	0.036	Imazamox	1.0 EC	0.032	0.036
Halosulfuron	75% DF	0.047	0.053	Imazamox	1.0 EC	0.040	0.045
Isoxaben	75% DF	0.500	0.560	Isoxaben	75% DF	0.250	0.280
Napropamide	50% DF	4.000	4.480	Rimsulfuron	25% DF	0.031	0.035
Rimsulfuron	25% DF	0.016	0.017	SAN 582	6.0 EC	1.500	1.680
Rimsulfuron	25% DF	0.031	0.035	Sulfentrazone	75% DF	0.150	0.170
SAN 582	6.0 EC[x]	0.940	1.050	Sulfentrazone	75% DF	0.250	0.280
SAN 582	6.0 EC	1.200	1.350	Triflusulfuron	50% DF	0.016	0.017
Sulfentrazone	75% DF	0.175	0.196	Triflusulfuron	50% DF	0.031	0.035
Sulfentrazone	75% DF	0.250	0.280				

[z]Dry flowable.
[y]Wettable powder.
[x]Emulsifiable concentrate.

Table 2. Crop injury ratings, plant diameter measurements and fresh weight for 'Selva' strawberry treated with herbicides applied immediately after transplanting.

		Crop injury[z]		Diam (inches)[y]		Fresh wt (lb)[x]	
		DAT[w]					
	Rate	47	50	153	161	181	183
Treatment	(lb/acre)[v]	1999	2000	1999	2000	1999	2000
Carfentrazone	0.075	0.5	0.0	14.0	10.4	4.2	3.8
Carfentrazone	0.150	1.2	0.0	13.7	9.8	3.9	3.3
Cloransulam	0.016	1.6	4.5	10.2	8.2	2.7	1.8
Cloransulam	0.031	2.3	4.0	9.5	8.0	1.9	1.5
Flumioxazin	0.063	0.5	0.1	13.3	9.6	4.2	3.1
Flumioxazin	0.125	1.2	0.1	12.0	10.0	4.2	3.0
Halosulfuron	0.032	2.1	5.5	5.6	5.9	0.6	0.9
Halosulfuron	0.047	4.8	7.0	3.1	5.4	0.1	0.4
Isoxaben	0.500	0.2	0.0	13.2	9.1	4.2	2.6
Napropamide	4.000	0.7	0.0	13.0	10.8	3.8	3.8
Rimsulfuron	0.016	1.8	7.0	8.0	6.9	1.9	1.4
Rimsulfuron	0.031	4.3	7.3	5.4	6.6	0.6	0.8
SAN 582	0.940	0.7	0.0	10.0	8.6	2.0	2.4
SAN 582	1.200	0.6	0.1	8.1	8.6	1.6	2.2
Sulfentrazone	0.175	0.1	0.1	13.5	10.2	4.2	3.5
Sulfentrazone	0.250	0.4	0.3	13.6	10.1	4.7	3.0
Untreated	---	0.0	0.0	13.3	10.0	4.4	3.3
$LSD_{(0.05)}$		1.2	1.1	2.5	2.0	1.2	0.6

[z]Visually assessed crop injury scale of 0 to 10; 0 = no symptoms, 10 = plant death.
[y]Plant diameter = average of plant width measurements taken parallel and perpendicular to the row orientation for five plants in each plot; 1.0 inch = 2.54 cm.
[x]Fresh weight = above ground fresh weight from 10 ft (3.0 m) of row; 1.0 lb = 0.454 kg.
[w]DAT = days after transplanting.
[v]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

Table 3. Crop injury ratings, plant diameter measurements and fresh weight for 'Camarosa' strawberry treated with herbicides applied immediately after transplanting.

		Crop injury[z]		Diam (inches)[y]		Fresh wt (lb)[x]	
		DAT[w]					
	Rate	47	50	153	161	181	183
Treatment	(lb/acre)[v]	1999	2000	1999	2000	1999	2000
Carfentrazone	0.075	0.8	0.0	13.1	10.1	3.9	3.5
Carfentrazone	0.150	1.2	0.0	13.7	9.9	3.6	3.1
Cloransulam	0.016	2.7	5.0	9.4	7.4	1.9	1.4
Cloransulam	0.031	2.8	6.0	7.8	7.3	1.1	1.2
Flumioxazin	0.063	3.1	0.1	11.4	9.6	2.7	3.2
Flumioxazin	0.125	4.6	0.1	7.6	9.3	1.2	2.7
Halosulfuron	0.032	3.6	5.5	4.4	6.5	0.2	0.8
Halosulfuron	0.047	7.2	7.0	2.6	5.0	0.1	0.7
Isoxaben	0.500	0.7	0.1	9.9	8.7	2.1	2.4
Napropamide	4.000	0.8	0.1	11.0	9.8	3.1	3.5
Rimsulfuron	0.016	1.8	6.5	6.5	7.8	1.0	1.4
Rimsulfuron	0.031	5.1	7.8	3.6	5.0	0.2	0.4
SAN 582	0.940	1.6	0.0	7.3	9.7	1.3	3.0
SAN 582	1.200	0.8	0.2	8.1	7.9	1.1	1.7
Sulfentrazone	0.175	0.4	0.1	13.3	9.6	3.3	3.1
Sulfentrazone	0.250	0.3	0.4	13.1	10.4	3.2	3.0
Untreated	---	0.0	0.0	12.9	9.7	3.6	3.5
$LSD_{(0.05)}$		1.7	0.9	2.8	1.6	1.1	0.8

[z]Visually assessed crop injury scale of 0 to 10; 0 = no symptoms, 10 = plant death.
[y]Plant diameter = average of plant width measurements taken parallel and perpendicular to the row orientation for five plants in each plot; 1.0 inch = 2.54 cm.
[x]Fresh weight = above ground fresh weight from 10 ft (3.0 m) of row; 1.0 lb = 0.454 kg.
[w]DAT = days after transplanting.
[v]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

Table 4. Crop injury ratings, plant diameter measurements and fresh weight for 'Selva' strawberry treated with herbicides applied 3 weeks after transplanting.

		Crop injury[z]		Diam (inches)[y]		Fresh wt (lb)[x]	
		DAT[w]					
	Rate	47	50	153	161	181	183
Treatment	(lb/acre)[v]	1999	2000	1999	2000	1999	2000
Carfentrazone	0.010	3.8	0.3	13.9	9.6	4.7	2.9
Carfentrazone	0.030	6.6	0.6	11.9	9.3	3.6	3.0
Cloransulam	0.008	1.3	0.9	8.7	8.7	1.8	2.7
Cloransulam	0.016	2.3	0.9	5.1	8.9	0.7	2.3
Halosulfuron	0.032	1.6	2.0	7.0	8.3	1.3	2.5
Halosulfuron	0.047	2.1	2.8	6.9	6.7	0.9	1.4
Imazamox	0.032	1.3	2.3	5.8	9.2	0.5	2.0
Imazamox	0.040	2.3	2.8	4.6	9.1	0.5	2.1
Isoxaben	0.250	0.5	0.0	11.5	9.6	2.9	3.5
Rimsulfuron	0.031	1.8	1.5	5.7	6.9	0.8	1.9
SAN 582	1.500	1.6	0.0	6.9	9.8	1.1	3.0
Sulfentrazone	0.150	4.6	0.1	12.9	9.8	4.0	3.0
Sulfentrazone	0.250	7.6	1.3	11.1	9.6	2.8	3.0
Triflusulfuron	0.016	0.3	0.4	13.8	9.7	5.1	3.7
Triflusulfuron	0.031	0.3	0.6	14.2	10.2	5.1	3.6
Untreated	---	0.0	0.0	13.3	10.0	4.4	3.3
$LSD_{(0.05)}$		1.3	1.1	2.7	2.0	1.3	0.7

[z]Visually assessed crop injury scale of 0 to 10; 0 = no symptoms, 10 = plant death.
[y]Plant diameter = average of plant width measurements taken parallel and perpendicular to the row orientation for five plants in each plot; 1.0 inch = 2.54 cm.
[x]Fresh weight = above ground fresh weight from 10 ft (3.0 m) of row; 1.0 lb = 0.454 kg.
[w]DAT = days after transplanting.
[v]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

Table 5. Crop injury ratings, plant diameter measurements and fresh weight for 'Camarosa' strawberry treated with herbicides applied 3 weeks after transplanting.

		Crop injury[z]		Diam (inches)[y]		Fresh wt (lb)[x]	
		DAT[w]					
	Rate	47	50	153	161	181	183
Treatment	(lb/acre)[v]	1999	2000	1999	2000	1999	2000
Carfentrazone	0.010	6.3	1.3	10.7	9.5	2.3	2.5
Carfentrazone	0.030	7.8	2.8	11.2	9.6	2.4	2.8
Cloransulam	0.008	4.8	1.7	6.7	9.8	1.0	2.9
Cloransulam	0.016	3.6	1.8	3.9	8.6	0.3	1.9
Halosulfuron	0.032	3.3	2.6	5.7	7.9	0.6	1.7
Halosulfuron	0.047	4.6	3.6	4.4	5.6	0.3	0.5
Imazamox	0.032	4.3	2.3	5.8	8.4	0.6	1.8
Imazamox	0.040	2.8	2.8	6.0	7.4	0.7	1.6
Isoxaben	0.250	0.3	0.1	11.7	8.7	2.9	2.8
Rimsulfuron	0.031	3.6	2.3	3.9	5.6	0.3	0.9
SAN 582	1.500	2.6	0.0	5.9	9.1	0.7	2.6
Sulfentrazone	0.150	6.6	0.7	11.9	9.6	2.7	3.1
Sulfentrazone	0.250	8.1	2.8	9.9	9.3	1.9	2.4
Triflusulfuron	0.016	1.6	0.2	12.6	10.2	3.3	3.3
Triflusulfuron	0.031	1.3	1.3	11.4	10.4	2.6	3.5
Untreated	---	0.0	0.0	12.9	9.7	3.6	3.5
$LSD_{(0.05)}$		1.7	1.5	2.6	1.9	0.7	0.7

[z]Visually assessed crop injury scale of 0 to 10; 0 = no symptoms, 10 = plant death.
[y]Plant diameter = average of plant width measurements taken parallel and perpendicular to the row orientation for five plants in each plot; 1.0 inch = 2.54 cm.
[x]Fresh weight = above ground fresh weight from 10 ft (3.0 m) of row; 1.0 lb = 0.454 kg.
[w]DAT = days after transplanting.
[v]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

and reduced 'Camarosa' plant diameter and fresh weight in 2000. This product may be safe to the crop and provide acceptable weed control at lower rates; therefore, further evaluation of isoxaben is recommended. Flumioxazin was safe for use on 'Selva' at rates up to 0.125 lb/acre, but was safe for use on 'Camarosa' only at 0.063 lb/acre. Flumioxazin may have a role in strawberry weed management, therefore further evaluation should be considered at the IPT application timing. In these studies 'Camarosa' was generally more susceptible to herbicide injury than 'Selva'. It is possible that 'Camarosa' was not as well adapted to the growing conditions at the northern California trial site since it is predominately a southern California cultivar.

CROP TOLERANCE TO DPT HERBICIDE APPLICATIONS. Triflusulfuron at 0.016 and 0.031 lb/acre (0.017 and 0.035 $kg \cdot ha^{-1}$) was the only herbicide treatment applied DPT that resulted in crop injury ratings <2.0 and did not reduce stand, plant diameter, or fresh weight in 'Selva' (Table 4). Similarly, triflusulfuron at 0.016 lb/acre was the only herbicide treatment applied DPT that resulted in crop injury levels <2.0 and no stand, diameter, or fresh weight reduction in 'Camarosa' (Table 5). Delayed posttransplant applications of carfentrazone, cloransulam, halosulfuron, imazamox, isoxaben, rimsulfuron, SAN 582, and sulfentrazone resulted in crop injury ratings >2.0, or significant reductions in plant diameter or fresh weight on both cultivars. As a result, no further evaluation of these compounds at the DPT timing is recommended in strawberry.

WEED CONTROL. The field sites were fumigated with chloropicrin both years, and as a result overall weed pressure was light to moderate. Weed density counts were taken both years, but were too low in 1999 to provide meaningful differences among treatments. In 2000, moderate populations of bur clover and shepherd's purse infested the trial site. Weed densities are reported for the 2 Feb. (85 DAT) rating in 2000. Weed control resulting from the IPT treatments was entirely preemergence activity since there were no weeds present at the time of application. Immediate posttransplant treatments that significantly reduced bur clover densities below those of the untreated checks were flumioxazin at 0.063 and 0.125 lb/acre, halosulfuron at 0.047 lb/acre (0.053 $kg \cdot ha^{-1}$), isoxaben at 0.5 lb/acre, napropamide at 4.0 lb/acre, rimsulfuron at 0.016 and 0.031 lb/acre, SAN 582 at 0.94 and 1.2 lb/acre (1.05 and 1.35 $kg \cdot ha^{-1}$), and sulfentrazone at 0.175 and 0.25 lb/acre (Table 6). All IPT treatments reduced shepherd's purse densities compared to the untreated check. Delayed posttransplant treatments halosulfuron at 0.047 lb/acre, rimsulfuron at 0.031 lb/acre, SAN 582 at 1.5 lb/acre (1.7 $kg \cdot ha^{-1}$), and sulfentrazone at 0.25 lb/acre reduced bur clover densities relative to the untreated check (Table 7). All DPT treatments reduced shepherd's purse den-

Table 6. Bur clover and shepherd's purse densities resulting from herbicide applications made immediately after transplanting.

		Weed density (no./10 ft^2)[z]	
Treatment	Rate (lb/acre)[y]	Bur clover	Shepherd's purse
Carfentrazone	0.075	2.1	0.5
Carfentrazone	0.150	4.5	0.0
Cloransulam	0.016	2.8	0.3
Cloransulam	0.031	2.3	0.0
Flumioxazin	0.063	0.5	0.0
Flumioxazin	0.125	0.0	0.0
Halosulfuron	0.032	2.3	0.0
Halosulfuron	0.047	0.3	0.0
Isoxaben	0.500	0.3	0.0
Napropamide	4.000	0.3	0.0
Rimsulfuron	0.016	0.3	0.9
Rimsulfuron	0.031	0.3	0.0
SAN 582	0.940	1.7	0.0
SAN 582	1.200	2.1	0.5
Sulfentrazone	0.175	1.7	0.3
Sulfentrazone	0.250	2.1	0.7
Untreated	---	4.2	9.6
$LSD_{(0.05)}$		2.1	2.0

[z]Weed densities were measured 2 Feb. 2000; 1.0 weed/10 ft^2 = 10.76 weeds/m^2.
[y]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

Table 7. Bur clover and shepherd's purse densities resulting from herbicide applications made 3 weeks after transplanting.

		Weed density (no./10 ft^2)[z]	
Treatment	Rate (lb/acre)[y]	Bur clover	Shepherd's purse
Carfentrazone	0.010	3.5	0.5
Carfentrazone	0.030	3.1	0.0
Cloransulam	0.008	5.9	0.5
Cloransulam	0.016	1.9	0.5
Halosulfuron	0.032	1.9	0.7
Halosulfuron	0.047	0.0	0.0
Imazamox	0.032	5.4	0.3
Imazamox	0.040	3.3	0.3
Isoxaben	0.250	1.7	1.7
Rimsulfuron	0.031	0.0	0.3
SAN 582	1.500	0.5	2.8
Sulfentrazone	0.150	4.0	0.3
Sulfentrazone	0.250	0.7	0.3
Triflusulfuron	0.016	4.0	3.3
Triflusulfuron	0.031	3.7	3.1
Untreated	---	4.2	9.6
$LSD_{(0.05)}$		2.8	3.2

[z]Weed densities were measured 2 Feb. 2000; 1.0 weed/10 ft^2 = 10.76 weeds/m^2.
[y]1.000 lb/acre = 1.1208 $kg \cdot ha^{-1}$.

sities compared to the untreated check in 2000. We assume that the DPT weed control activity was a combination of postemergence and preemergence activity, since weeds were present at the time of application, and additional weed emergence occurred between time of application and the time of the weed density counts.

Conclusions and recommendations

Herbicides applied IPT that were considered to be safe, irrespective of strawberry cultivar, included carfentrazone at 0.075 and 0.15 lb/acre, sulfentrazone at 0.175 and 0.25 lb/acre, flumioxazin at 0.063 lb/acre, and the industry standard, napropamide, at 4.0 lb/acre. Strawberry was less tolerant of herbicide applications made DPT than of applications made IPT; triflusulfuron at 0.016 lb/acre was the only DPT treatment that both cultivars tolerated. We assume that because the strawberry plants were dormant at the IPT timing, they were more tolerant of herbicides than when actively growing at the DPT timing. The differences in selectivity between 'Selva' and 'Camarosa' to many of the treatments tested here indicates that the crop safety of any herbicide should be verified by testing on many strawberry cultivars. Triflusulfuron demonstrated relatively weak activity on bur clover and shepherd's purse compared to many of the other herbicides (Table 7). Care must be taken in future evaluations to determine if triflusulfuron can provide a useful level of weed control for strawberry. Sulfentrazone at 0.25 lb/acre applied immediate posttransplant appeared to provide the best combination of crop safety and weed control in strawberry and should be evaluated further.

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Rapid Equilibration of Leaf and Stem Water Potential under Field Conditions in Almonds, Walnuts, and Prunes

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Summary. Covering a plant leaf with a reflective, water impervious bag ensures that equilibrium is reached between the nontranspiring leaf and the stem, and appears to improve the accuracy of determining plant water status under field conditions. However, the inconvenience of covering the leaf for 1 to 2 hours before measuring stem water potential (SWP) has constrained on-farm adoption of this irrigation management technique. A second constraint has been that the requirement of midafternoon determinations limits the area that can be monitored by one person with a pressure chamber. This paper reports findings from field studies in almonds (*Prunus dulcis*),

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