Herbicidal Efficacy Testing, Crop Safety Evaluations, and Glyphosate-Resistant Weed Management in Central Valley Almond Orchards

Project No.: **12-HORT12-Hanson**

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Objectives:

The overall goals of the tree and vine weed science research and extension program at UC Davis (http://ucanr.org/brad.hanson) is to provide information on weed management and herbicide issues to California growers, Pest Control Advisors, and the UC Cooperative Extension network. The almond industry is one of the key stakeholder groups for this program; however, the majority of our research is broadly applicable to, and partially supported by, other orchard and vineyard commodities in the state as well as the pest control industry.

The objectives proposed for the 2012-13 Almond Board of California fiscal year mirror the major research areas in our program:

1. Evaluation and testing of herbicides, tank mixes, and application techniques with a focus on glyphosate-resistant weeds in almond orchards
2. Evaluation of herbicide injury symptoms in almond orchards and developing training tools for Farm Advisors, and pest control industry advisors and consultants
3. Support of orchard replant disease management research

Interpretive Summary:

Note: 1) Figure 1 cross references herbicide tradenames with common names;
2) DAT = Days After Treatment

Weed management issues such as new weeds, herbicide resistance, crop injury, and changing pesticide regulations significantly impact orchard cropping systems. Rapid and accurate responses depend on having an experienced research team with direct knowledge of weed control tactics used in each crop. The broad weed management research partially supported by this Almond Board of California project provides direct and practical benefits to almond producers, pest control advisors, county-based cooperative extension advisors, as well as related orchard and nursery industries.

Our statewide research and extension program is designed to balance the solutions-based research needs of orchardists and the crop protection industry with the need to develop an understanding of biological principles that impact weeds and weed control in these cropping systems. Results are routinely disseminated through conventional outreach venues such as the annual Almond Industry Conference and the UC Cooperative Extension network as well as online resources like the Weed Research and Information Center (www.wric.ucdavs.edu) and the UC Weed Science blog (http://ucanr.edu/blogs/UCDWeedScience/index.cfm).

Materials and Methods:

Herbicide efficacy: We conducted approximately 50 herbicide efficacy trials in commercial orchards or at research stations in FY2012-13-13, the majority of which were in almonds and other tree nuts. In order to address differences in weeds, soil conditions, and production practices, orchard trials ranged from Colusa to Kern Co during this reporting period. Herbicides in the small-plot experiments generally were applied using CO2 pressurized backpack sprayers while treatments in several large-plot experiments were treated with an ATV mounted research sprayer. In the small plot trial, plots were usually 7 ft wide (strips) by 20-40 ft long and replicated four times. In the large plot trials, plots were 7 ft wide and 100-250 ft long replicated three times. In most field trials, visual weed control evaluations were made at approximately monthly intervals during the season. In a few specific trials, quantitative weed count and biomass data also were collected.

Herbicide efficacy treatments focused on residual herbicide comparisons and on POST control of key weeds including glyphosate-resistant hairy fleabane and junglerice. Other common orchard weeds including yellow nutsedge, mallow, and cutleaf evening primrose among others were also evaluated.

Several greenhouse trials were conducted in support of this project as well. Some of the herbicide-resistant hairy fleabane and junglerice work was tested in the greenhouse before validation in subsequent field experiments. Suspected glyphosate resistant species were also subjected to dose-response testing in the greenhouse to evaluate the level of tolerance/resistance in populations from field-collected seed. One example includes three spike goosegrass from the Merced area. In this experiment, seed was collected from an almond orchard, and greenhouse grown seedlings were treated with one of 8 doses of glyphosate ranging from 1/8x to 16x (1x = 1 lb ae/A) at either the 2-tiller or 15-tiller growth stage to document glyphosate performance on this difficult species. Similar methods are being used for other species as needed.

A related weed biology line of research was initiated in this reporting period primarily with support from the CA Pistachio Research Board. This project is intended to evaluate the effect of summer “preharvest” herbicide applications on reproductive capacity of hairy fleabane. In this project, hairy fleabane plants of various growth stages were treated with glyphosate, glufosinate, paraquat, saflufenacil using a greenhouse track sprayer. Data collection includes plant mortality, biomass reduction, and reproductive output (flower and seedhead production). These experiments are ongoing.

Crop safety experiments: Several research and demonstration experiments are underway to address herbicide injury questions from the almond industry and UCCE Farm Advisors. We plan to continue and modify these experiments as needed to address real or perceived evolving issues with herbicide safety in tree crops.

Herbicide symptomology demonstrations were conducted on young almond trees at the Nickels Soil Lab near Arbuckle, CA. Research personnel applied simulated drift rates of glyphosate, glufosinate, penoxsulam, oxyfluorfen, simazine, and other herbicides directly to the almond foliage. Rates included 20%, 10%, and 5% of nominal use rates. Short-term injury, long term growth reductions, and a symptomology photo set are being developed to assist in answering industry questions on accidental injury to almond orchards. Related research is planned in the future for root exposure to similar herbicides.

Two glufosinate (Rely 280) field trials initiated in FY2011 were treated in Fall 2012 and summer 2013. In this trial, almond nursery stock (Nonpareil, Sonora, Aldrich) on Lovell rootstock was planted at the Nickels Soil Lab near Arbuckle. Treatments in the original experiment included various concentrations, tank mix partners, and application rates. In a related experiment, glufosinate rate and spray application volume were tested. All treatments were applied by research personnel using CO2 pressurized back pack spray equipment in September 2012 and the plots were retreated in July 2013.

With the support of the Almond Board of California, Bayer Crop Sciences, and the Western Society of Weed Science, an additional laboratory experiment was conducted in summer and fall 2012 to determine the absorption and translocation characteristics of glufosinate (Rely 280) relative to glyphosate in young almond trees. In this experiment, radiolabeled (14C) herbicides were applied to leaf tissue, green bark or brown bark of potted almond nursery stock. Plants were destructively harvested 1, 3, or 7 days after treatment. Plant material was dried in an oven, combusted in a biological oxidizer, and radioactivity in each sample determined using liquid scintillation spectrometry. The relative amount of absorbed and translocated radioactivity was used as a proxy for absorbed and translocated glufosinate or glyphosate.

For future crop safety and efficacy testing, a new experimental orchard was established in 2013. These projects are supported by Sierra Gold Nurseries, the Almond Board of California and the California Dried Plum Board. Approximately 250 almond trees (Nonpareil and Aldrich) were planted in conventional spacing at the UC Davis pomology farm. Additionally, 36 almond trees and 26 prune trees were planted in double-density rows; half of these trees are planted in a very sandy soil imported from Merced County and half in native Yolo County soil for use in future herbicide leaching studies.

Orchard replant disease management. A minor objective in the FY2012-13-13 weed control proposal was to continue support of the almond replant disease management projects. The Almond Board of California provided the initial support for a non-fumigant soil disinfestation project; this funding was used to leverage additional research funds from EPA Region 9 and the CDFA Specialty Crop Block Grant Program to conduct four almond replant trials in the

Delhi, Livingston, Atwater, and Wasco areas. The steam treatments were also compared to traditional fumigant-based replant disease management in projects led by David Doll and Greg Browne and more details are available in their reports (12-Air9-Doll and 12-Path1-Browne).

Results and Discussion:

Because of the number of almond-related projects conducted and the diverse funding that supported this research, only a portion of the FY2012-13-13 weed science research will be presented and discussed. The selected data that follows present some of the most relevant results and reflect the breadth of our program that is partially supported by the Almond Board of California.

Label changes: Few major herbicide registration changes were made in FY2012-13 that affect almond (**Figure 1**). The preemergence material isoxaben (Gallery) was rebranded as Trellis recently. The new Trellis label allows use in bearing almonds whereas the old label was non-bearing only. Pyraflufen (Venue) had a label change and can now be used any time of the year, not just prior to flowering. While not a label change, glufosinate (Rely 280) has been in very short supply this season. This shortage is directly due to glyphosate-resistant weeds in other cropping systems (glufosinate is also sold as Ignite and Liberty and used in Liberty Link cotton, corn, and other crops). Bayer Crop Sciences and other manufacturers are optimistic that this shortfall will be alleviated in California by FY2014.

Residual herbicides: Several trials were conducted to compare POST programs to PRE programs and focused on products with various modes of action including penoxsulam/oxyfluorfen (Pindar GT), indaziflam (Alion), flumioxazin (Chateau), isoxaben (Trellis), pendimethalin (Prowl H2O), among others. With effective burndown partners, most of the residual products provided good residual control of broadleaf weeds in a 2011-12 Delhi trial especially glyphosate-resistant hairy fleabane (**Figure 2**).

In a series of large- and small-plot demonstration experiments, residual herbicides (plus glyphosate) provided good control of most weeds at a UC Davis site (**Table 1**). At a walnut orchard site near Davis, Pindar GT and Matrix + Prowl controlled lambsquarters other summer weeds most consistently but all treatments were variable in controlling ryegrass and hairyfleabane. At a Wasco site dominated by glyphosate-resistant junglerice, only glyphosate alone, Chateau, and Trellis did not provide acceptable residual control of junglerice. At the Delhi site, split treatments of glyphosate (alone or with a partner) provided quite good control and, of the residual materials, Matrix plus Prowl was quite effective on the mixed weed population that included hairy fleabane, evening primrose, and a mix of other grasses and broadleaf weeds.

Various tankmix and sequential applications of Matrix and Alion were tested in several orchards and compared to Pindar GT (**Tables 2** and **3**). Tank mixes and sequential applications usually were better than either product alone (**Table 2**). By 116 DAT, both sequential applications (with glyphosate) still had nearly perfect weed control. At the Wasco site with glyphosate resistant junglerice, Matrix alone (4 oz), Alion alone (5 oz), and Pindar GT at 2.5 pt/A started to lose some efficacy by 86 DAT(**Table 3**). However, all treatment combinations completely controlled a light population of prostrate knotweed.

Two experiments were conducted to evaluate rate combinations and sequential applications of Pindar GT plus Prowl H2O (**Tables 4** and **5**). At the Wheatland site, all treatments included Gramoxone as a burndown partner due to the age of the trees and control of California burclover, filaree and other tough weeds was moderate due to regrowth of the weeds present at application but tended to be better with the split applications due to an extra burn down treatment (**Table 4**). Weed control was better with all treatments at the Delhi site due to the glyphosate tank mix partner and the weed size at application (**Table 5**). In general, the higher rate of Pindar GT (3 pt/A) sustained weed control longer than 2.5 pt regardless of Prowl or Surflan rates; however this site had few summer grasses or broad leaves that would likely be affected by those herbicides.

Post emergence herbicides: An experiment conducted in Delhi to evaluate yellow nutsedge control suggested that repeated applications were more effective than any single product (**Table 6**). Spray coverage (10, 20, or 40 GPA) made little difference in glyphosate performance in this study. A soon-to-be-registered glufosinate formulation had similar activity to Rely 280 in this trial. Total nutsedge tubers were reduced by most of the herbicide treatments except for glyphosate + Goal and the two glufosinate treatments. Tuber viability tests are currently underway in the greenhouse.

A trial to evaluate GoalTender plus “kickers” in comparison to Goal 2XL was conducted near Wheatland (**Table 7**). At this site, the GoalTender plus glyphosate treatments performed similarly to glyphosate plus Goal 2XL on the weed spectrum present. Of the treatments that did not contain glyphosate, only Gramoxone plust GoalTender provided acceptable control of these weeds which suggests challenges in sites with glyphosate resistant weeds. Partially based on the results of these types of experiments, CDPR decided to grant a low-rate (up to 0.125 lb/A) exemption to the proposed ban on high VOC oxyfluorfen formulations during the summer season for burn down treatments in orchards.

A similar burndown trial was conducted in an orchard with a dense mallow population (**Table 8**). In this experiment, additional treatments that included low rates of PRE herbicides were added as well as a few additional POST materials. Although mallow control was moderate with most treatments several combinations provided numerically better mallow control than the glyphosate + oxyfluorfen treatment (**Table 8**).

In recent years, many growers and advisors have commented on growing problems with three spike goosegrass, particularly in the Merced area. Three spike goosegrass plants that survived several glyphosate applications in 2012 were dug up and grown to maturity in UC Davis greenhouse. Seed from these plants were collected and the resulting seedlings subjected to a range of glyphosate doses (**Figure 3**). Plants treated at the 2-tiller stage survived up to a 2x rate and but when treated a few weeks later at the 15-tiller stage they survived up to 16x! Clearly, this species is quite tolerant (or resistant) to glyphosate. Additional greenhouse and field trials will be conducted to develop information on alternative strategies for this weed.

Hairy fleabane: A key orchard weed and a focus of our program is glyphosate-resistant hairy fleabane. We identified a glyphosate and paraquat-resistant population several years ago

(Moretti et al. 2013) and have continued greenhouse and field studies on this issue. Greenhouse trials in 2012 indicated that glufosinate (Rely 280) and saflufenacil (Treevix) provided the best control of both resistant and susceptible hairy fleabane as solo products (**Figure 4**). However, several tank mix partners with glyphosate also provided acceptable control of the resistant biotype. In a subsequent field experiment, Treevix and Rely 280 along with Gramoxone, 2,4-D, and a low rate of Chateau controlled glyphosate-resistant fleabane well (**Figure 5**).

Following up on earlier greenhouse work at Fresno State University and UC Davis by Moretti et al., we conducted our first field evaluation of glyphosate-paraquat resistant fleabane in an almond orchard in Merced County. The strips in this orchard had been treated at least once with glyphosate and twice with Gramoxone, leaving only hairy fleabane. Rely 280, Treevix, and 2,4-D provided complete control of this population 14 DAT (**Table 9**). This work is ongoing and will be repeated.

One of the least understood parts of orchard weed lifecycles is the seed and seedbank. A new project was started in 2012 to help understand the effects of preharvest POST herbicide applications on the reproductive capacity and seed viability of hairy fleabane. Herbicides were applied at rates intended to not quite kill hairy fleabane to mimic the often poor success of these treatments that often only facilitate harvest rather than reduce seed set in orchard. In general, earlier (although still too late) applications had a much greater reduction on hairy fleabane flower and seed head production (**Figure 6**). Averaged over herbicides, treating already flowering plants resulted in plants still able to produce up to 350 flowers per plant. Among the herbicides, glyphosate, glufosinate, paraquat, and saflufenacil reduced seed head production similarly (**Figure 7**) but there was a substantial size by herbicide interaction that is still being evaluated. Additionally, some of the treatments appeared to result in malformed seed heads and it is not known of the seed from those flowers are fully viable. This seed and seedbank work is expected to continue for several years.

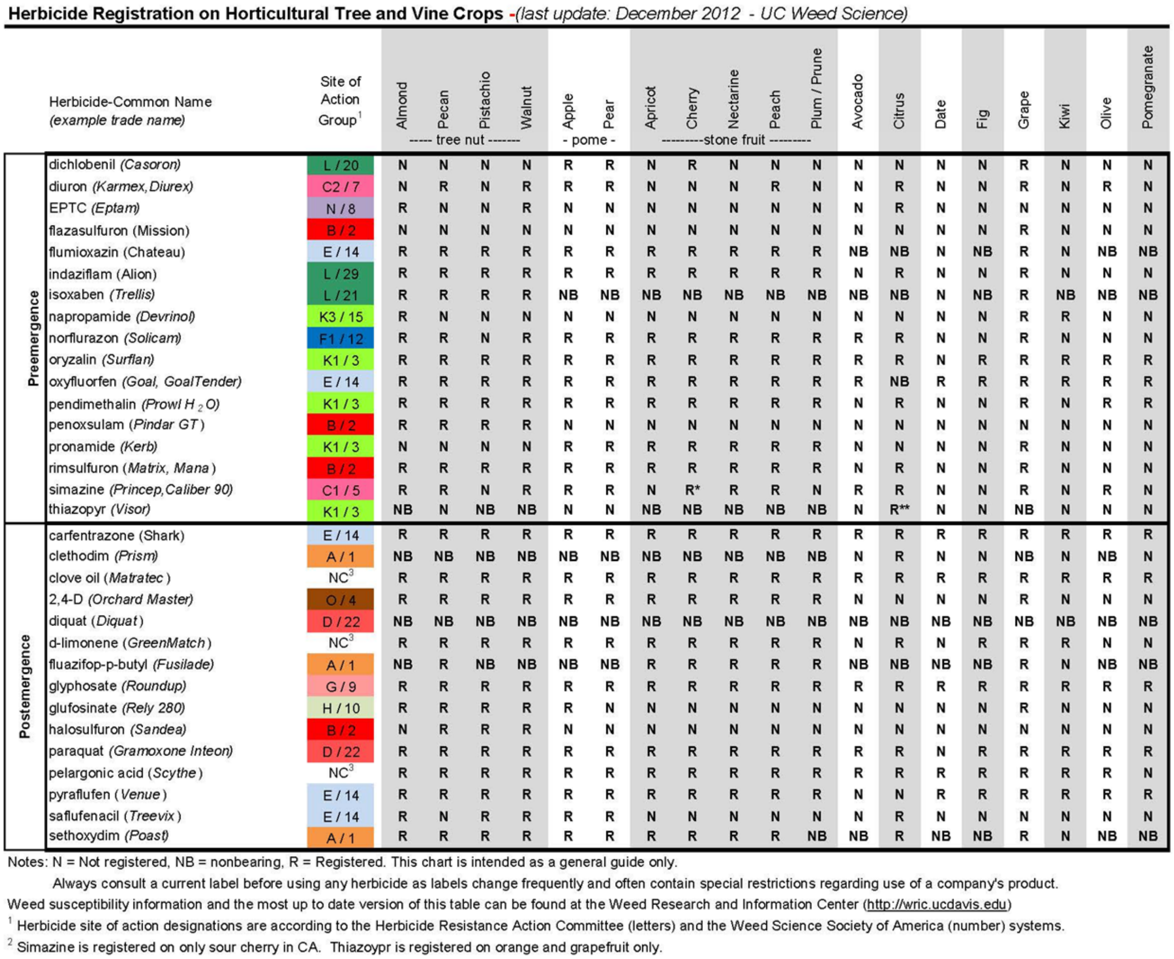
Junglerice: Echinochloa colona, or junglerice, is another key glyphosate-resistant weed in orchards. This was first reported a couple years ago and appears to be fairly widespread. We've tested populations from Butte to Kern Co and found some levels of resistance and possibly more than one mechanisms of resistance (data not known). In a 2012 greenhouse experiment, both glyphosate-susceptible and –resistant junglerice was controlled with the Group 1 herbicides (Fusilade, Poast, Select, etc.) (**Figure 8**). Matrix, Rely 280, and Gramoxone all also worked similarly on both biotypes. Two field studies were conducted in 2013 to validate these results. In an almond site near Discovery Bay (glyphosate susceptible junglerice), Roundup and Matrix plus Roundup provided the best control (**Figure 9**). The Group 1 herbicides were not included in this study due to label limitations (bearing and too close to PHI). However, in the trial conducted near Wasco on glyphosate-resistant junglerice population, Roundup plus Matrix, Matrix alone, Fusilade, Envoy, and Poast all provided at least 90% control of the resistant population (**Table 10**).

Crop injury: Crop injury experiments during this fiscal year period focused on suspected glufosinate injury to the trunks of young almond trees reported several years ago. An undergraduate student conducted an herbicide uptake and translocation experiment using radiolabeled glufosinate and glyphosate and presented the results at several scientific meetings (**Figures 10** and **11**). In general, glufosinate absorption from leaf tissue was higher with glufosinate than with glyphosate (41 vs 32%) but more of the absorbed glyphosate moved out of the treated leaf (62%) (**Figure 11**). When applied to green bark, absorption was similar for the herbicides (43-45%) but translocation was much greater for glyphosate (62%) than for glufosinate (37%). When applied to the most mature bark on the almond rootstock, absorption was greater for glyphosate (94%) than for glufosinate (65%) but translocation out of the treated zone was similar (11-13%) for both. These results suggest that glufosinate can translocate more than expected; however, at this point it is not known if the detected ratioactivity is in the form of the parent herbicide or a metabolite and additional work is need if this is to be clarified.

A glufosinate rate response and spray coverage experiment was conducted at the Nickels Soil Lab near Arbuckle, CA on second leaf almond trees (Aldrich on Lovell). Treatments were applied in September 2012 to the lower 18 inches of the scion and included the graft union. Injury (trunk gumming on a 0-5 scale) was rated 28 and 56 DAT. Although there was a clear rate response, all glufosinate treatments resulted in minor to moderate gumming (0.3 to 2.7 on the 5-point scale) by the 28 DAT rating (**Table 11**). By the 56 DAT rating, injury symptoms had nearly disappeared from the 1x rate (1.5 lb/A) but was still evident with the 2x and 4x treatments. Trunk diameter during the following winter was not different among glufosinate treatments. These treatments and growth evaluations were repeated in summer 2013.

A second glufosinate safety experiment was conducted at Nickels Soil Lab in 2012 and was repeated in 2013. In this experiment, three scion varieties (Aldrich, Nonpareil, and Sonora) were subjected to trunk or lower limb applications of glufosinate. Two glufosinate formulations (Rely 280 and the old Rely 200) were compared to their respective blank formulations in an attempt to isolate any effects of the active ingredient from the formulation. Rely 280 was also paired with several surfactants (NIS, MSO, silicon surfactant) and tank mix partners (**Table 12**). As in the previous experiment, the greatest injury was associated with the above-label rates (4x in this study) but there was not a strong effect of the formulation or inert ingredients (**Figure 12**). The highest injury rating was observed in the treatment in which the trunk was “wounded” with sandpaper prior to the glufosinate application; however, gumming injury due to physical injury could not be separated from injury caused by the herbicide. Trunk diameter during the following winter was not different among glufosinate treatments. These treatments and growth evaluations were repeated in summer 2013 and will continue through at least 2014.

Almond replant disease management: During this reporting period, our team provided support to several almond replant disease management projects associated with Almond Board of California projects led by G.T. Browne and by D.A. Doll and full details of those projects (12-PATH1-Browne and 12-AIR9-Doll) can be found in their reports. Our main efforts were related the non-fumigant steam disinfestation projects initiated in 2010 and 2011 with EPA Region 9 and CDFA funding. In the longest established trial near Delhi, various levels of steam auger treatments were compared in small plot experiments and a steam auger treatment was compared to strip- and broadcast fumigants. The steam auger marginally improved almond growth during the first two growing seasons compared to the untreated control but usually was not better than disturbance with no steam (**Figure 13**). In the large plot trials at the same site, steam was no better than the untreated control and the trees were much smaller than the fumigation treatments after 1 and 2 growing seasons (**Figure 13**, lower). The primary pest at this site is the ring nematode which may account for the poor performance of the non-fumigant treatments. While disappointing, these results highlight the serious and complex issues that can affect a long-lived crop like almond orchards.



Herbicide Registration on Horticultural Tree and Vine Crops -*(last update: December 2012 - UC Weed Science)*

	Herbicide-Common Name *(example trade name)*	Site of Action Group[1]	Almond	Pecan	Pistachio	Walnut	Apple	Pear	Apricot	Cherry	Nectarine	Peach	Plum / Prune	Avocado	Citrus	Date	Fig	Grape	Kiwi	Olive	Pomegranate
			----- tree nut -------				- pome -		---------stone fruit ---------												
Preemergence	dichlobenil *(Casoron)*	L / 20	N	N	N	N	R	R	N	R	N	N	N	N	N	N	N	R	N	N	N
	diuron *(Karmex, Diurex)*	C2 / 7	N	R	N	R	R	R	N	N	N	R	N	N	R	N	N	R	N	R	N
	EPTC *(Eptam)*	N / 8	R	N	N	R	N	N	N	N	N	N	N	N	R	N	N	N	N	N	N
	flazasulfuron (Mission)	B / 2	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	R	N	N	N
	flumioxazin (Chateau)	E / 14	R	R	R	R	R	R	R	R	R	R	R	NB	NB	N	NB	R	N	NB	NB
	indaziflam (Alion)	L / 29	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	N	N
	isoxaben *(Trellis)*	L / 21	R	R	R	R	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	NB	R	NB	NB	NB
	napropamide *(Devrinol)*	K3 / 15	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	R	R	N	N
	norflurazon *(Solicam)*	F1 / 12	R	R	N	R	R	R	R	R	R	R	R	R	R	N	N	R	N	N	N
	oryzalin *(Surflan)*	K1 / 3	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	R
	oxyfluorfen *(Goal, GoalTender)*	E / 14	R	R	R	R	R	R	R	R	R	R	R	R	NB	R	R	R	R	R	R
	pendimethalin *(Prowl H_2O)*	K1 / 3	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	R	R
	penoxsulam (*Pindar GT*)	B / 2	R	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	pronamide *(Kerb)*	K1 / 3	N	N	N	N	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	rimsulfuron (*Matrix, Mana*)	B / 2	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	N	N
	simazine *(Princep, Caliber 90)*	C1 / 5	R	R	N	R	R	R	N	R*	R	R	N	R	R	N	N	R	N	R	N
	thiazopyr *(Visor)*	K1 / 3	NB	N	NB	NB	N	N	NB	NB	NB	NB	NB	N	R**	N	N	NB	N	N	N
Postemergence	carfentrazone (Shark)	E / 14	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	clethodim *(Prism)*	A / 1	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	R	N	N	NB	N	NB	N
	clove oil (*Matratec*)	NC[3]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	2,4-D *(Orchard Master)*	O / 4	R	R	R	R	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	diquat (*Diquat*)	D / 22	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
	d-limonene (*GreenMatch*)	NC[3]	R	R	R	R	R	R	R	R	R	R	R	N	R	N	R	R	R	N	N
	fluazifop-p-butyl *(Fusilade)*	A / 1	NB	R	NB	NB	NB	NB	R	R	R	R	R	NB	NB	NB	NB	R	N	NB	NB
	glyphosate *(Roundup)*	G / 9	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	glufosinate *(Rely 280)*	H / 10	R	R	R	R	R	N	N	N	N	N	N	N	N	N	N	R	N	N	N
	halosulfuron *(Sandea)*	B / 2	N	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	paraquat *(Gramoxone Inteon)*	D / 22	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	R
	pelargonic acid (*Scythe*)	NC[3]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	N
	pyraflufen (*Venue*)	E / 14	R	R	R	R	R	R	R	R	R	R	R	N	N	R	R	R	R	R	R
	saflufenacil (*Treevix*)	E / 14	R	N	R	R	R	R	N	N	N	N	N	N	R	N	N	N	N	N	N
	sethoxydim *(Poast)*	A / 1	R	R	R	R	R	R	R	R	R	R	NB	NB	R	NB	NB	R	N	NB	NB

Notes: N = Not registered, NB = nonbearing, R = Registered. This chart is intended as a general guide only.

Always consult a current label before using any herbicide as labels change frequently and often contain special restrictions regarding use of a company's product.

Weed susceptibility information and the most up to date version of this table can be found at the Weed Research and Information Center (http://wric.ucdavis.edu)

[1] Herbicide site of action designations are according to the Herbicide Resistance Action Committee (letters) and the Weed Science Society of America (number) systems.

[2] Simazine is registered on only sour cherry in CA. Thiazoypr is registered on orange and grapefruit only.

Figure 1. Current California herbicide registrations in tree and vine crops and key to active ingredient and example trade names for orchard herbicides. The most current version of this chart can be found at http://ucanr.org/t&v-registrations (Hanson)

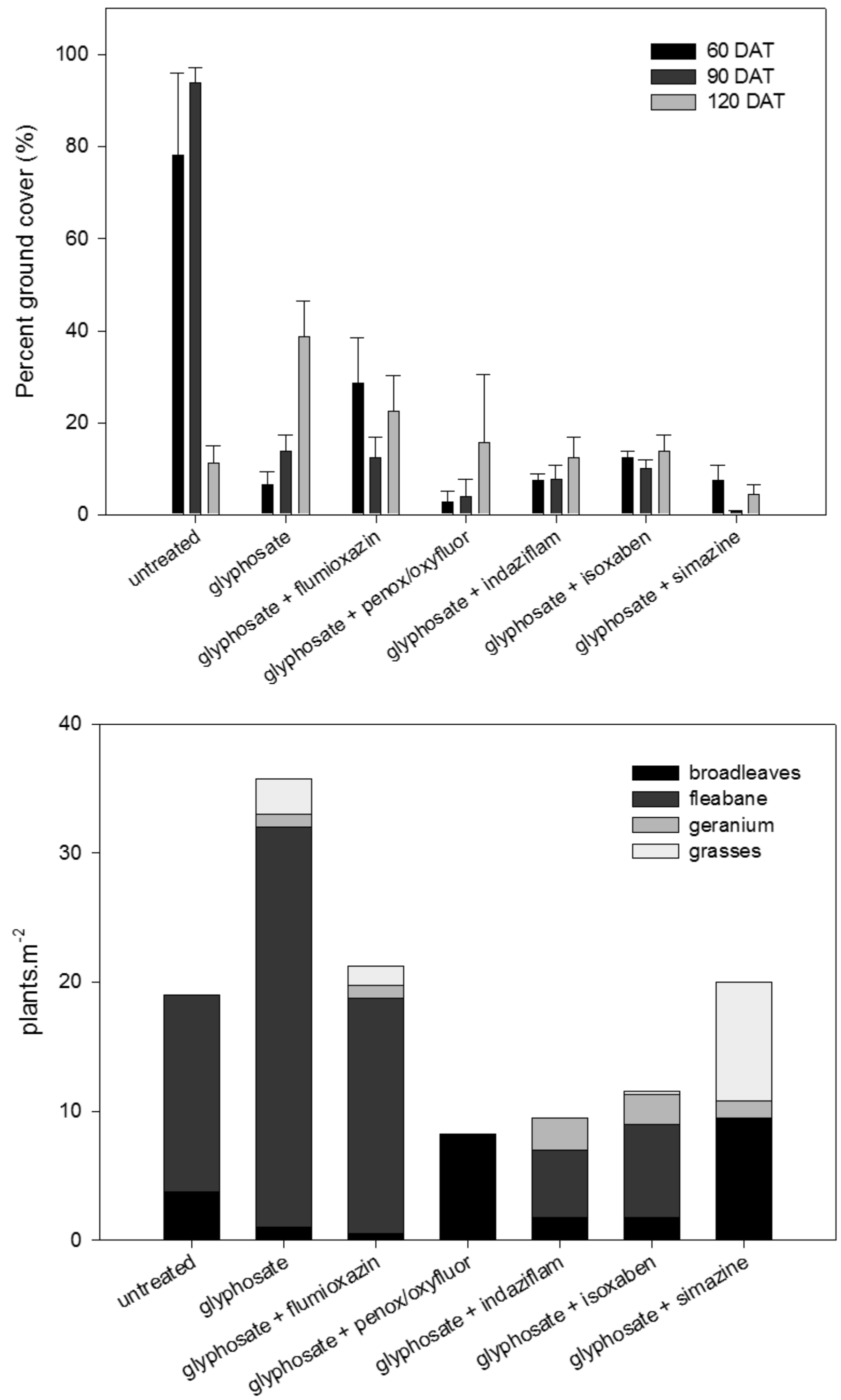


Figure 2. Residual weed control in an almond orchard trial near Delhi, CA in 2011-12. Top panel shows weed ground cover over time and the lower figure shows weed density at 120 days after treatment. Note that the untreated plots were oversprayed about 90 days after residual herbicides were applied due to excessive weed growth. (Moretti, Johnson, Hanson). (DAT = Days after Treatment).

Table 1. Selected weed control evaluations from 2012-13 statewide large plot demonstrations of orchard residual herbicides. This protocol was conducted as large plot experiments at 5 tree nut sites (Arbuckle, Wheatland, Davis, Delhi, Lost Hills) and small plot experiments at 3 sites (Davis, Sanger, Wasco). (Watkins and Hanson)

					UC Davis almond	**Davis ------------- walnut-------------**			**Wasco almond**	**Delhi ------------ almond ------------**		
					Overall control	Rye grass	Common lambs quarters	Hairy fleabane	Jungle rice	Hairy fleabane	Cutleaf evening primrose	Overall control
	Treatment	Rate			120 DAT*	122 DAT	122 DAT	122 DAT	86 DAT	95 DAT	95 DAT	95 DAT
					%	%	%	%	%	%	%	%
1	Untreated check				0 c	0 d	--	--	0 d	0 b	--	--
2	Roundup PowerMax	1	lb ae/a	A	91 a	100 a	13 b	67 ab	70 bc	99 ab	100 a	89 a
	AMS	2	qt/100 gal	A								
	Roundup PowerMax	1	lb ae/a	B								
	AMS	10	lb/100 gal	B								
3	Roundup PowerMax	1	lb ae/a	A	98 a	70 a	58 ab	50 ab	100 a	67 bcde	50 bc	60 ab
	AMS	2	qt/100 gal	A								
	Goal 2XL	5	pt/a	A								
	Surflan	4	qt/a	A								
4	Roundup PowerMax	1	lb ae/a	A	99 a	60 a	100 a	67 ab	100 a	65 bcde	47 bc	60 ab
	AMS	2	qt/100 gal	A								
	Pindar GT	3	pt/a	A								
5	Roundup PowerMax	1	lb ae/a	A	77 b	90 a	80 ab	53 ab	100 a	62 cde	40 bc	40 b
	AMS	2	qt/100 gal	A								
	Prowl H20	4	qt/a	A								
6	Roundup PowerMax	1	lb ae/a	A	99 a	77 a	13 b	53 ab	85 ab	53 de	64 bc	67 ab
	AMS	2	qt/100 gal	A								
	Chateau	10	oz/a	A								
7	Roundup PowerMax	1	lb ae/a	A	99 a	87 a	40 ab	40 b	100 a	41 e	50 bc	57 ab
	AMS	2	qt/100 gal	A								
	Prowl H20	4	qt/a	A								
	Chateau	10	oz/a	A								
8	Roundup PowerMax	1	lb ae/a	A	98 a	83 a	100 a	80 ab	100 a	94 a-d	86 ab	73 ab
	AMS	2	qt/100 gal	A								
	Prowl H20	4	qt/a	A								
	Matrix SG	4	oz/a	A								
9	Roundup PowerMax	1	lb ae/a	A	96 a	97 a	40 ab	70 ab	93 a	46 de	25 c	50 ab
	AMS	2	qt/100 gal	A								
	Alion	6.5	oz/a	A								
10	Roundup PowerMax	1	lb ae/a	A	96 a	87 a	60 ab	50 ab	55 c	47 de	13 c	37 b
	AMS	2	qt/100 gal	A								
	Trellis	1.3	lb/a	A								
11	Roundup PowerMax	1	lb ae/a	A	100 a	73 a	90 a	60 ab	100 a	96 abc	98 a	77 ab
	AMS	2	qt/100 gal	A								
	Prowl H20	3	qt/a	A								
	Roundup PowerMax	1	lb ae/a	B								
	AMS	2	qt/100 gal	B								
	Prowl H20	2	qt/a	B								
12	Roundup PowerMax	1	lb ae/a	A	100 a	83 a	100 a	90 a	100 a	100 a	100 a	92 a
	AMS	2	qt/100 gal	A								
	Pindar GT	3	pt/a	A								
	Roundup PowerMax	1	lb ae/a	B								
	AMS	2	qt/100 gal	B								
	Prowl H20	2	qt/a	B								

“A” timings were applied on December 13, 2012 at UC Davis, December 28, 2013 at Davis, January 14, 2013 at Delhi, February 6, 2013 at Wasco. “B” timings were made in mid-March 2013.
Note: the large-plot trials did not include an untreated control and, thus, had only 11 treatments.

Table 2. Effects of Alion and Matrix tank mix and sequential combinations on broadleaf weed control in an almond orchard trial near Delhi CA in a 2012-13. (Watkins and Hanson)

Trt	Treatment	Rate		Appl	Mallow 77 DAT	Cutleaf evening primrose 77 DAT	Filaree 77 DAT	Cutleaf geranium 116 DAT	Hairy fleabane 116 DAT
					-------------------------------------	% control	-------------------------------------		
1	untreated control				0	0	0	0	0
2	rimsulfuron (Matrix)	4	oz wt/a	A	99.7	94.8	82.5	75	100
3	indaziflam (Alion)	5	fl oz/a	A	90.9	81.3	72.5	70	90
4	rimsulfuron (Matrix)	4	oz wt/a	A	99.7	96.8	82.5	95	100
	indaziflam (Alion)	5	fl oz/a	A					
5	rimsulfuron (Matrix)	4	oz wt/a	A	100	92.3	75	92.5	100
	indaziflam (Alion)	2.5	fl oz/a	A					
6	rimsulfuron (Matrix)	2	oz wt/a	A	97.1	95.4	90.9	77.5	100
	indaziflam (Alion)	5	fl oz/a	A					
7	rimsulfuron (Matrix)	4	oz wt/a	A	100	100	98.8	100	100
	indaziflam (Alion)	5	fl oz/a	B					
8	indaziflam (Alion)	5	fl oz/a	A	100	100	99.3	100	100
	rimsulfuron (Matrix)	4	oz wt/a	B					
9	penox/oxyfluor (PindarGT)	2.5	pt/a	A	98.7	76.3	72.5	55	100
10	penox/oxyfluor (PindarGT)	3	pt/a	A	100	91	87.5	65	100
	Fishers LSD (0.05)				9.9	15.8	13.7	19.8	5.3

The A timing was applied on February 1, 2013 and B timing on March 25, 2013. All treatments included 1.0 lb ae/A glyphosate in the tank mix.

Table 3. Effects of Alion and Matrix tank mix and sequential combinations on broadleaf weed control in an almond orchard trial near Wasco, CA in a 2012-13. (Watkins and Hanson)

Trt	Treatment	Rate		Appl	Annual bluegrass 86 DAT	Common chickweed 86 DAT	Hairy fleabane 86 DAT	Junglerice 86 DAT	Prostrate knotweed 114 DAT	Junglerice 114 DAT
					----------------	----------------	---------------- % control	----------------	----------------	----------------
1	untreated control				0	0	0	0	0	0
2	rimsulfuron (Matrix)	4	oz wt/a	A	100	100	100	57.5	100	47.5
3	indaziflam (Alion)	5	fl oz/a	A	100	100	100	85	100	77.5
4	rimsulfuron (Matrix) indaziflam (Alion)	4 5	oz wt/a fl oz/a	A A	100	100	100	92.5	100	84.3
5	rimsulfuron (Matrix) indaziflam (Alion)	4 2.5	oz wt/a fl oz/a	A A	100	100	99.7	87.5	100	67.5
6	rimsulfuron (Matrix) indaziflam (Alion)	2 5	oz wt/a fl oz/a	A A	93.8	100	99.7	92.5	100	81.3
7	rimsulfuron (Matrix) indaziflam (Alion)	4 5	oz wt/a fl oz/a	A B	100	100	99.7	100	100	93.8
8	indaziflam (Alion) rimsulfuron (Matrix)	5 4	fl oz/a oz wt/a	A B	100	100	100	92.5	100	72
9	penox/oxyfluor (PindarGT)	2.5	pt/a	A	85	100	100	85	100	63.8
10	penox/oxyfluor (PindarGT)	3	pt/a	A	77.5	98.8	100	100	100	100
	Fishers LSD (0.05)				4.2	1.2	0.1	2.5	0	30.4

The A timing was applied on February 1, 2013 and B timing on March 25, 2013. All treatments included 1.0 lb ae/A glyphosate in the tank mix. Site was dominated by glyphosate-resistant junglerice.

Table 4. Residual weed control tankmix and sequential applications of PindarGTand Prowl H2O or Surflan in a young walnut orchard near Wheatland CA in 2012-13. All treatments included Gramoxone SL as a burndown partner at this site. (Watkins and Hanson)

					Shepherd's purse	Calif. Burclover	Filaree	Shepherd's purse	Calif. Burclover	Filaree	Hairy fleabane	Ryegrass
		Rate		Applic.	34 DAT	34 DAT	34 DAT	69 DAT	69 DAT	69 DAT	103 DAT	103 DAT
					-- % control --							
1	Untreated			A	0	0	0	0	0	0	0	0
2	PINDAR GT	2	pt/a	A	100	77.5	100	70	37.5	100	70	75
	Prowl H2O	2	qt/a	A								
3	PINDAR GT	2	pt/a	A	96.3	77.5	95	65	35	77.5	85	40
	Prowl H2O	3	qt/a	A								
4	PINDAR GT	2	pt/a	A	97.5	70	65	57.5	32.5	57.5	80	75
	Prowl H2O	2	qt/a	B								
5	PINDAR GT	2	pt/a	A	100	65	85	50	32.5	80	82.5	100
	Prowl H2O	3	qt/a	B								
6	PINDAR GT	3	pt/a	A	97.5	83.8	100	75	55	85	75	27.5
	Prowl H2O	2	qt/a	A								
7	PINDAR GT	3	pt/a	A	100	86.3	100	77.5	60	95	77.5	62.5
	Prowl H2O	3	qt/a	A								
8	PINDAR GT	3	pt/a	A	100	83.8	100	75	50	100	75	87.5
	Prowl H2O	2	qt/a	B								
9	PINDAR GT	3	pt/a	A	100	83.8	100	70	50	100	85	90
	Prowl H2O	3	qt/a	B								
10	PINDAR GT	3	pt/a	A	75	65	75	55	47.5	75	55	35
	SURFLAN A.S.	3	qt/a	A								
11	PINDAR GT	3	pt/a	A	100	80	90	65	42.5	85	67.5	100
	SURFLAN A.S.	3	qt/a	B								
	Fishers LSD (0.05)				22.3	23.6	30.0	30.9	21.3	40.1	37.4	42.5

The A timing was applied January 18, 2013 and the B timing was applied on April 3, 2013.
All treatments included 1.25 pt/A Gramoxone SL and 1% v/v methylated seed oil for POST control of emerged weeds.

Table 5. Residual weed control tankmix and sequential applications of PindarGTand Prowl H2O or Surflan in an almond orchard near Delhi, CA in 2012-13. All treatments included Roundup PowerMax as a burndown partner at this site. (Watkins and Hanson)

				Cutleaf evening primrose	Cheeseweed mallow	Hairy fleabane	Filaree	Brome	Overall control	Overall control
		Rate	Applic.	77 DAT	77 DAT	77 DAT	77 DAT	77 DAT	77 DAT	116 DAT
				% control						
1	UNTREATED		A	0	0	0	0	0	0	0
2	PINDAR GT	2 pt/a	A							
	Prowl H2O	2 qt/a	A	94.8	100	100	92.5	100	88.3	63.3
3	PINDAR GT	2 pt/a	A							
	Prowl H2O	3 qt/a	A	86.8	96.3	100	74.3	100	53.3	56.7
4	PINDAR GT	2 pt/a	A							
	Prowl H2O	2 qt/a	B	97.6	100	100	73.8	100	76.7	63.3
5	PINDAR GT	2 pt/a	A							
	Prowl H2O	3 qt/a	B	92.5	96.7	98.3	89.1	100	88.3	63.3
6	PINDAR GT	3 pt/a	A							
	Prowl H2O	2 qt/a	A	84.3	100	100	86.3	100	85	60
7	PINDAR GT	3 pt/a	A							
	Prowl H2O	3 qt/a	A	100	100	100	99.9	100	98	80
8	PINDAR GT	3 pt/a	A							
	Prowl H2O	2 qt/a	B	99.4	100	100	99.4	100	97.3	80
9	PINDAR GT	3 pt/a	A							
	Prowl H2O	3 qt/a	B	99.6	100	98.3	97.6	100	93.3	76.7
10	PINDAR GT	3 pt/a	A	100	100	100	100	100	98	76.7
	SURFLAN A.S.	3 qt/a	A							
11	PINDAR GT	3 pt/a	A	100	100	100	100	100	98	81.7
	SURFLAN A.S.	3 qt/a	B							
	Fishers LSD (0.05)			9.2	4.2	2.2	14.2	0	26.5	13.9

The A timing was applied February 1, 2013 and the B timing was applied on March 25, 2013.
All treatments included 1.125 qt/A Roundup PowerMax and 1 qt/A Crop Oil Concentrate for POST control of emerged weeds.

Table 6. Effects of POST herbicides on cutleaf evening primrose and yellow nutsedge in an almond orchard trial near Delhi, CA in 2013. (Moretti and Hanson)

						Cutleaf evening primrose	Yellow nutsedge					
		GPA	Rate		Timing	Control 28 DAT	Control 28 DAT	Control 56 DAT	Plant density	Large tubers	Small tubers	Total tubers
Trt	Treatment					%	%	%	#/sq m	-- # / 4 inch dia x 6 inch deep --		
1	UTC					0.0	0.0	0.0	51.2	6.5	32.3	40.3
2	Roundup Powermax + NIS + AMS	10	32	fl oz/a	A	95.3	59.6	34.9	27.5	1.7	23.9	26.5
3	Roundup Powermax + NIS + AMS	20	32	fl oz/a	A	82.5	65.1	19.5	22.2	1.1	26.0	27.4
4	Roundup Powermax + NIS + AMS	40	32	fl oz/a	A	80.3	62.6	24.3	24.2	2.2	28.2	30.9
5	Roundup Powermax + NIS + AMS Goal 2XL	20	32 8	fl oz/a fl oz/a	A A	88.3	62.6	10.0	47.2	1.1	35.1	36.7
6	Roundup Powermax + NIS + AMS Shark	20	32 2	fl oz/a fl oz/a	A A	83.8	62.7	10.9	32.1	2.6	22.7	26.5
7	Roundup Powermax + NIS + AMS Roundup Powermax + NIS + AMS	20	32 32	fl oz/a fl oz/a	A B	86.8	63.9	83.8	13.4	0.9	20.5	21.6
8	Rely 280 + AMS Rely 280 + AMS	20	3 3	pt/a pt/a	A B	99.8	85.8	85.2	4.5	2.7	28.5	31.5
9	Gramoxone SL + AMS + MSO Gramoxone SL + AMS + MSO	20	3 3	pt/a pt/a	A B	51.3	37.0	76.9	7.9	0.6	18.4	19.3
10	Roundup Powermax + NIS + AMS Rely 280 + AMS	20	32 3	fl oz/a pt/a	A A	96.0	67.8	19.1	36.6	1.8	22.5	24.5
11	Roundup Powermax + NIS + AMS Gramoxone SL + AMS + MSO	20	32 3	fl oz/a pt/a	A B	95.0	79.1	76.6	13.2	1.4	19.1	20.6
12	Roundup Powermax + NIS + AMS Matrix	20	32 1	fl oz/a oz ai/a	A A	84.0	67.4	50.9	23.5	1.3	26.0	27.8
13	Roundup Powermax + NIS + AMS Chateau	20	32 3	fl oz/a oz ai/a	A A	93.3	75.2	42.5	16.1	0.6	26.6	27.3
14	Roundup Powermax + NIS + AMS	20	64	fl oz/a	A	76.8	85.0	38.5	23.3	3.0	23.6	28.8
15	Roundup Powermax + NIS + AMS	20	106	fl oz/a	A	99.3	80.5	29.4	38.5	1.5	30.1	32.1
16	Rely 280 + AMS	20	3	pt/a	A	98.3	89.6	41.1	23.7	1.9	39.2	41.7
17	Summit Agro Glufosinate + AMS	20	3	pt/a	A	99.5	75.2	21.2	42.5	3.1	42.7	46.8
	Tukeys HSD (0.05)					45.7	21.7	22.7	0.6	0.9	4.3	4.5

A timing made April 26, 2013 and B timing made 28 days later.

Table 7. Effects of low VOC oxyfluorfen (GoalTender) combinations plus “kickers” on POST weed control in a tree nut orchard near Wheatland CA in 2013. (Watkins and Hanson)

				Annual bluegrass	CA burclover	Creeping buttercup	Fillaree	Overall weeds
				------------------------- % control, 28 DAT				-------------------------
1	Untreated			0.6	2.5	0.6	2.5	2.5
2	Goal 2XL (oxyfluorfen)	0.125	lb ai/a	45	50	87.2	93.3	70
	Roundup WM (glyphosate)	1	lb ae/a					
	AMS	2	qt/100 gal					
3	Goal 2XL (oxyfluorfen)	0.25	lb ai/a	60.5	65	88.8	97.3	77.5
	Roundup WM (glyphosate)	1	lb ae/a					
	AMS	2	qt/100 gal					
4	GoalTender (oxyfluorfen)	0.125	lb ai/a	38.5	40	79.2	82.3	62.5
	Roundup WM (glyphosate)	1	lb ae/a					
	AMS	2	qt/100 gal					
5	GoalTender (oxyfluorfen)	0.25	lb ai/a	52.5	52.5	92.5	99	67.5
	Roundup WM (glyphosate)	1	lb ae/a					
	AMS	2	qt/100 gal					
6	GoalTender (oxyfluorfen)	0.5	lb ai/a	42.5	47.5	85.5	99	65
	Roundup WM (glyphosate)	1	lb ae/a					
	AMS	2	qt/100 gal					
7	GoalTender (oxyfluorfen)	0.25	lb ai/a	96.5	40	88.1	99.3	70
	Gramoxone (paraquat)	0.625	lb ai/a					
	MSO	1	% v/v					
8	GoalTender (oxyfluorfen)	0.25	lb ai/a	5.7	45	10	54.8	25
	Shark (carfentrazone)	0.031	lb ai/a					
	NIS	0.25	% v/v					
9	GoalTender (oxyfluorfen)	0.25	lb ai/a	90.5	64.8	32.7	99.3	72.5
	Rely 280 (glufosinate)	22	fl oz/a					
	AMS	2	qt/100 gal					
10	GoalTender (oxyfluorfen)	0.25	lb ai/a	19.9	22.5	12.2	76.8	27.5
	Venue (pyraflufen)	4	fl oz/a					
	MSO	1	% v/v					
11	GoalTender (oxyfluorfen)	0.25	lb ai/a	12.2	69.8	31.2	98	35
	Treevix (saflufenacil)	1	oz/a					
	MSO	1	% v/v					
12	GoalTender (oxyfluorfen)	0.25	lb ai/a	2.6	10	2.6	7.5	10
	Hasten (est. veg. oil)	2	pt/a					
	Fishers LSD (0.05)			12.9	31.5	28.5	27.2	18.7

Treatments applied January 30, 2013.

Table 8. POST control of cheeseweed mallow with various burndown treatments in an orchard trial at the UC Davis research station in summer 2013. (Moretti, Watkins, and Hanson)

				Cheeseweed mallow		
Trt	Treatment		Rate	Control 7 DAT	Control 30 DAT	Biomass 30 DAT
				%	%	g/m2
1	untreated control			0	0	384.4
2	Roundup Powermax + NIS + AMS	32	fl oz/a	21.8	38.5	140.2
3	Roundup Powermax + NIS + AMS	64	fl oz/a	42	70.6	38.1
4	Rely 280 + AMS	1.5	pt/a	39.5	22.1	80.4
5	Treevix + AMS + MSO	1	oz/a	92.5	50.1	62.1
6	Shark EW + NIS + AMS	2	fl oz/a	67.8	17.7	230.5
7	Gramoxone SL + NIS	1.5	pt/a	19.5	11.2	174.7
8	Roundup Powermax + AMS	32	fl oz/a	32.2	38.5	151.0
	Rely 280	1.5	pt/a			
9	Roundup Powermax + AMS + MSO	32	fl oz/a	89.9	53.5	160.1
	Treevix	1	oz/a			
10	Roundup Powermax + NIS + AMS	32	fl oz/a	80	67.8	43.1
	Shark EW	2	fl oz/a			
11	Roundup Powermax + NIS + AMS	32	fl oz/a	62.6	55	95.6
	Goal 2XL	0.125	lb ai/a			
12	Roundup Powermax + NIS + AMS	32	fl oz/a	73.7	87.2	57.2
	Pindar GT	1.5	pt/a			
13	Roundup Powermax + NIS + AMS	32	fl oz/a	67.8	60.1	124.9
	Chateau	3	oz/a			
14	Roundup Powermax + NIS + AMS	32	fl oz/a	47.5	60.1	98.6
	Matrix	2	oz/a			
15	Roundup Powermax + MSO+ AMS	32	fl oz/a	18.8	67.6	125.2
	Matrix	2	oz/a			
	Treevix	1	oz/a			
16	Goal 2XL + MSO + AMS	0.125	lb ai/a	89.3	37	129.1
	Treevix	1	oz/a			
17	Roundup Powermax + NIS + AMS	32	fl oz/a	40	75.7	65.7
	Orchard Star	2	pt/a			
18	Roundup Powermax + NIS + AMS	32	fl oz/a	55.1	57.5	85.0
	Goal Tender	0.125	lb ai/a			
19	Roundup Powermax + COC + AMS	32	fl oz/a	50	55.1	138.6
	Venue	4	fl oz/a			
20	Summit Agro glufosinate + AMS	1.5	pt/a	21.6	11	248.7
21	Goal Tender + NIS + AMS	0.125	lb ai/a	31.7	5.7	211.8
22	Goal 2XL + AMS + NIS	0.125	lb ai/a	39.8	6.6	191.7
23	Orchard Star + NIS + AMS	2	pt/a	32.2	65.1	155.4
24	Pindar GT + NIS + AMS	1.5	pt/a	60	65.4	76.4
25	Chateau + NIS + AMS	3	oz/a	57.7	24	180.3
26	Matrix + NIS + AMS	2	oz/a	19.5	33.6	131.7
	Tukeys HSD (0.05)			17.6	30.7	9.3

All treatments applied June 10, 2013.

Figure 3. Greenhouse grown three spike goosegrass treated with a range of glyphosate doses at the 2-tiller (top) or 15-tiller (bottom) growth stage. Glyphosate doses ranged from 1/8x (second to left) to 16x (right) and the reference 1 lb ae/A rate is the center of the dose range. (Watkins and Hanson)

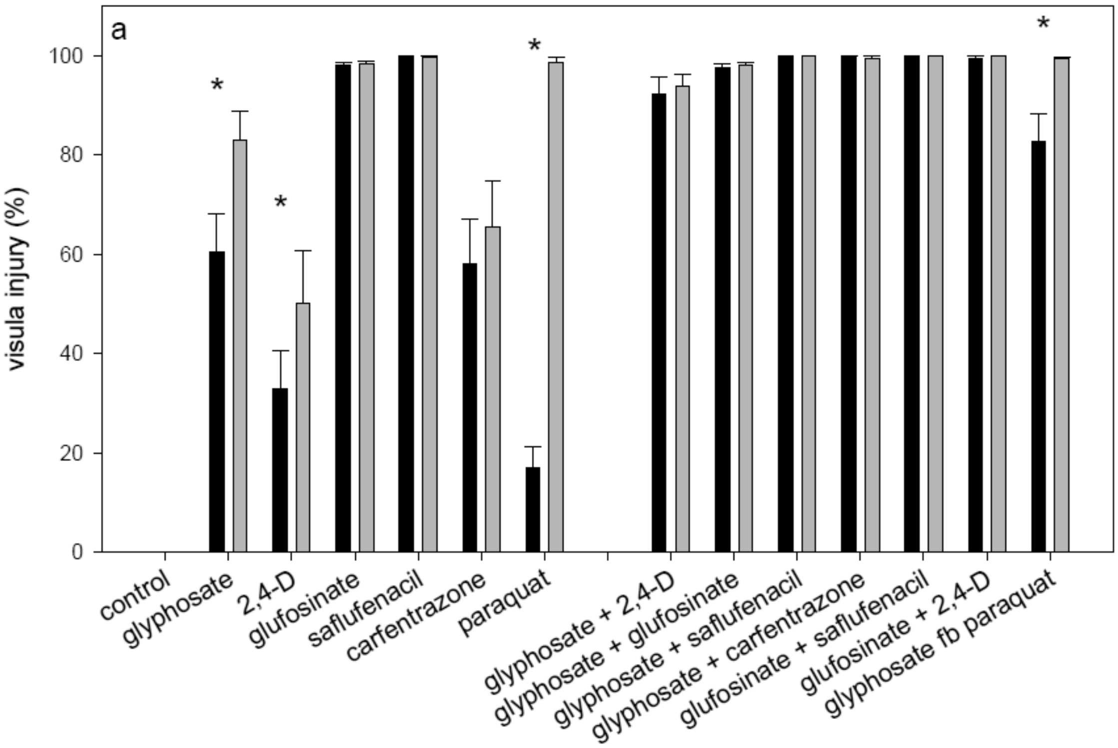


Figure 4. Postemergence control of glyphosate-resistant hairy fleabane in a greenhouse experiment. (Moretti and Hanson)

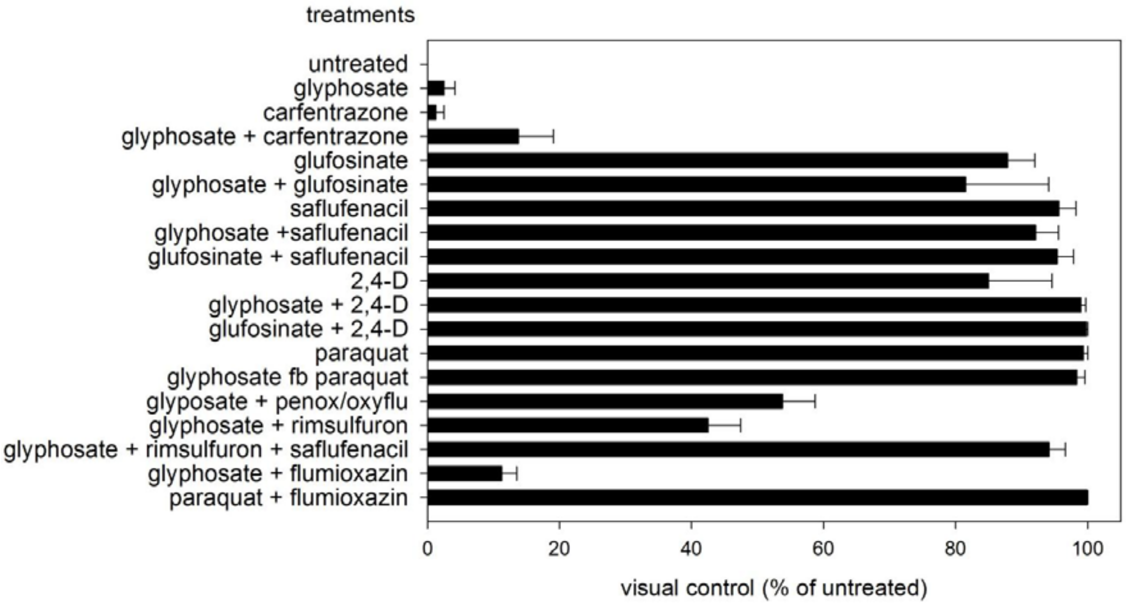


Figure 5. Postemergence control of hairy fleabane in an almond orchard trial near Delhi, CA in 2012. (Moretti and Hanson).

Table 9. POST control of glyphosate and paraquat-resistant (multiple resistant) hairy fleabane in in an almond orchard trial near Cressey, CA in 2013. (Moretti and Hanson)

Trt	Treatment	Active ingred.	Rate		Hairy fleabane Control 14 DAT
					%
1	Roundup Powermax + NIS + AMS	glyphosate	28	fl oz/a	1.7
2	Rely 280 + AMS	glufosinate	69	fl oz/a	99
3	Treevix + MSO + AMS	saflufenacil	1	oz/a	100
4	Shark EW + NIS + AMS	carfentrazone	2	fl oz/a	5
5	Roundup Powermax + AMS	glyphosate	27.6	fl oz/a	99.7
	Rely 280	glufosinate	69	fl oz/a	
6	Roundup Powermax + MSOS + AMS	glyphosate	27.6	fl oz/a	99
	Treevix	saflufenacil	1	oz/a	
7	Rely 280 + MSO + AMS	glufosinate +	69	fl oz/a	100
	Treevix		1	oz/a	
8	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	9.2
	Shark EW	carfentrazone	2	fl oz/a	
9	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	1.7
	Gramoxone SL + NIS	paraquat	4	pt/a	
10	Gramoxone SL + NIS	paraquat	4	pt/a	3.3
11	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	10
	Pindar GT	penox/oxyfluor	1.5	pt/a	
12	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	6.7
	Chateau	flumioxazin	6	oz/a	
13	Roundup Powermax + NIS + AMS	paraquat	4	pt/a	7.5
	Chateau	flumioxazin	6	oz/a	
14	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	19.2
	Matrix	rimsulfuron	2	oz/a	
15	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	99.8
	Matrix	rimsulfuron	2	oz/a	
	Treevix	saflufenacil	1	oz/a	
16	untreated control				0
17	Orchard Star	2,4-D	2	pt/a	30
18	Roundup Powermax + NIS + AMS	glyphosate	27.6	fl oz/a	27.5
	Orchard Star	2,4-D	2	pt/a	
19	Rely 280 + AMS	glufosinate	69	fl oz/a	100
	Orchard Star	2,4-D	2	pt/a	
	Tukeys HSD (0.05)				9.9

Treatments applied June 27, 2013

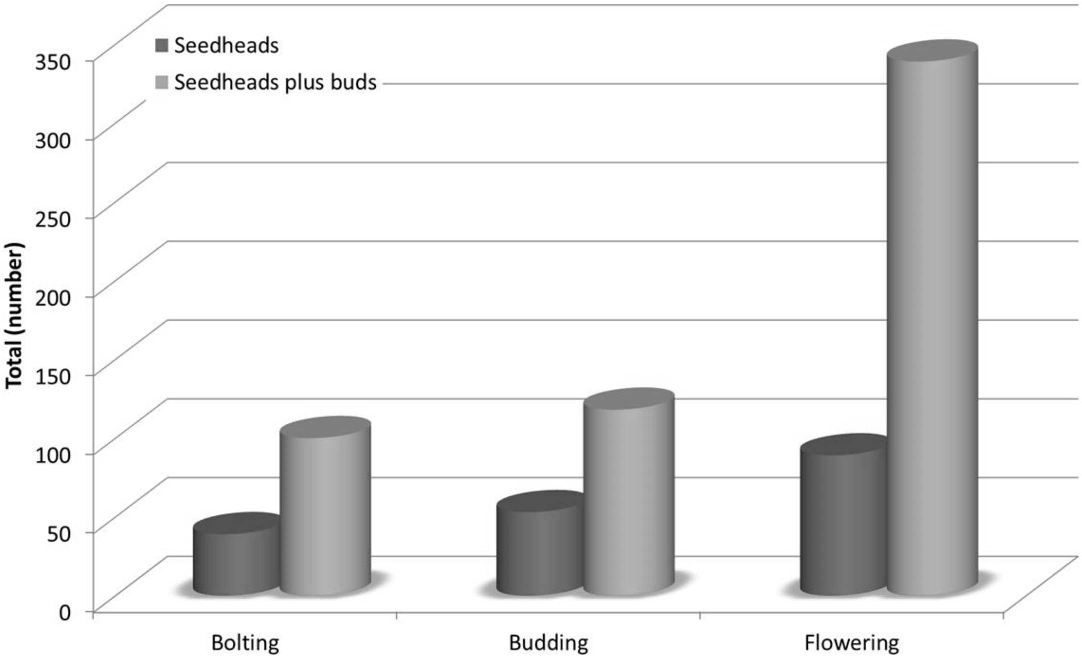


Figure 6. Effects of hairy fleabane growth stage on the reproductive output of hairy fleabane following late post emergence (e.g., "preharvest") herbicide applications in a greenhouse experiment. Data are averaged over four POST herbicides (glyphosate, glufosinate, paraquat, and saflufenacil). (Sosnoskie and Hanson)

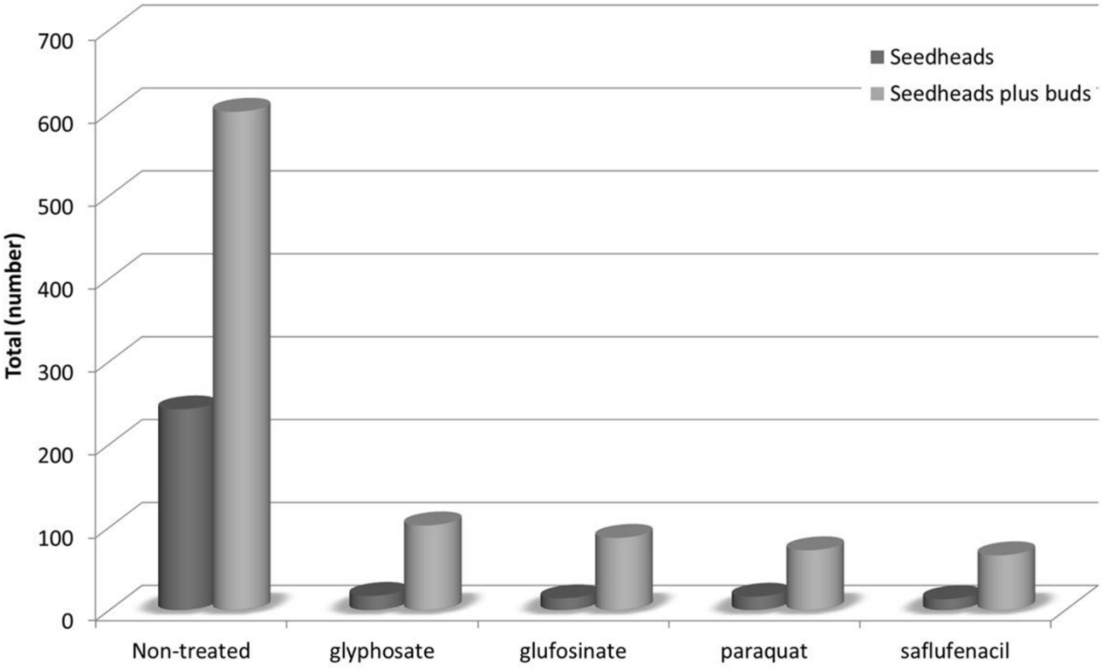


Figure 7. Effects of late post emergence (e.g., "preharvest") herbicide applications on reproductive output of hairy fleabane in a greenhouse experiment. Data are averaged over three growth stages (bolting, budding, and flowering). (Sosnoskie and Hanson)

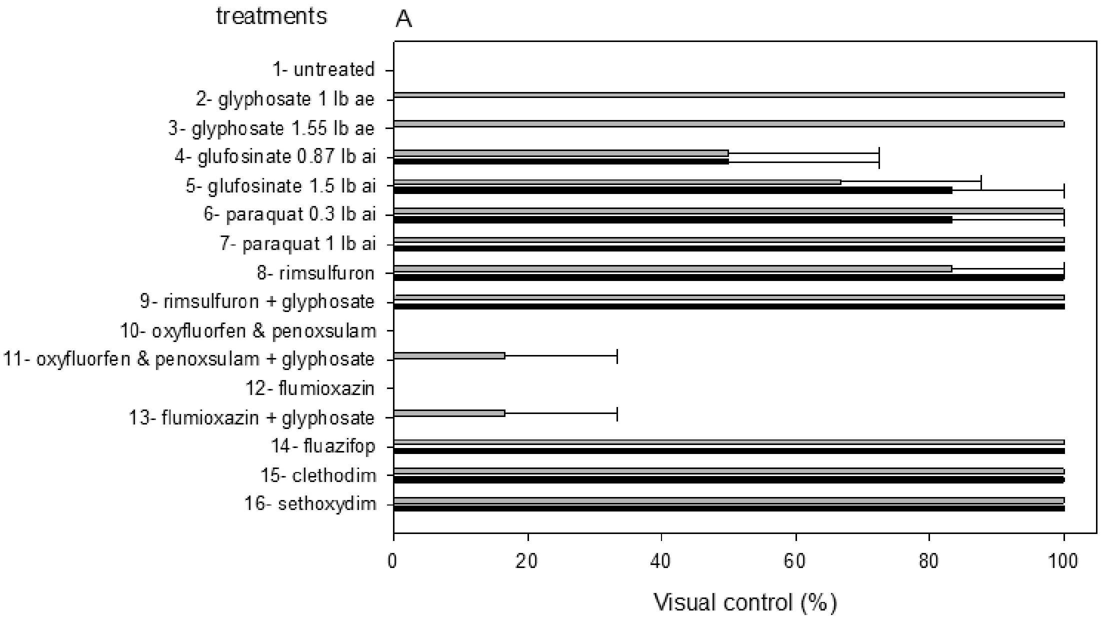


Figure 8. Postemergence control of glyphosate-resistant junglerice in a 2012 greenhouse experiment. Light colored bars were glyphosate-susceptible biotypes and the dark colored bars were glyphosate-resistant. (Moretti and Hanson)

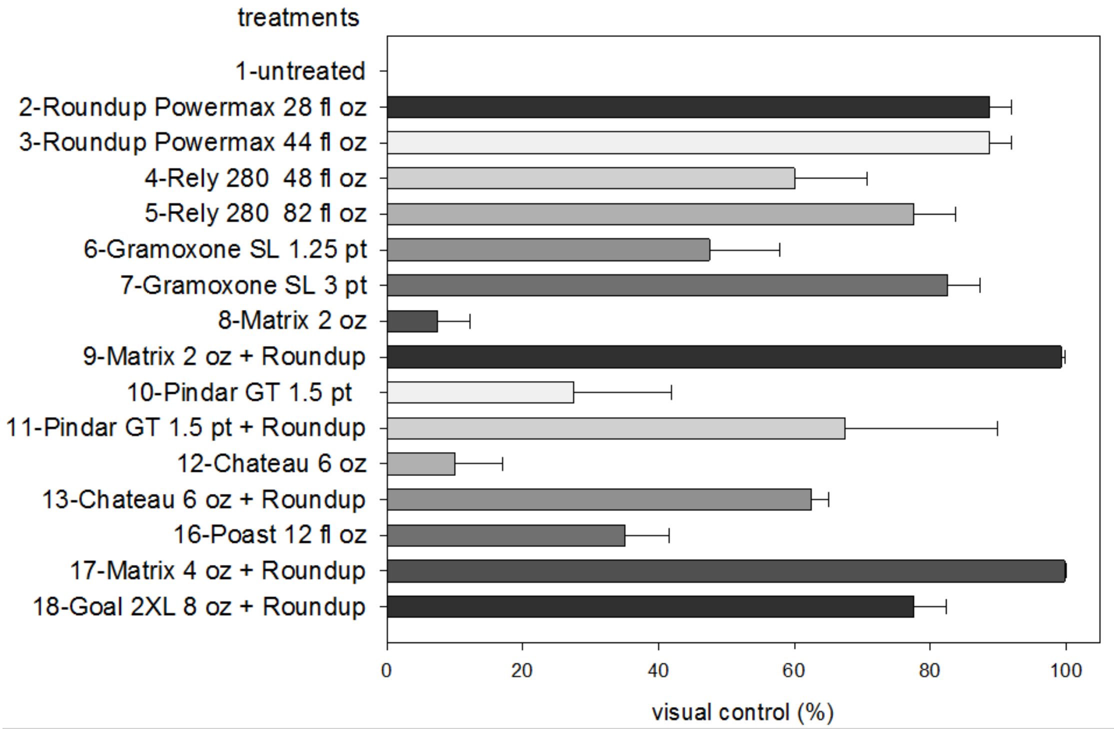


Figure 9. Postemergence control of glyphosate-susceptible junglerice in an almond orchard near Discovery Bay, CA in spring 2013. Visual evaluation made 28 days after treatment. (Moretti and Hanson)

Table10: Effect of herbicide treatment combinations on junglerice visual control, biomass, and stand 28 days after treatment in a 2013 almond orchard trial near Wasco, CA. (Moretti, Watkins, and Hanson)

Nº	Treatment	active ingredient	rate		visual control %	biomass g/m^2	Density plants/m^2
1	untreated control				0	256	558
2	Roundup Powermax + NIS + AMS	glyphosate	1	lb ae/a	8	80	174
3	Roundup Powermax + NIS + AMS	glyphosate	44	fl oz/a	3	109	305
4	Rely 280 + AMS	glufosinate	48	fl oz/a	78	24	49
5	Rely 280 + AMS	glufosinate	82	fl oz/a	70	27	26
6	Gramoxone SL + NIS	paraquat	1.25	pt/a	58	25	94
7	Gramoxone SL + NIS	paraquat	4	pt/a	80	3	58
8	Matrix + NIS + AMS	rimsulfuron	2	oz/a	98	14	35
9	Roundup Powermax + NIS + AMS Matrix	glyphosate rimsulfuron	1 2	lb ae/a oz/a	99	9	48
10	Pindar GT+NIS + AMS	penox/oxyfl	1.5	pt/a	63	6	54
11	Roundup Powermax + NIS + AMS Pindar GT	glyphosate penox/oxyfl	1 1.5	lb ae/a pt/a	67	23	45
12	Chateau + NIS + AMS	flumioxazin	6	oz/a	66	7	33
13	Roundup Powermax + NIS + AMS Chateau	flumioxazin glyphosate	6 1	oz/a lb ae/a	88	0	30
14	Fusilade II + AMS + COC	fluazifop	12	fl oz/a	95	29	23
15	Envoy + AMS	clethodim	16	fl oz/a	92	15	53
16	Poast + AMS+COC	sethoxydim	1.5	pt/a	90	0	91
17	Roundup Powermax + NIS + AMS Matrix	glyphosate rimsulfuron	1 4	lb ae/a oz/a	98	19	59
18	Roundup Powermax + NIS + AMS Goal 2XL	glyphosate oxyfluorfen	1 0.125	lb ae/a lb ai/a	18	143	487
Tukey's HSD (P = 0.05)					45	65	57

Abbreviations: NIS - non-ionic surfactant at 0.25 % V/V; AMS - ammonium sulfate 10 lbs/100 gallons; COC - crop oil concentrate 1 % V/V; penox/oxyfl – penoxsulam / oxyfluorfen

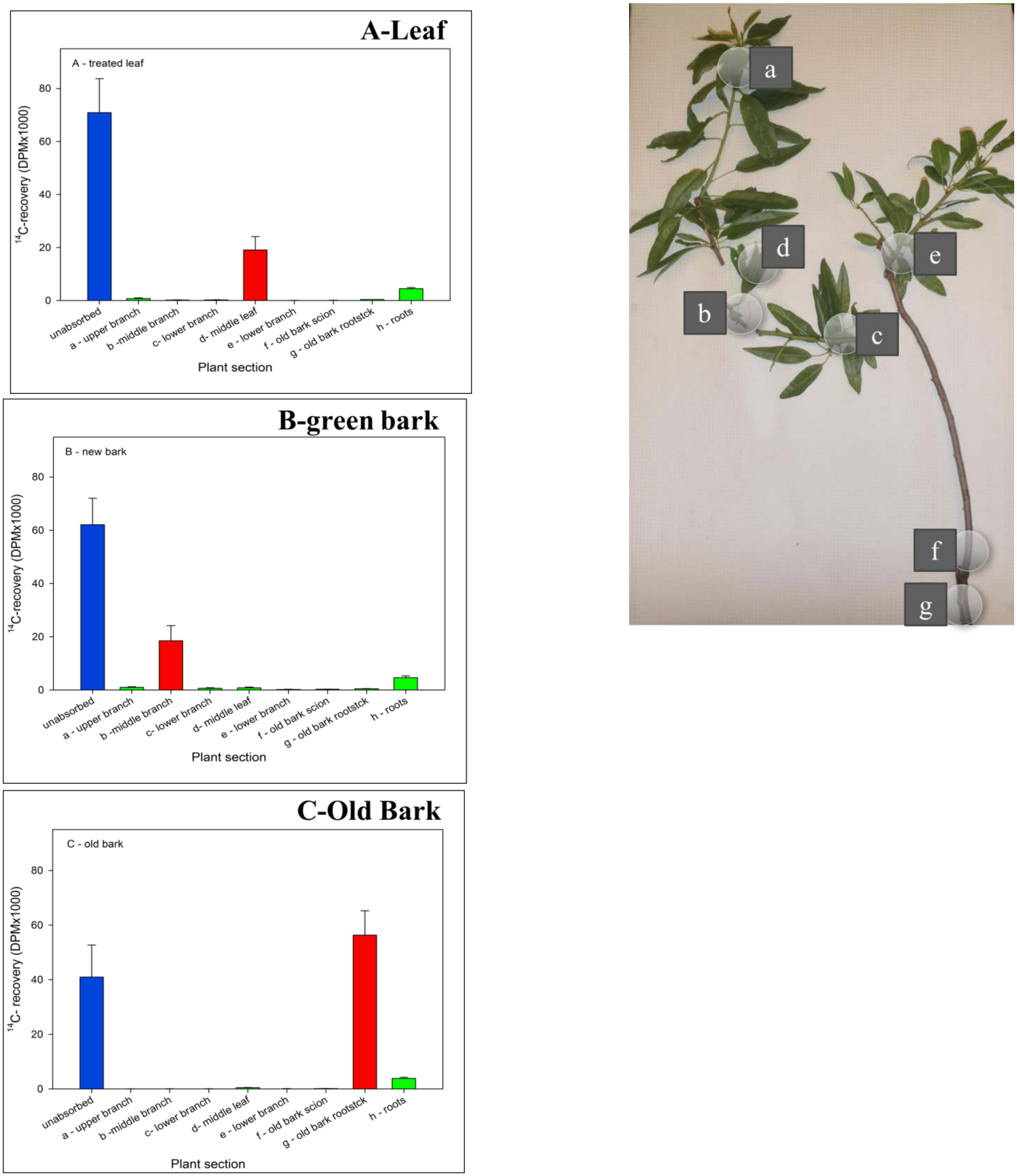
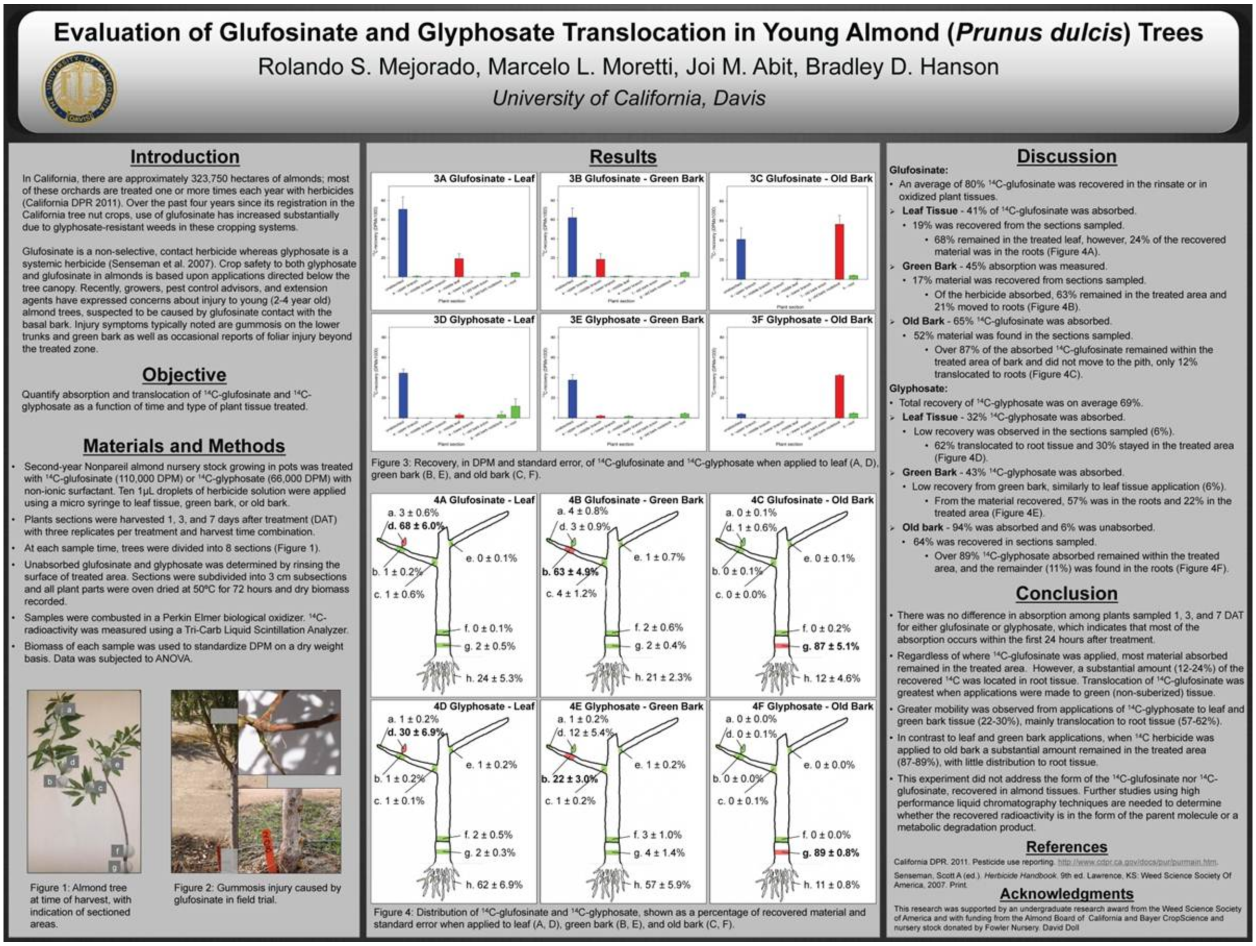


Figure 10. Movement of radiolabeled (14C) glufosinate in young almond trees in a laboratory experiment. Labeled herbicide was applied to leaf tissue (A), green bark (B), or mature bark (C) of two-year old almond nursery stock in pots. (Mejorado, Moretti, and Hanson)



Evaluation of Glufosinate and Glyphosate Translocation in Young Almond (*Prunus dulcis*) Trees

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Introduction

In California, there are approximately 323,750 hectares of almonds; most of these orchards are treated one or more times each year with herbicides (California DPR 2011). Over the past four years since its registration in the California tree nut crops, use of glufosinate has increased substantially due to glyphosate-resistant weeds in these cropping systems.

Glufosinate is a non-selective, contact herbicide whereas glyphosate is a systemic herbicide (Senseman et al. 2007). Crop safety to both glyphosate and glufosinate in almonds is based upon applications directed below the tree canopy. Recently, growers, pest control advisors, and extension agents have expressed concerns about injury to young (2-4 year old) almond trees, suspected to be caused by glufosinate contact with the basal bark. Injury symptoms typically noted are gummosis on the lower trunks and green bark as well as occasional reports of foliar injury beyond the treated zone.

Objective

Quantify absorption and translocation of ^{14}C-glufosinate and ^{14}C-glyphosate as a function of time and type of plant tissue treated.

Materials and Methods

- Second-year Nonpareil almond nursery stock growing in pots was treated with ^{14}C-glufosinate (110,000 DPM) or ^{14}C-glyphosate (66,000 DPM) with non-ionic surfactant. Ten 1μL droplets of herbicide solution were applied using a micro syringe to leaf tissue, green bark, or old bark.
- Plants sections were harvested 1, 3, and 7 days after treatment (DAT) with three replicates per treatment and harvest time combination.
- At each sample time, trees were divided into 8 sections (Figure 1).
- Unabsorbed glufosinate and glyphosate was determined by rinsing the surface of treated area. Sections were subdivided into 3 cm subsections and all plant parts were oven dried at 50ºC for 72 hours and dry biomass recorded.
- Samples were combusted in a Perkin Elmer biological oxidizer. ^{14}C-radioactivity was measured using a Tri-Carb Liquid Scintillation Analyzer.
- Biomass of each sample was used to standardize DPM on a dry weight basis. Data was subjected to ANOVA.

Figure 1: Almond tree at time of harvest, with indication of sectioned areas.

Figure 2: Gummosis injury caused by glufosinate in field trial.

Results

Figure 3: Recovery, in DPM and standard error, of ^{14}C-glufosinate and ^{14}C-glyphosate when applied to leaf (A, D), green bark (B, E), and old bark (C, F).

Figure 4: Distribution of ^{14}C-glufosinate and ^{14}C-glyphosate, shown as a percentage of recovered material and standard error when applied to leaf (A, D), green bark (B, E), and old bark (C, F).

Discussion

Glufosinate:

- An average of 80% ^{14}C-glufosinate was recovered in the rinsate or in oxidized plant tissues.
- **Leaf Tissue** - 41% of ^{14}C-glufosinate was absorbed.
  - 19% was recovered from the sections sampled.
    - 68% remained in the treated leaf, however, 24% of the recovered material was in the roots (Figure 4A).
- **Green Bark** - 45% absorption was measured.
  - 17% material was recovered from sections sampled.
    - Of the herbicide absorbed, 63% remained in the treated area and 21% moved to roots (Figure 4B).
- **Old Bark** - 65% ^{14}C-glufosinate was absorbed.
  - 52% material was found in the sections sampled.
    - Over 87% of the absorbed ^{14}C-glufosinate remained within the treated area of bark and did not move to the pith, only 12% translocated to roots (Figure 4C).

Glyphosate:

- Total recovery of ^{14}C-glyphosate was on average 69%.
- **Leaf Tissue** - 32% ^{14}C-glyphosate was absorbed.
  - Low recovery was observed in the sections sampled (6%).
    - 62% translocated to root tissue and 30% stayed in the treated area (Figure 4D).
- **Green Bark** - 43% ^{14}C-glyphosate was absorbed.
  - Low recovery from green bark, similarly to leaf tissue application (6%).
    - From the material recovered, 57% was in the roots and 22% in the treated area (Figure 4E).
- **Old bark** - 94% was absorbed and 6% was unabsorbed.
  - 64% was recovered in sections sampled.
    - Over 89% ^{14}C-glyphosate absorbed remained within the treated area, and the remainder (11%) was found in the roots (Figure 4F).

Conclusion

- There was no difference in absorption among plants sampled 1, 3, and 7 DAT for either glufosinate or glyphosate, which indicates that most of the absorption occurs within the first 24 hours after treatment.
- Regardless of where ^{14}C-glufosinate was applied, most material absorbed remained in the treated area. However, a substantial amount (12-24%) of the recovered ^{14}C was located in root tissue. Translocation of ^{14}C-glufosinate was greatest when applications were made to green (non-suberized) tissue.
- Greater mobility was observed from applications of ^{14}C-glyphosate to leaf and green bark tissue (22-30%), mainly translocation to root tissue (57-62%).
- In contrast to leaf and green bark applications, when ^{14}C herbicide was applied to old bark a substantial amount remained in the treated area (87-89%), with little distribution to root tissue.
- This experiment did not address the form of the ^{14}C-glufosinate nor ^{14}C-glufosinate, recovered in almond tissues. Further studies using high performance liquid chromatography techniques are needed to determine whether the recovered radioactivity is in the form of the parent molecule or a metabolic degradation product.

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Acknowledgments

This research was supported by an undergraduate research award from the Weed Science Society of America and with funding from the Almond Board of California and Bayer CropScience and nursery stock donated by Fowler Nursery. David Doll

Figure 11. Student poster presentation on glyphosate and glufosinate absorption and translocation in almond. Western Society of Weed Science meeting January 2013 San Diego, CA. (Mejorado, Moretti, and Hanson.)

Table 11. Effects of glufosinate rate and spray coverage on almond trunk gumming and trunk diameter in an orchard trial near Arbuckle, CA in 2012-13 (Watkins, Johnson, and Hanson)

				Trunk gumming		Trunk diameter
Trt	Treatment	Rate	Coverage	28 DAT	56 DAT	1/22/13
		lb ia/A	GPA	0-5 scale (0=no gumming)		mm
1	Untreated	--	--	0	0	60
2	Rely 280 + AMS	1.5	10	1.0	1.7	60
3	Rely 280 + AMS	3.0	10	1.3	1.3	60
4	Rely 280 + AMS	6.0	10	1.7	2.7	58
5	Rely 280 + AMS	1.5	20	0.3	0	63
6	Rely 280 + AMS	3.0	20	0.7	1.7	58
7	Rely 280 + AMS	6.0	20	1.3	1.7	62
8	Rely 280 + AMS	1.5	40	0.3	0.7	64
9	Rely 280 + AMS	3.0	40	2.0	2.0	57
10	Rely 280 + AMS	6.0	40	2.7	3.0	59
	Fishers LSD (0.05)			1.1	1.1	12

Treatments applied directly to lower 18 inches of 2nd leaf almond tree trunks on September 6, 2012.

Figure 12. Trunk gumming injury on Nonpareil almond in a 2012 field experiment at the Nickels Soil Lab. Photo was taken 56 days after treatment with a 4x use rate of Rely 280 + AMS. For reference, this particular tree was given a gumming rating of 3 on a 0-5 scale and was one of the most symptomatic at this rating date. (Watkins and Hanson)

Table 12. Effects of glufosinate rate, formulation, tankmix partner, and placement on almond trunk gumming and trunk diameter in an orchard trial near Arbuckle, CA in 2012-1.3 (Watkins, Johnson, and Hanson)

		Rate		Aldrich	Nonpareil	Sonora	Aldrich	Nonpareil	Sonora	Aldrich	Nonpareil	Sonora
Trt	Treatment	lb/A		--------------------- 0-5 scale (0=no gumming) ---------------------						-------- mm diameter --------		
1	Untreated			0	0	0	0	0	0	59	55	64
2	Rely 280	1.5	trunk	0	0.4	0.3	1	1.3	0.3	63	56	65
3	Rely 280	6	trunk	2	1.8	0.5	2	2.3	0.8	65	58	65
4	Rely 280 BLANK formul'n	6	trunk	0	0	0	0	0.3	0.5	59	57	64
5	Rely 200	6	trunk	1.3	2.7	1.3	2	2.5	1.3	54	62	64
6	Rely 200 BLANK formul'n	6	trunk	0	0	0	0.3	0.3	1	62	57	58
7	Rely 280 Hasten (MSO)	1.5 1	trunk trunk	0	0.8	0	0	1.3	0.5	57	56	61
8	Rely 280 Pro 90 (NIS)	1.5 0.25	trunk trunk	0	1.4	0.5	0.6	2.3	0.5	68	56	60
9	Rely 280 Silwet (organosilicone)	1.5 0.1	trunk trunk	0.5	0.9	0	1.4	0.8	0	63	56	67
10	Rely 280 oxyflourfen (Goal 2XL)	1.5 0.5	trunk trunk	1	1.6	0.3	0.6	1.8	0.8	62	61	61
11	Rely 280 glyphosate (RU Powermax)	1.5 1	trunk trunk	0	0.2	0	0.3	0.5	0.3	60	58	66
12	Rely 280	1.5	wounded bark	2.3	1.5	1.5	2.2	1.5	1.5	66	61	66
13	Rely 280	1.5	lower limb	0	0	0	0	0	0	61	64	64
14	Rely 280 oxyflourfen (Goal 2XL)	1.5 0.5	lower limb	0	0	0	0	0.3	0.3	60	54	63
15	Rely 280 glyphosate (RU Powermax)	1.5 1	lower limb	0	0.4	0	0.2	0.5	0	57	54	61
	Fishers LSD (0.05)			0.7	0.5	0.7	0.2	1.0	0.8	11	6	6

Treatments applied September 6, 2012. All treatments included AMS at 10 lb/100 gal.

Treatments 4 and 6 were blank formulations of Rely 280 and Rely 200 with no glufosinate applied at a rate equivalent to a 4x use rate of the commercial product.

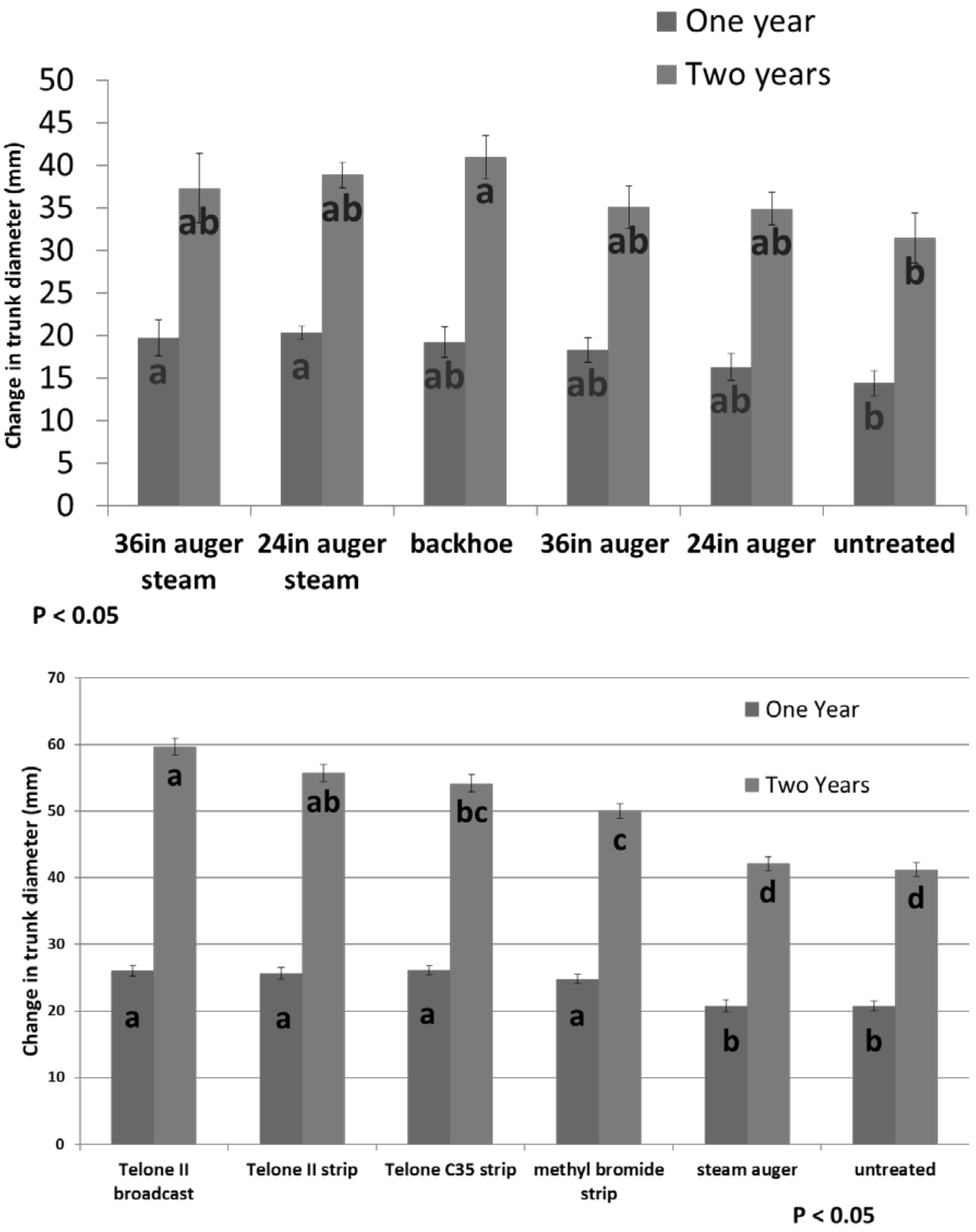

Figure 13. Almond trunk diameter measurements in an almond replant trial near Delhi, CA after one (red bars) and two (blue bars) growing seasons. Top figure is from an experiment comparing different levels of soil disturbance and steam injection and the lower figure is from an experiment comparing soil fumigants to a steam treatment. Please see Almond Board Reports by G.T. Browne and D.A. Doll (12-PATH1-Browne and 12-AIR9-Doll) for more information on these trials. (Johnson and Hanson)

Research Effort Recent Publications:

Moretti, M. L., B.D. Hanson, K.J. Hembree, and A. Shrestha. 2013. Glyphosate resistance is more variable than paraquat resistance in a multiple-resistant hairy fleabane (*Conyza bonariensis*) population. Weed Sci. 61:396-402.

Abit, M.J.M. and B.D. Hanson. 2013. Evaluation of pre emergence and post-directed herbicides on Prunus rootstock safety infield-grown almond tree nurseries. Hort Technology (in press)

Okada, M., B.D. Hanson, K.J. Hembree, Y. Peng, A. Shrestha, C.N. Stewart Jr., S.D. Wright, and M. Jasieniuk. 2013. Evolution and spread of glyphosate resistance in *Conyza canadensis* in California. Evolutionary Applications.6:761-777

Peachey, E., R. Boydston, B. Hanson, K. Al-Khatib, and T. Miller. 2013. Preventing and managing glyphosate-resistant weeds in orchards and vineyards. University of California, Division of Agriculture and Natural Resources, ANR Publication 8501. 5 pg.

Hanson, B., A. Fisher, A. Shrestha, M. Jasieniuk, E. Peachey, R. Boydston, T. Miller, K. Al-Khatib. 2013. Selection pressure, shifting populations, and herbicide resistance and tolerance. University of California, Division of Agriculture and Natural Resources, ANR Publication 8493. 5 pg.

Miller, T, B. Hanson, E. Peachey, R. Boydston, K. Al-Khatib. 2013. Glyphosate stewardship: keeping an effective herbicide effective. University of California, Division of Agriculture and Natural Resources, ANR Publication 8492. 4 pg.

Mejorado, R.S., M.L. Moretti, M.J.M Abit, and B.D. Hanson. 2013. Evaluation of C14-glufosinate translocation in young almond (Prunus dulcis) trees. Proc. Calif. Weed Science Society.

Hanson, B., A. Shrestha, K.J. Hembree, S. Wright, and J.A. Roncoroni. 2012. Managing glyphosate-resistant weeds in California orchards and vineyards. Proc. Western Soc. Weed Sci.

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Johnson, B., B. Hanson, D Doll, G. Browne, and S. Fennimore. 2012. Development and optimization of the steam auger for management of almond replant disease. Proc. Calif. Plant and Soil Conf. p 162.

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Sosnoskie, L. and B. Hanson. 2013. Selection pressure, shifting populations, and herbicide resistance. CWSS Research Update 9:2-5

Hanson, B.D., A. Shrestha, K.J. Hembree, S. D. Wright, J.A, Roncoroni. 2012. Managing glyphosate-resistant weeds in California orchards and vineyards. Abstr. Inter. Weed Sci. Soc.

Shrestha, A., K. Steinhauer, M. Jasieniuk, and B.D. Hanson. 2012. Growth and development of fall and spring planted glyphosate-resistant and -susceptible Conyza sp. Abstr. Weed Sci. Soc. Am.

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Moretti, M. L., B.D. Hanson, K.J. Hembree, and A. Shrestha. 2013. Glyphosate resistance is more variable than paraquat resistance in a multiple-resistant hairy fleabane (*Conyza bonariensis*) population. Weed Sci. 61:396-402.

Recent Extension Effort:

During FY2012-13, members of the Hanson lab group made over 30 extension presentations to tree nut growers, pest control advisors, and industry representatives as a part of the outreach efforts related to weed control and weed biology research in perennial crops. An MS graduate student in our lab group, Andrew (Bob) Johnson, also took an educational leave in order to participate in a UC Farm Advisor Internship program supported by the Almond Board and the Dried Plum Board which further expanded our outreach efforts. Additionally, information from Almond Board supported research has been used to answer dozens of direct (email or phone) questions on herbicide performance, herbicide safety, and weed identification in almond orchards and other tree nut crops.