Weed Management and Herbicide Safety in the Almond Production System

Project No.: **15-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. Although the almond industry is one of the key stakeholder groups for this program, the majority of our research is broadly applicable to, and partially supported by, other orchard and vineyard commodities in the state and the pest control industry.

Similar to previous years, the objectives proposed for the 2015-16 Almond Board of California fiscal year mirror the major research areas in our program:

1. Evaluation and testing of newly registered materials, tank mix partners, and application techniques for control of weeds with a special focus on glyphosate-resistant species.
2. Evaluating and diagnosing herbicide injury symptoms in almonds and developing training tools for Farm Advisors and pest control industry advisors and consultants. This research includes both general herbicide problems as well as the more specific issues related to glyphosate and micronutrient status in soil and plant tissue.

Interpretive Summary:

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), the UC Weed Science blog (http://ucanr.edu/blogs/UCDWeedScience/index.cfm), and the Almond Doctor blog (http://thealmonddoctor.com/).

Materials and Methods:

Herbicide efficacy: We conducted several herbicide efficacy trials in commercial orchards or at research stations in FY2015, primarily in almonds but some protocols were also tested in other orchard and vineyard crops. In order to address differences in weeds, soil conditions, and production practices, orchard trials ranged from Glenn to Fresno Co.

Herbicides in the small-plot experiments usually were applied using CO_2 pressurized backpack sprayers. Occasionally, large-plot experiments were treated with an ATV mounted research sprayer. In the small plot trials, plots typically were 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 and 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 are collected. Herbicide efficacy treatments focused on residual herbicide comparisons and on POST control of key weeds including glyphosate-resistant hairy fleabane and junglerice.

Greenhouse experiments and weed screening tests were conducted to support the field work, answer grower questions, and to develop extension materials. Species focus this year included hairy fleabane and horseweed, Italian ryegrass, junglerice, and field bindweed. Other species tested to a lesser extent included sprangletop, threespike goosegrass, and shepherd’s purse. A number of herbicide panel screens and level of resistance studies were conducted. to evaluate the level of tolerance/resistance to glyphosate or other herbicides.

Because almonds and other tree nuts are harvested from the orchard floor, late season weed control is very important; however, complete control of mature weeds can be difficult to achieve. In some cases, survivors regrow and still set seed and contribute to the soil seed bank. This partial control may be a contributing factor to herbicide resistance in some species. Greenhouse and field experiments continue in order to evaluate the effects of weed size on the reproductive ability of glyphosate-resistant weeds in Central Valley perennial cropping systems.

Crop safety experiments: We typically conduct several experiments or demonstrations related to herbicide injury or crop safety to address herbicide injury questions from the almond industry and UCCE Farm Advisors. We expect that these types of projects will continue and evolve as needed to address real or perceived evolving issues with herbicide safety in tree crops. Photos from previous demonstrations have been used during Farm Advisor training sessions and many were also uploaded into an online symptomology website previously developed by Dr. Kassim Al-Khatib (http://herbicidesymptoms.ipm.ucanr.edu/index.cfm).

In 2016, Hanson and Al-Khatib from UC Davis and John Roncoroni (UCCE Napa) started a new one-day workshop “Diagnosing Herbicide Symptoms”. This workshop, held at the UC Davis campus, filled quickly to the maximum of 60 attendees which included an interesting mix of UC Farm Advisors, crop damage investigators, lawyers, county ag commissioner personnel, and ag chemical industry representatives. The workshop included several lectures and a two-hour walk-through of a nearly half-acre demonstration of herbicide symptomology on a range of crop plants. Participant reviews for the workshop were quite positive and we anticipate conducting similar workshops in the future as part of the Weed Research and Information Center education and training program.

Related research: Although not directly supported by the Almond Board of California, several lines of research applicable to almond production continue. With support of the CDFA-Specialty Crop Block Grant Program, we are conducting research to determine the underlying genetics and physiological causes of glyphosate resistance in junglerice and other related grasses. This three-year project includes collaborators at UC Davis, UCCE in Fresno, Napa, and Tulare Counties, and CSU Fresno. In this work, a postdoctoral geneticist at UC Davis is determining the physiological mechanisms of resistance to glyphosate and, so far, has found three different amino acid substitutions in the EPSPS target site. Evidence also suggests that some junglerice population also have a non-target site based resistance mechanism. Other researchers in the team are exploring the biology and morphology of junglerice under different environmental constraints (temperature, shading, salt stress) to further understand the drivers for spread of this weed in California cropping systems.

In addition to our weed management work, members of our research team also conduct pesticide residue trials as part of the USDA IR4 program. This program provides the field support necessary to create the data packages that are submitted to USEPA in minor crops for which there may be insufficient market to justify a registrant’s investment. Almond is a large enough market that we typically don’t get many almond trials in this part of the program. However, in 2015/16 we conducted multiple phosphite trials in almond and walnut to help address the urgent data needs related to the European Union stance on phosphite residues on import crops like almond. The Almond Board of California helped make this a priority issue with the USDA and Foreign Ag Service.

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 FY2015 weed science research is presented and discussed. The selected data that follows present some of the most relevant results and reflect the breadth of our program partially supported by the Almond Board of California.

Label changes: Few major herbicide registration changes were made in FY2015 that affect almond (**Figure 1**). One new herbicide was registered, Broadworks (mesotrione) from Syngenta, for use in several tree fruit and nut crops. This is a broadleaf herbicide with both PRE and POST activity although it is stronger as a PRE. After several years in pre-registration testing, growers, PCAs and the research community are now exploring the strengths and weaknesses of the product on the commercial scale. The major changes last year included a maximum rate reduction for Alion herbicide (indaziflam) and market entry of several glufosinate herbicides after that active ingredient went off-patent. The grower and PCA community has pretty quickly adapted to the Alion rate change. Originally that change also included a prohibition on use in flood-irrigated orchards, but that has since been removed.

Residual herbicides: As in the past few years, drought conditions challenged our residual herbicide research just like the commercial orchards. However, several experiments were conducted to compare the efficacy of PRE herbicides alone or in combination with a particular focus on tankmix combinations including Alion, Broadworks, PindarGT, and Matrix (example data in **Figures 2 - 3**).

Because of the Alion label changes, trials were conducted to evaluate the duration of weed control with lower rates of this herbicide alone or in combination with other preemergence products (**Figure 2**). As expected, the lower rates of Alion should not be expected to maintain weed control efficacy for as long as the previous maximum label rates. However, with effective tankmix partners or sequential treatments, excellent weed control and better resistance management is obtainable.

A comparison trial was conducted near Davis to evaluate residual suppression of field bindweed following winter applications of Alion or Pindar GT (**Figure 3**). Because of the relatively more normal rainfall patterns experienced in 2015, there were no significant differences between applications made in November, December or January in terms of field bindweed suppression.

Performance of several PRE herbicide programs was tested at a Hamilton City orchard site with Italian ryegrass known to be glyphosate-resistant and suspected to be paraquat-resistant. Most PRE herbicide programs tested provided adequate control of ryegrass with the exception of the reduced rates of Prowl or Surflan; however, this is likely due to the low rate rather than an indication of further resistance (**Table 3**). Also tested at this site was a new formulation of Alion (500SC) in comparison to the 200SC formulation with no apparent performance difference among the two products.

Postemergence herbicides: POST herbicide programs were evaluated for control of the glyphosate-resistant Italian ryegrass population from Hamilton City. In the greenhouse, there was some indication that the ryegrass at this site was highly resistant to both paraquat and glyphosate but also to ACCase inhibiting herbicides and possibly ALS inhibiting herbicides (**Table 1**). This was confirmed with subsequent field experiments which indicated fairly broad resistance in the population but that Rely 280 and other glufosinate herbicides were still effective (**Table 2**).

A few formulation or surfactant comparisons were conducted in 2015-16. For example, the surfactant code-numbered OR009 was compared to a nonionic surfactant (NIS) in mixture with glufosinate and glyphosate herbicides at a site with a mix of winter annual weeds (Table 4). In that trial, there were no clear performance differences between the two surfactant packages.

Previously identified populations of glyphosate- or glyphosate-paraquat-resistant hairy fleabane and horseweed were evaluated in a cross-resistance screening study in the greenhouse. In this work, the paraquat-resistant populations were also resistant to diquat, another PSI inhibitor (**Figure 4**) but were sensitive to PSII, ALS inhibiting, and PPO inhibiting herbicides tested (**Table 5**).

Glyphosate and micronutrients: In 2015, several trials were conducted to evaluate interactions between glyphosate and micronutrients. In one trial, glyphosate was amended to field soil at a modest and an extremely high rate and soil micronutrient availability monitored after a several-day incubation. In this trial, there were no statistical differences in the availability of micronutrients in either a very sandy soil or a clay loam soil, amended with glyphosate at up to 32 times a common use rate (**Table 6**). This suggests that micronutrient deficiencies due to glyphosate chelation is not very likely a problem in California almonds.

In a related field study, glyphosate was applied to almond trees planted in 2013 and treated three times per season with 1, 2, or 4 lb ae/A. In 2015 as in previous years, no clear effect of glyphosate on almond growth or vigor was noted; even in the “worst case” treatment that included: planting site amended with very sandy soil, 24 lb ae/A glyphosate applied over the course of two seasons, and an immediate “water drench” to push the herbicide into the root zone (**Table 7**).

When almonds are inadvertently exposed to glyphosate via drift, many growers use applications of foliar micronutrients in an attempt to ameliorate the damage. An exploratory line of research was conducted on pot-grown almond trees to explore this practice. In the work conducted to date, there has been little or no direct interaction between glyphosate activity and subsequently-applied micronutrient solutions (**Table 8, Figure 10** and data not shown). However, when the micronutrient treatments were applied before the simulated glyphosate drift, there was occasionally a reduction in symptom severity which suggests micronutrients on the leaf surface could reduce glyphosate absorption.

Herbicide-resistant weed biology: An understanding of the genetics and biology of herbicide-resistant weeds is part of developing integrated weed management programs. Several lines of research complementary to our almond weed management work continued in the current project.

The genetics and physiology of glyphosate-resistant junglerice is being evaluated as part of a CDFA-SCBG project also supported by the Almond Board of California. In this work, junglerice lines derived from populations originally collected in almond orchards have demonstrated different responses to foliar glyphosate as measured by shikimate accumulation assays (**Figure 7**). In subsequent evaluations of the genes coding for the EPSPS target enzyme, three different amino acid substitutions were found in various junglerice lines (**Figures 8 and 9**). However, it was interesting to note there were differences in the level of glyphosate resistance even among populations with the same mutation which suggests the likelihood of another contributing mechanism of resistance in some populations. This raises further questions about the accumulation of resistance traits within junglerice populations and also for movement of resistance genes among related weedy species.

A small greenhouse study was conducted by a visiting undergraduate scholar to evaluate the relative growth and vigor of glyphosate- and glyphosate-paraquat resistant Conyza species. In this work, the susceptible hairy fleabane population had a roughly similar production of above- and below-ground biomass whereas the two resistant populations produced more above ground mass but this trend was not observed in horseweed (**Figure 5**). Total leaf area was greatest in the glyphosate-paraquat resistant fleabane and in the susceptible horseweed which suggest that a simple difference in biomass allocation is not a major contributor to resistance in the Conyza complex of California. However, because this study was quite limited in scope, conclusions are still somewhat open.

Finally, several studies were initiated or conducted to evaluate the biology and morphology of several glyphosate-resistant junglerice populations from California. Germination success at different temperatures indicated a broad temperature range for this species in the state but did not suggest a wider or more narrow range related to glyphosate resistance (**Figure 11**). Similarly, while temperature and degree of shading significantly affected junglerice biomass allocation in growth chamber and shade tent studies, there were no clear relationships that appear to be related to glyphosate resistance (**Figure 12)**.

Research Effort Recent Publications:

Sosnoskie, L.M. and B.D. Hanson. 2016. Field bindweed control in early- and late-planted processing tomatoes. Weed Technology (in press).

Moretti, M.L., L.M. Sosnoskie, A. Shrestha, S.D. Wright, K.J. Hembree, M. Jasieniuk, and B.D. Hanson. 2016. Distribution of Conyza sp. In orchards of California and response to glyphosate and paraquat. Weed Science 64:339-347.

Moretti, M.L. 2016. Resistance to Glyphosate and Paraquat in *Conyza bonariensis* and *Conyza canadensis* from California Orchards: Management, Distribution, and Mechanism of Resistance. Ph.D. Davis, CA: University of California. 111 p.

Qin, R., S. Gao, H. Ajwa, and B.D. Hanson. 2016. Effect of application rate on fumigant degradation in five agricultural soils. STOTEN 541:528-534.

Moretti, M., A. Shrestha, K.J. Hembree, and B.D. Hanson. 2015. Postemergence control of glyphosate-paraquat resistant hairy fleabane (Conyza bonariensis) in tree nut orchards in the Central Valley of California. Weed Technol. 29:501-508.

Table 1. Response of Italian ryegrass populations S and PRHC to POST herbicides in the greenhouse. Davis, 2015/2016 (Brunharo and Hanson).

Herbicide	S	PRHC	
	GR_{50}	GR_{50}	RF
	g ha^{-1}	g ha^{-1}	
Envoy Plus	60.6	537.4	8.9
Fusilade	35.6	3.3	0.1
Roundup PowerMax	97.6	1438.2	14.7
Osprey	28.6	48.6	1.7
Gramoxone	NA*	1364.5	NA
Simplicity	1.8	42.9	23.6
Matrix	15.7	44.5	2.8
Poast	35.2	85038.9	2415.7

* NA: Could not be calculated.

Table 2. Field trial with POST herbicides or POST/PRE combinations for the control of Italian ryegrass. Hamilton City, CA, 2015 (Brunharo and Hanson).

	Treatment	**Mean ± SE (%)***
1	Untreated Check	-
2	Roundup PowerMax (32 fl oz/A)	47 ± 27
3	Gramoxone (2.5 pt/A)	67 ± 22
4	Gramoxone (4 pt/A)	72 ± 14
5	Rely (56 fl oz/A)	90 ± 10
6	Roundup PowerMax (32 fl oz/A) + Poast (1.5 pt/A)	75 ± 15
7	Roundup PowerMax (32 fl oz/A) + Fusilade (12 fl oz/A)	22 ± 13
8	Roundup PowerMax (32 fl oz/A) + Envoy (32 fl oz/A)	35 ± 15
9	Roundup PowerMax (32 fl oz/A) + Matrix (32 fl oz/A)	67 ± 14
10	Rely (56 fl oz/A) + Poast (1.5 pt/A)	47 ± 27
11	Rely (56 fl oz/A) + Fusilade (12 fl oz/A)	100 ± 0
12	Rely (56 fl oz/A) + Envoy (32 fl oz/A)	100 ± 0
13	Rely (56 fl oz/A) + Matrix (32 fl oz/A)	100 ± 0
14	Rely (56 fl oz/A) + Alion (2.5 fl oz/A)	50 ± 21
15	Rely (56 fl oz/A) + Surflan AS (2.5 pt/A)	88 ± 3

* Visual control at 28 days after treatment; mean visual control among four replications; means followed by the same letter are not significantly different, at the 5% level of the HSD test. Due to large variability among replicates, few statistical differences were noted among treatments

Table 3. Field trial with PRE herbicides for the control of Italian ryegrass. Hamilton City, CA, 2015/2016 (Brunharo and Hanson).

	Treatment	Rate	Visual Control (%) Mean ± SE*
1	Untreated Check		-
2	Alion	3.5 fl oz/A	100 ± 0 a
3	Alion	5 fl oz/A	100 ± 0 a
4	Alion + Chateau	3.5 fl oz/A + 6 oz/A	100 ± 0 a
5	Alion + GoalTender	3.5 fl oz/A + 3 pt/A	100 ± 0 a
6	Alion + Matrix	3.5 fl oz/A + 2 oz/A	100 ± 0 a
7	Matrix	4 oz/A	46 ± 5 d
8	Chateau	12 oz/A	90 ± 2 bc
9	Chateau + Prowl	6 oz/A + 4 qt/A	95 ± 2 abc
10	Chateau + Surflan AS	6 oz/A + 2 qt/A	89 ± 2 bc
11	Surflan AS	4 qt/A	96 ± 1 ab
12	GoalTender	3 pt/A	93 ± 3 abc
13	Prowl	4 qt/A	93 ± 3 abc
14	Broadworks + Prowl	6 fl oz/A + 2 qt/A	67 ± 3 d
15	Broadworks + Surflan AS	6 fl oz/A + 2 qt/A	85 ± 3 c
16	Alion 500 SC	1.4 fl oz/A	100 ± 0 a
17	Alion 500 SC + Matrix	1.4 fl oz/A + 2 oz/A	100 ± 0 a

* Visual control at 150 days after treatment; means followed by the same letter are not significantly different, at the 5% level of the HSD test.

Table 4. Burndown comparison of OR-009 surfactant vs NIS with glyphosate or glufosinate in an orchard trial in 2016 near Davis, CA (Brunharo and Hanson).

Pest Name				Milk thistle	Filaree	Shep. purse	Henbit	Groundsel	Fiddleneck	Redmaids
Trt-Eval Interval				---------------% control 8 days after application ---------------						
1	Untreated Check			0	0	0	0	0	0	0
2	Rely 280	56	fl oz/a	76.3	85	55	87.5	57.5	75	73.8
	AMS	10	lb ai/100 gal							
	NIS	0	% v/v							
3	Rely 280	56	fl oz/a	85	82.5	57.5	85	55	63.8	70
	AMS	10	lb ai/100 gal							
	OR 009	0	% v/v							
4	Rely 280	72	fl oz/a	95	95	62.5	98.8	67.5	66.3	77.5
	AMS	10	lb ai/100 gal							
	NIS	0	% v/v							
5	Rely 280	72	fl oz/a	93.8	92.5	52.5	97.5	60	65	77.5
	AMS	10	lb ai/100 gal							
	OR 009	0	% v/v							
6	Roundup PowerMax	22	fl oz/a	15	37.5	30	45	22.5	35	42.5
	AMS	10	lb ai/100 gal							
	NIS	0	% v/v							
7	Roundup PowerMax	22	fl oz/a	25	50	42.5	55	25	35	45
	AMS	10	lb ai/100 gal							
	OR 009	0	% v/v							
8	Roundup PowerMax	32	fl oz/a	17.5	55	25	45	20	42.5	50
	AMS	10	lb ai/100 gal							
	NIS	0	% v/v							
9	Roundup PowerMax	32	fl oz/a	17.5	57.5	35	47.5	22.5	40	37.5
	AMS	10	lb ai/100 gal							
	OR 009	0	% v/v							
LSD P=.05				23.0	26.1	15.6	22.0	21.1	13.2	18.0

Table 5. Greenhouse cross-resistance screening of glyphosate- and paraquat-resistant Conyza biotypes. Resistance to diquat was noted; however, no cross resistance to other herbicide modes of action was observed (Moretti, Bobadilla, and Hanson).

		C. bonariensis			C. canadensis		
Herbicide	Biotype	GR50	±SE	R/S	GR50	±SE	R/S
		kg ha-1			kg ha-1		
Rimsulfuron	GPS	0.2	0.15		0.57	0.25	
	GR	0.16	0.11	0.8	0.18	0.07	0.3*
	GPR	0.2	0.02	0.1*	0.13	0.03	0.2*
2,4-D	GPS	0.14	0.09		0.14	0.4	
	GR	0.12	0.05	0.9	0.2	0.05	1.4
	GPR	0.33	0.11	2.4	0.26	0.1	1.8
Dicamba	GPS	0.5	0.02		0.01	0.002	
	GR	0.11	0.02	2.3*	0.004	0.005	0.5
	GPR	0.6	0.01	1.2	0.054	0.021	5.7*
Hexazinone	GPS	0.005	0.002		0.005	0.001	
	GR	0.003	0	0.7	0.002	0.001	0.5*
	GPR	0.005	0.001	1	0.003	0.001	0.6
Glufosinate	GPS	0.13	0.04		0.12	0.03	
	GR	0.06	0.02	0.4	0.07	0.02	0.6
	GPR	0.14	0.06	1.1	0.09	0.02	0.8
Flumioxazin	GPS	0.006	0.002		0.004	0	
	GR	0.007	0.002	1.2	0.004	0	1
	GPR	0.003	0.001	0.6	0.003	0	0.8
Saflufenacil	GPS	0.001	n/c		0.001	0	
	GR	0	0	0.2	0	0	0.3
	GPR	0	0	0.2	0	0	0.2
Diquat	GPS	0.03	0.07		0.02	0	
	GR	0.01	0.001	0.4	0.01	0	0.8
	GPR	0.2	0.01	6.0*	0.27	0.05	14.5*
Mesotrione	GPS	0.07	n/c		0.012	0.003	
	GR	0.066	n/c	0.9	0.071	n/c	6
	GPR	0.014	0.017	0.2	0.018	0.007	1.5

Table 6. Effects of glyphosate on soil micronutrients. Glyphosate was mixed into a Rincon clay loam or Delhi sand at rates approximating 1 lb ae/A (low) or 32 lb ae/A (high) and micronutrients determined using three extraction techniques after four days of incubation in the greenhouse. Soils were fertilized with a balanced micronutrient solution or left unfertilized prior to the addition of the glyphosate solution (Yildiz Kutman and Hanson).

DTPA Extractable Soil Nutrients (mg L^{-1})

Soil Type	Soil Glyphosate	Soil Nutrients	[Zn]	[Fe]	[Cu]	[Mn]	[Ni]	[Ca]	[Mg]
Clay Loam	None	None	3.6 ± 0.3	26 ± 1	10.6 ± 0.4	26.7 ± 1.3	6.1 ± 0.2	224 ± 12	800 ± 6
	Low		3.9 ± 0.1	26 ± 1	10.8 ± 0.2	25.2 ± 1.4	6.0 ± 0.1	233 ± 19	808 ± 7
	High		3.8 ± 0.3	27 ± 1	10.7 ± 0.3	24.7 ± 1.4	6.0 ± 0.2	243 ± 13	816 ± 9
	None	Fertilized	4.2 ± 0.2	27 ± 1	10.5 ± 0.2	24.6 ± 0.6	5.8 ± 0.1	379 ± 12	854 ± 9
	Low		4.2 ± 0.4	25 ± 1	10.2 ± 0.2	23.4 ± 0.4	5.7 ± 0.1	361 ± 18	838 ± 10
	High		4.2 ± 0.1	26 ± 1	10.4 ± 0.2	24.9 ± 1.5	5.8 ± 0.1	375 ± 19	846 ± 13
Sandy Loam	None	None	0.1 ± 0.0	9 ± 0	0.25 ± 0.01	1.5 ± 0.0	*n.d.* ± *n.d.*	90 ± 6	34 ± 0
	Low		0.1 ± 0.0	9 ± 0	0.23 ± 0.02	1.5 ± 0.1	*n.d.* ± *n.d.*	91 ± 11	34 ± 1
	High		0.1 ± 0.0	10 ± 0	0.25 ± 0.01	1.8 ± 0.0	*n.d.* ± *n.d.*	96 ± 3	34 ± 1
	None	Fertilized	0.7 ± 0.0	10 ± 0	0.29 ± 0.01	4.3 ± 0.1	*n.d.* ± *n.d.*	312 ± 15	35 ± 2
	Low		0.7 ± 0.0	11 ± 0	0.29 ± 0.01	4.3 ± 0.1	*n.d.* ± *n.d.*	307 ± 13	34 ± 1
	High		0.7 ± 0.0	11 ± 0	0.32 ± 0.00	4.5 ± 0.1	*n.d.* ± *n.d.*	318 ± 9	36 ± 1

Mehlich III Extractable Soil Nutrients (mg L-1)

Soil Type	Soil Glyphosate	Soil Nutrients	[Zn]	[Fe]	[Cu]	[Mn]	[Ni]	[Ca]	[Mg]
Clay Loam	None	None	7.2 ± 0.2	145 ± 4	22.3 ± 0.5	217 ± 4	16.8 ± 0.2	2172 ± 22	2125 ± 23
	Low		7.4 ± 0.2	143 ± 3	21.5 ± 0.5	211 ± 4	16.3 ± 0.2	2096 ± 30	2050 ± 22
	High		7.3 ± 0.4	145 ± 3	22.1 ± 0.6	212 ± 4	16.2 ± 0.3	2116 ± 18	2065 ± 20
	None	Fertilized	7.9 ± 0.3	148 ± 2	21.6 ± 0.9	206 ± 7	16.0 ± 0.8	2326 ± 96	2038 ± 92
	Low		8.1 ± 0.4	147 ± 2	22.1 ± 0.3	212 ± 4	16.5 ± 0.3	2357 ± 19	2056 ± 9
	High		8.6 ± 1.4	144 ± 1	22.2 ± 0.1	205 ± 1	15.9 ± 0.2	2351 ± 20	2057 ± 13
Sandy Loam	None	None	0.3 ± 0.0	68 ± 1	0.44 ± 0.02	12 ± 0	0.13 ± 0.01	222 ± 4	45 ± 1
	Low		0.4 ± 0.0	68 ± 1	0.45 ± 0.03	12 ± 0	0.13 ± 0.01	225 ± 9	47 ± 2
	High		0.3 ± 0.0	66 ± 2	0.45 ± 0.02	11 ± 0	0.14 ± 0.01	228 ± 11	47 ± 3
	None	Fertilized	1.2 ± 0.0	73 ± 1	0.50 ± 0.02	14 ± 0	0.14 ± 0.01	523 ± 25	49 ± 3
	Low		1.2 ± 0.0	74 ± 2	0.48 ± 0.01	14 ± 0	0.14 ± 0.01	489 ± 37	47 ± 4
	High		1.2 ± 0.0	71 ± 1	0.50 ± 0.02	13 ± 0	0.15 ± 0.01	508 ± 18	49 ± 2

Water Extractable Soil Nutrients (mg L-1)

Soil Type	Soil Glyphosate	Soil Nutrients	[Zn]	[Fe]	[Cu]	[Mn]	[Ni]	[Ca]	[Mg]
Clay Loam	None	None	0.07 ± 0.04	0.60 ± 0.17	0.11 ± 0.01	0.05 ± 0.01	0.06 ± 0.00	19 ± 1	25 ± 1
	Low		0.03 ± 0.01	0.51 ± 0.08	0.10 ± 0.00	0.04 ± 0.01	0.06 ± 0.00	19 ± 1	24 ± 1
	High		0.02 ± 0.00	0.52 ± 0.09	0.11 ± 0.01	0.05 ± 0.01	0.06 ± 0.00	20 ± 2	25 ± 3
	None	Fertilized	0.31 ± 0.03	1.18 ± 0.03	0.55 ± 0.04	0.04 ± 0.01	0.11 ± 0.01	101 ± 4	125 ± 5
	Low		0.32 ± 0.01	1.20 ± 0.01	0.55 ± 0.03	0.04 ± 0.01	0.11 ± 0.00	101 ± 2	124 ± 2
	High		0.35 ± 0.01	1.25 ± 0.03	0.57 ± 0.03	0.05 ± 0.01	0.12 ± 0.00	105 ± 9	129 ± 12
Sandy Loam	None	None	*n.d.* ± *n.d.*	0.22 ± 0.06	*n.d.* ± *n.d.*	0.08 ± 0.01	*n.d.* ± *n.d.*	5 ± 0	1 ± 0
	Low		*n.d.* ± *n.d.*	0.19 ± 0.03	*n.d.* ± *n.d.*	0.07 ± 0.01	*n.d.* ± *n.d.*	5 ± 0	1 ± 0
	High		*n.d.* ± *n.d.*	0.40 ± 0.16	0.04 ± 0.01	0.10 ± 0.00	*n.d.* ± *n.d.*	6 ± 0	2 ± 0
	None	Fertilized	0.21 ± 0.01	1.88 ± 0.13	0.12 ± 0.01	0.89 ± 0.07	0.03 ± 0.01	232 ± 22	24 ± 2
	Low		0.22 ± 0.02	2.02 ± 0.22	0.13 ± 0.01	0.98 ± 0.10	0.04 ± 0.00	250 ± 23	26 ± 3
	High		0.25 ± 0.01	1.76 ± 0.10	0.14 ± 0.00	0.94 ± 0.06	0.04 ± 0.00	223 ± 18	23 ± 2

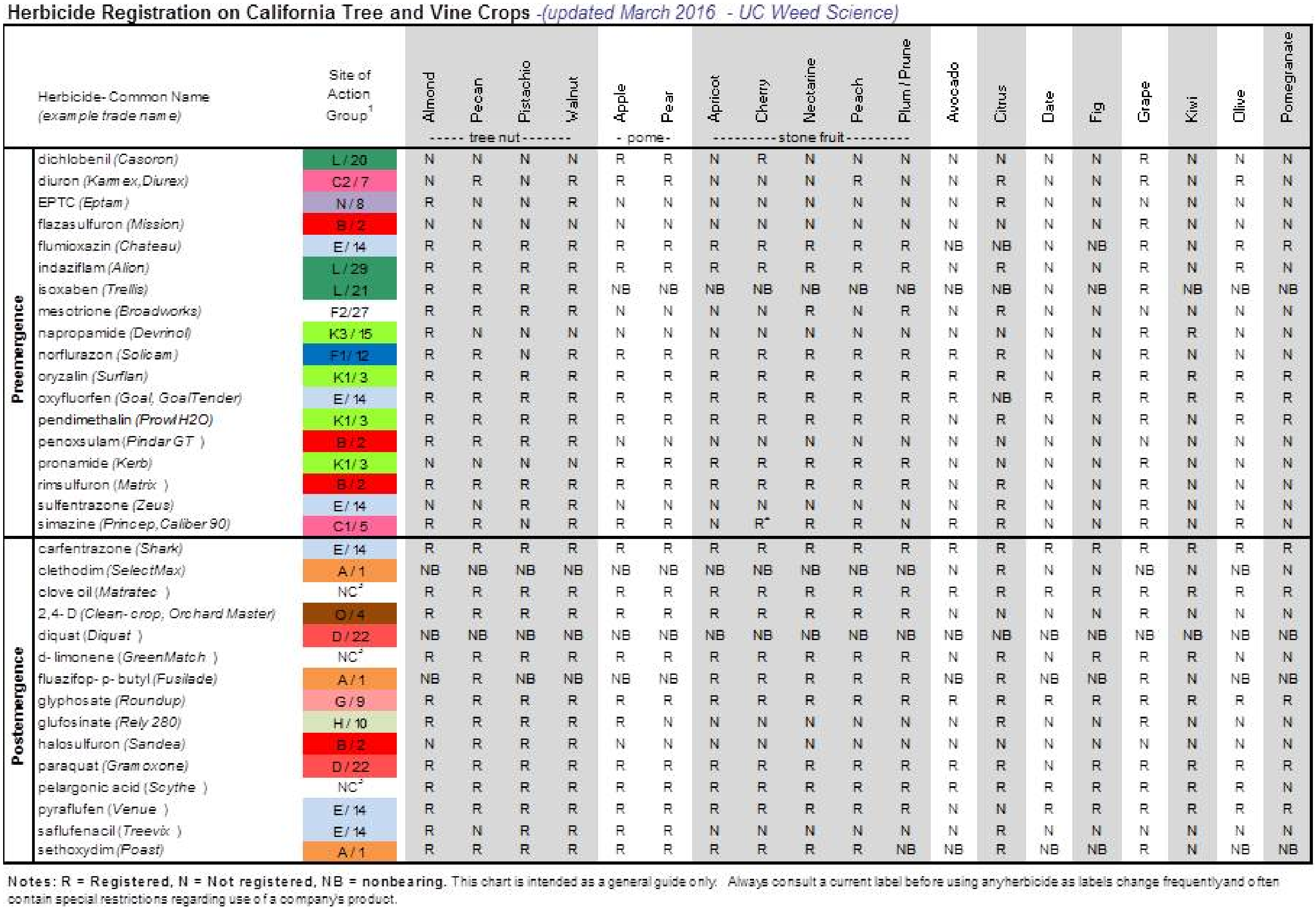
Table 7. Effects of glyphosate applications on almond leaf chlorophyll concentration (SPAD value). Glyphosate was applied three times in 2014 and three times in 2015 at 1, 2, and 4x rates and half received a post treatment drench of approximately 1 acre-inch around the crown of the tree immediately after spraying. Data presented are the SPAD values 30 days after each of the 2015 glyphosate applications (Yildiz Kutman and Hanson).

Soil Type	Post-treatment drench	Glyphosate rate	30 DAT trt 1	30 DAT trt 2	30 DAT trt 3
		(kg ae/ha)	SPAD values and SE		
Clay Loam	No	0.00	31 ± 1	36 ± 1	37 ± 2
		1.12	31 ± 2	34 ± 4	36 ± 1
		2.24	31 ± 1	36 ± 1	34 ± 6
		4.48	31 ± 1	35 ± 1	37 ± 2
	Yes	0.00	31 ± 2	35 ± 2	38 ± 1
		1.12	30 ± 1	34 ± 1	36 ± 3
		2.24	32 ± 1	34 ± 1	38 ± 1
		4.48	32 ± 2	34 ± 1	34 ± 2
Sandy Loam	No	0.00	31 ± 1	36 ± 0	37 ± 2
		1.12	31 ± 2	36 ± 5	37 ± 1
		2.24	32 ± 2	35 ± 2	35 ± 3
		4.48	30 ± 2	35 ± 1	37 ± 3
	Yes	0.00	31 ± 1	33 ± 3	38 ± 3
		1.12	31 ± 1	35 ± 1	34 ± 5
		2.24	32 ± 1	36 ± 2	38 ± 2
		4.48	32 ± 1	34 ± 1	36 ± 2

* *glyphosate treatments applied in April, June, and August of 2014 and 2015.*

Table 8. Effects of simulated glyphosate drift and foliar micronutrients on young almond trees in a greenhouse study in 2015. Glyphosate was applied as a foliar mist and solutions of elemental micronutrients were applied either three days before or after the glyphosate treatments (Yildiz Kutman and Hanson).

ALMOND Symptom Scoring						
Glyphosate rate (% rec*)	**Pre-treatment foliar application**	**Post-treatment foliar application**	**New Growth (0-2)**	**Leaf Injury (0-2)**	**Gumming Score (0-3)**	**SPAD**
0	None	None	1.3 ± 1.0	0.0 ± 0.0	0.0 ± 0.0	34 ± 1
3			0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	27 ± 3
6			0.0 ± 0.0	1.8 ± 0.4	1.2 ± 0.8	27 ± 6
0	Mn	None	1.0 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	34 ± 1
3			1.6 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	37 ± 1
6			0.0 ± 0.0	1.4 ± 0.5	1.0 ± 1.0	29 ± 3
0	Ni	None	1.0 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	34 ± 1
3			1.2 ± 1.1	0.4 ± 0.5	0.2 ± 0.4	33 ± 5
6			0.0 ± 0.0	2.0 ± 0.0	1.8 ± 1.3	30 ± 3
0	Zn	None	0.3 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	32 ± 2
3			1.2 ± 0.8	0.0 ± 0.0	0.0 ± 0.0	35 ± 1
6			0.6 ± 0.5	1.2 ± 0.4	0.2 ± 0.4	31 ± 3
0	None	Mn	1.4 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	33 ± 4
3			0.8 ± 0.8	0.6 ± 0.5	0.2 ± 0.4	33 ± 4
6			0.0 ± 0.0	1.6 ± 0.9	3.0 ± 0.0	*n.a.* ± *n.a.*
0	None	Ni	1.4 ± 0.9	0.0 ± 0.0	0.0 ± 0.0	33 ± 5
3			0.4 ± 0.5	0.8 ± 0.4	0.0 ± 0.0	31 ± 2
6			0.2 ± 0.4	2.0 ± 0.0	1.8 ± 1.1	*n.a.* ± *n.a.*
0	None	Zn	0.4 ± 0.5	0.4 ± 0.5	0.0 ± 0.0	34 ± 2
3			0.0 ± 0.0	1.2 ± 0.4	0.0 ± 0.0	33 ± 2
6			0.0 ± 0.0	1.8 ± 0.4	2.4 ± 1.3	*n.a.* ± *n.a.*



Herbicide Registration on California Tree and Vine Crops -*(updated March 2016 - 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	R	R
	indaziflam *(Alion)*	L / 29	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	R	N
	isoxaben *(Trellis)*	L / 21	R	R	R	R	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	NB	R	NB	NB	NB
	mesotrione *(Broadworks)*	F2/27	R	R	R	R	N	N	N	N	R	N	R	N	R	N	N	N	N	N	N
	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 H2O)*	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)*	B / 2	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	N	N
	sulfentrazone *(Zeus)*	E/ 14	N	N	R	R	N	N	N	N	N	N	N	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
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 *(SelectMax)*	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[2]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	2,4- D *(Clean- crop, 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[2]	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	R	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	R	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)*	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[2]	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: R = Registered, N = Not registered, NB = nonbearing. 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.

Figure 1. Most recent update of tree and vine herbicide registration table. (Hanson)

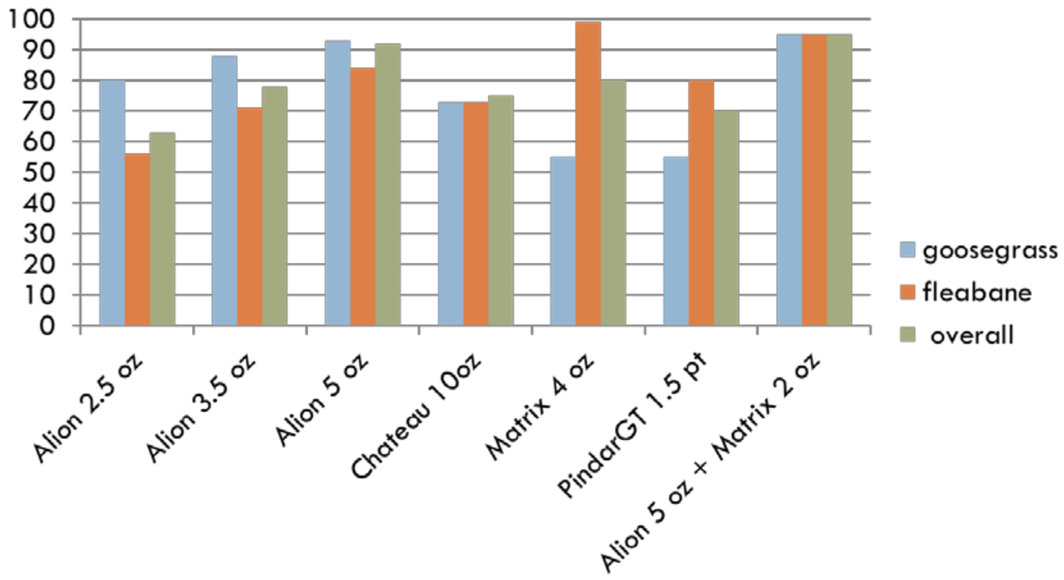


Figure 2. Weed control evaluations in an almond orchard trial near Escalon, CA. Treatments were applied to the same plots in December 2013 and January 2015; data are from May 2015 (Watkins and Hanson).

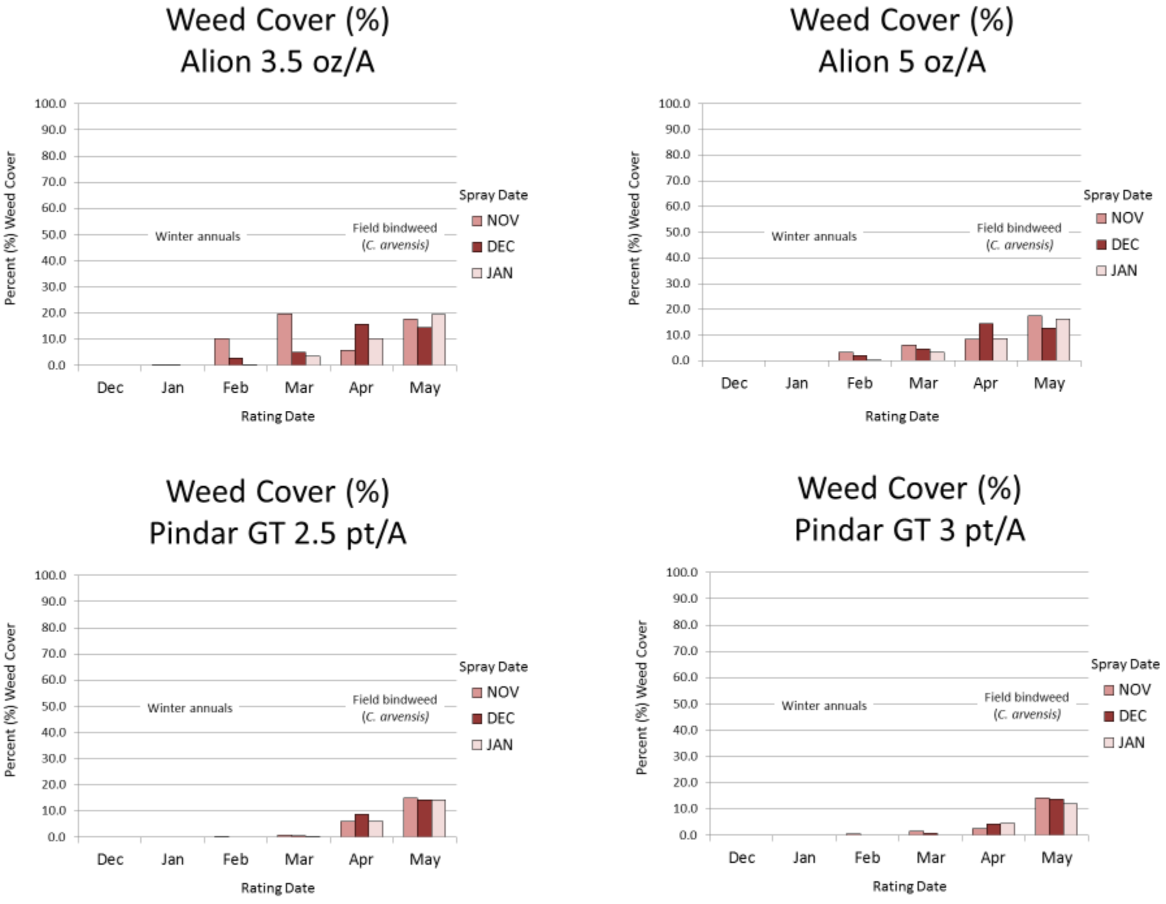


Figure 3. Residual control of winter annual weeds and field bindweed following winter (Nov., Dec., or Jan.) applications of Alion and Pindar GT. (Sosnoskie, Watkins, and Hanson).

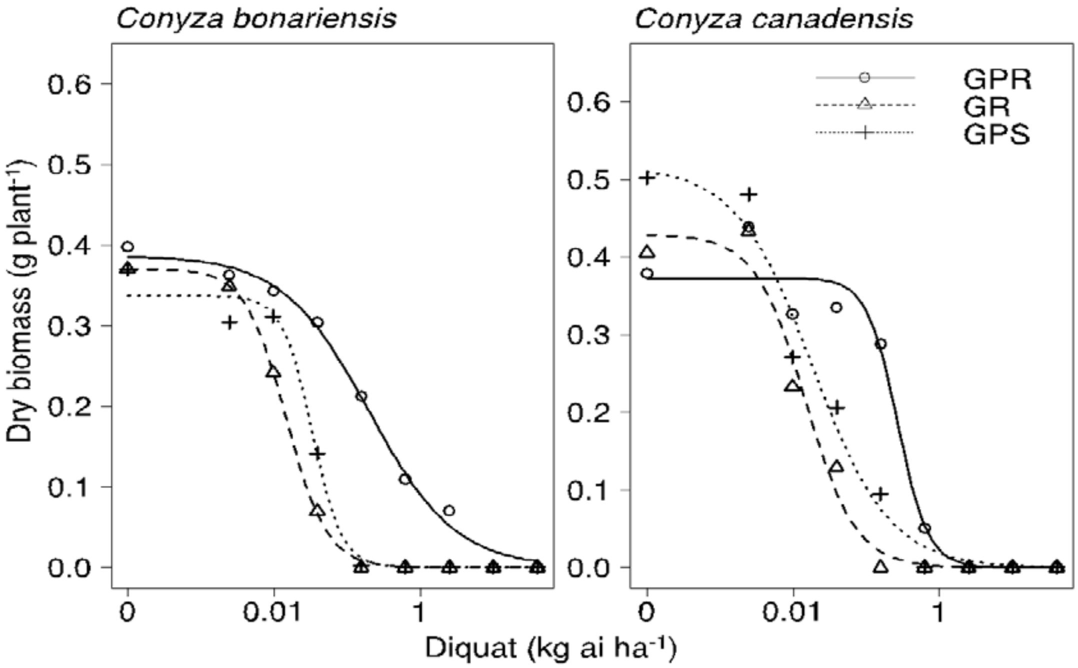


Figure 4. Greenhouse evaluations of glyphosate- and paraquat-resistant Conyza biotypes. Dry biomass 21 days after diquat treatment for glyphosate-paraquat-susceptible (GPS), glyphosate-resistant (GR), and glyphosate-paraquat-resistant (GPR) biotypes of Conyza bonariensis (left) and Conyza canadensis (right) (Moretti, Bobadilla, and Hanson).

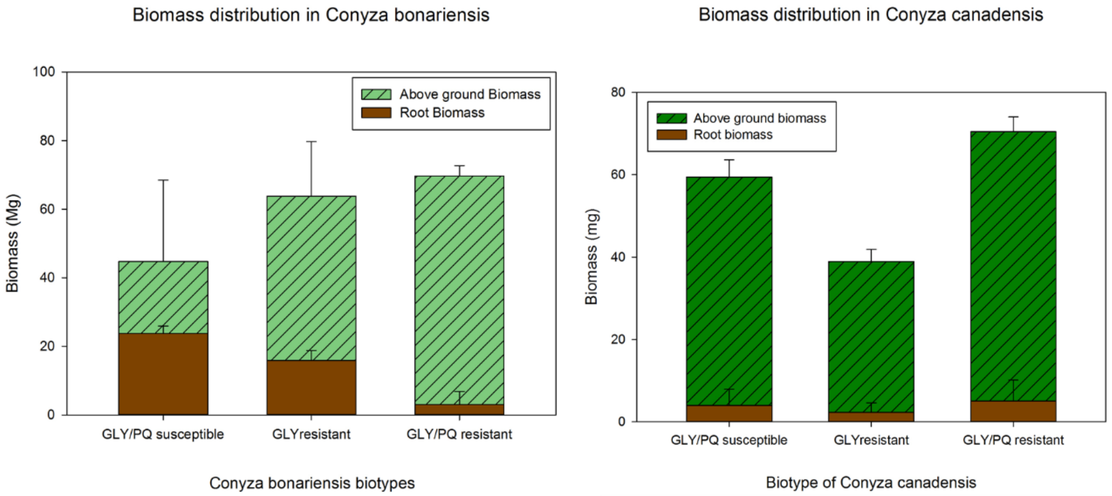


Figure 5. Above- and below-ground biomass distribution of glyphosate-susceptible, glyphosate-resistant, and glyphosate-paraquat resistant hairy fleabane (C. bonariensis) and horseweed (C. canadensis) in a greenhouse experiment (Bobadilla, Moretti, and Hanson).

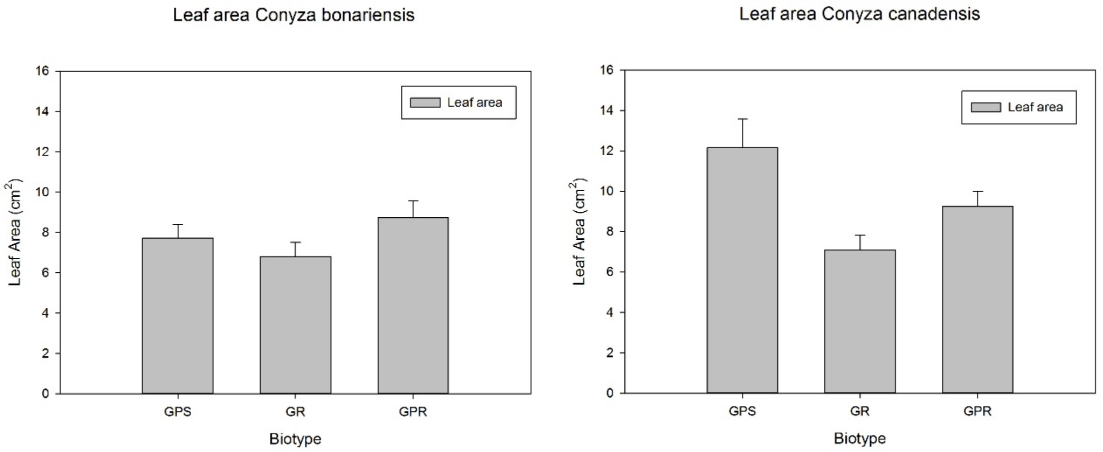


Figure 6. Leaf area comparisons of glyphosate-susceptible, glyphosate-resistant, and glyphosate-paraquat resistant hairy fleabane (C. bonariensis) and horseweed (C canadensis) in a greenhouse experiment (Bobadilla, Moretti, and Hanson).

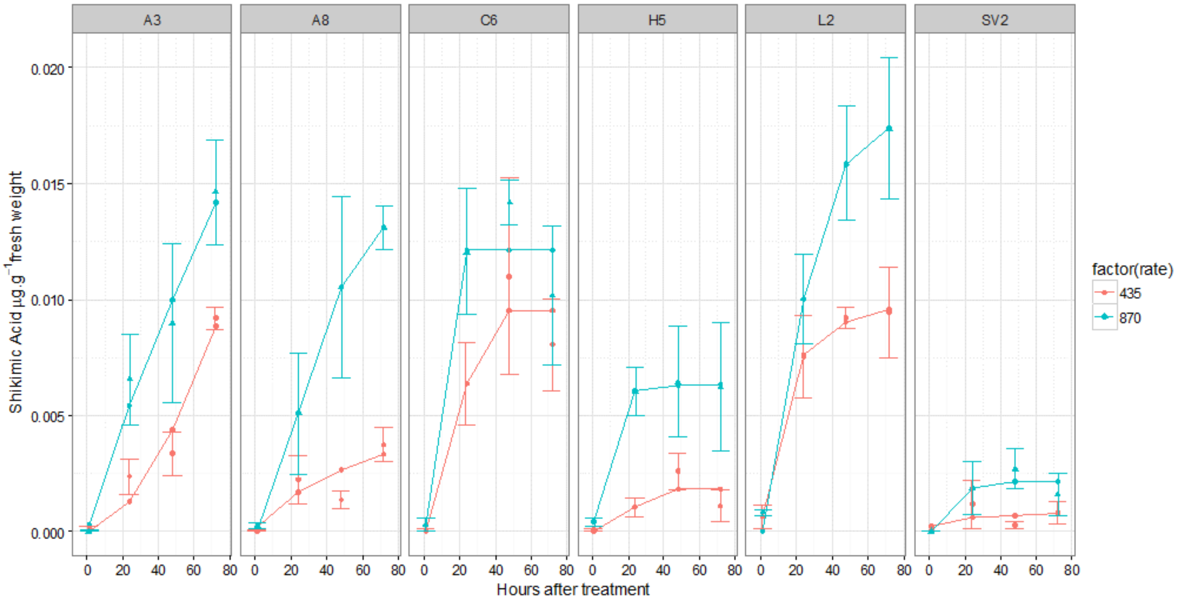
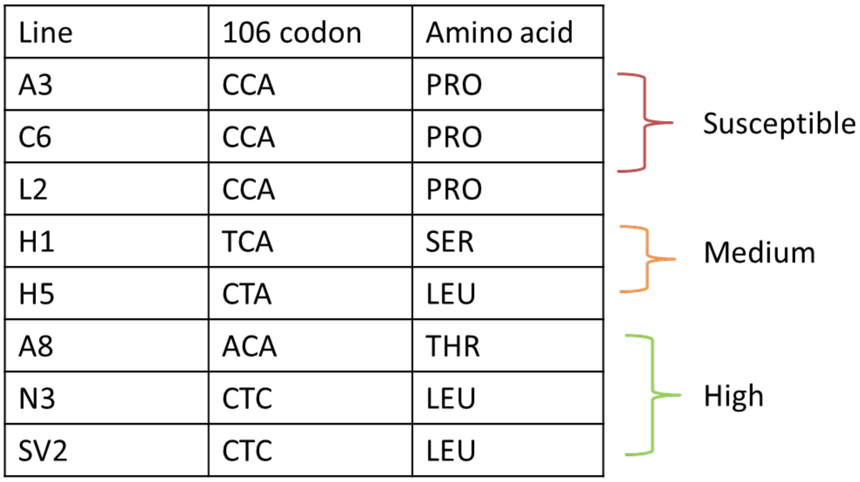


Figure 7. Shikimate accumulation as a measure of glyphosate activity in six junglerice populations from the Central Valley. Population “SV2” may have a novel mechanism of resistance or possibly multiple contribution mechanisms compared to other resistant populations (Morran and Hanson).



Line	106 codon	Amino acid
A3	CCA	PRO
C6	CCA	PRO
L2	CCA	PRO
H1	TCA	SER
H5	CTA	LEU
A8	ACA	THR
N3	CTC	LEU
SV2	CTC	LEU

Figure 8. Deduced amino acid residues at position 106 in the gene coding for the EPSPS enzyme (target site for glyphosate). Three different amino acid substitutions were found compared to the proline (PRO) in the wildtype. Interestingly, some populations with the same substitution had very different levels of resistance at the whole plant level which suggests additional mechanisms or other factors (Morran and Hanson).

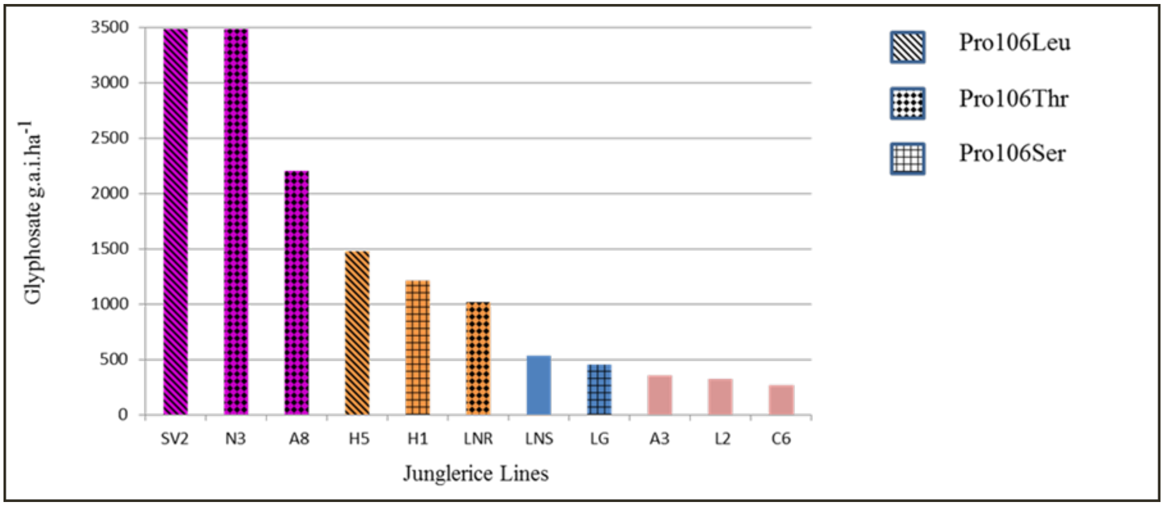


Figure 9. Relative sensitivity (GR50) of 11 junglerice populations with different amino acid substitutions and residue 106 in the EPSPS gene coding region (Morran and Hanson).

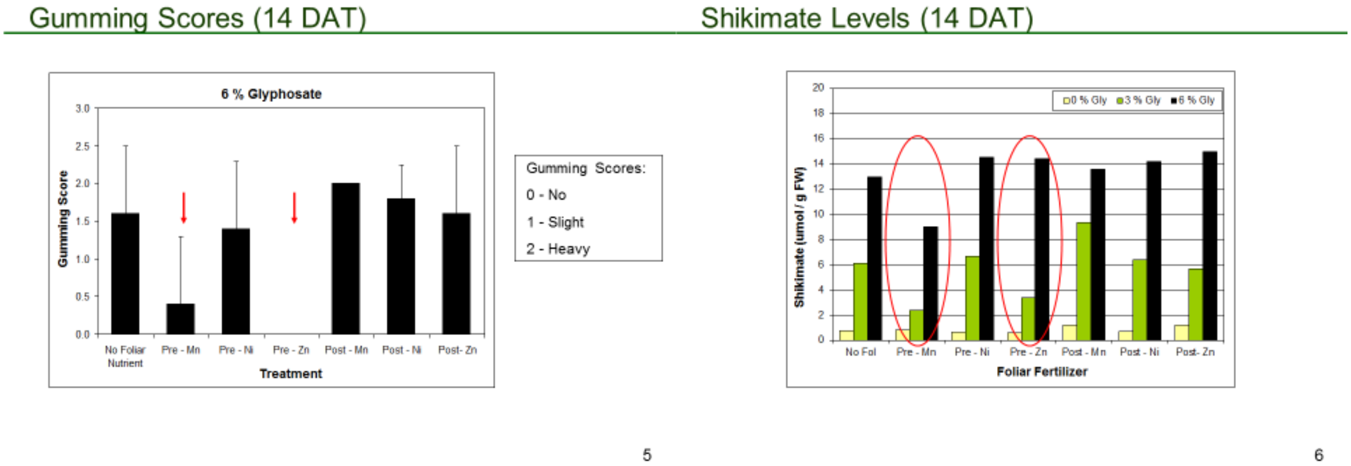
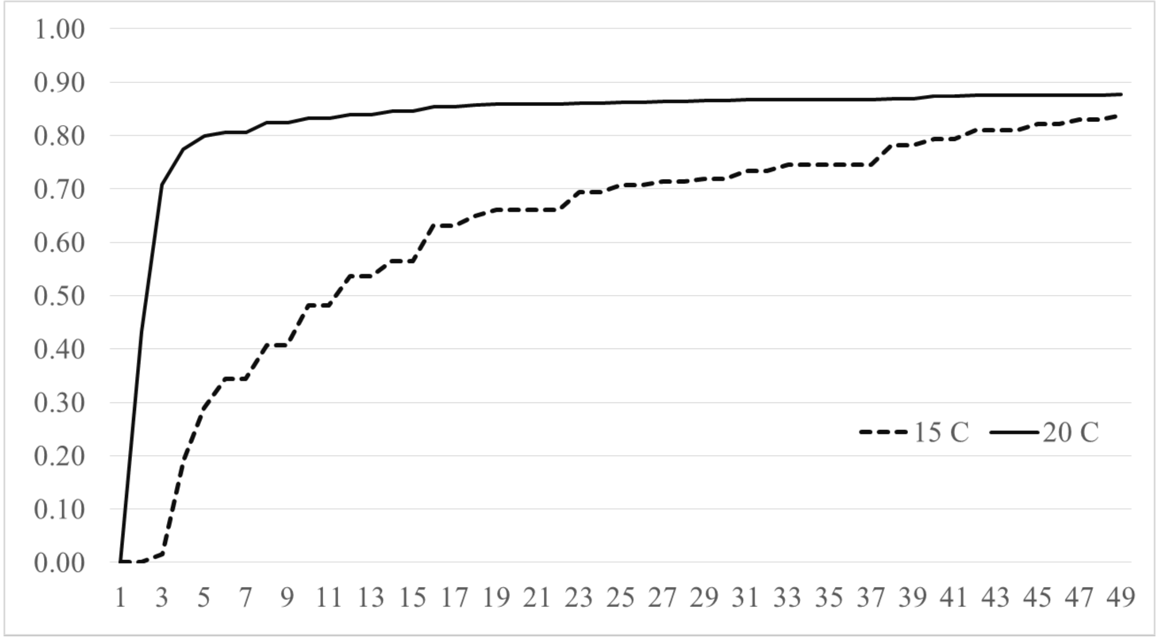


Figure 10. Effects of simulated glyphosate drift and foliar micronutrients on young almond trees in a greenhouse study in 2015. Glyphosate was applied as a foliar mist and solutions of elemental micronutrients were applied either three days before or after the glyphosate treatments (Yildiz Kutman and Hanson).



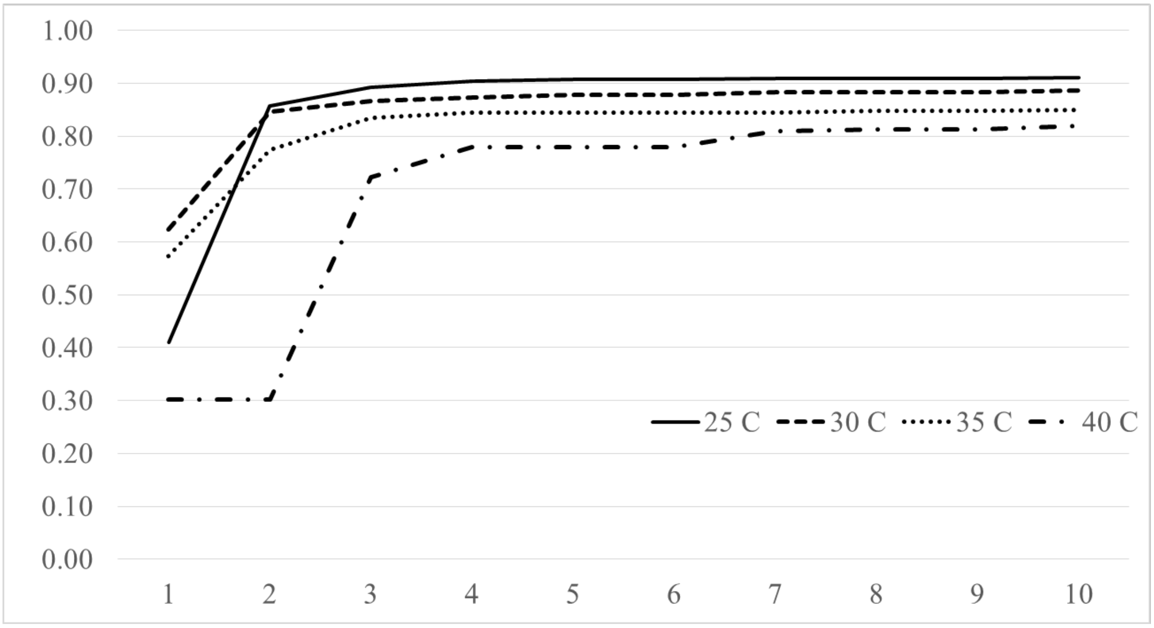


Figure 11. Proportion (cumulative) of junglerice seeds germinating over time (days) for each of six temperatures. Results for the 15 and 20°C temperatures are presented in **Figure A**; results for the 25 to 40 C temperatures are presented in **Figure B**. Data are averaged over all junglerice accessions (Sosnoskie, Ceseski, Parry, Shrestha, Hanson)

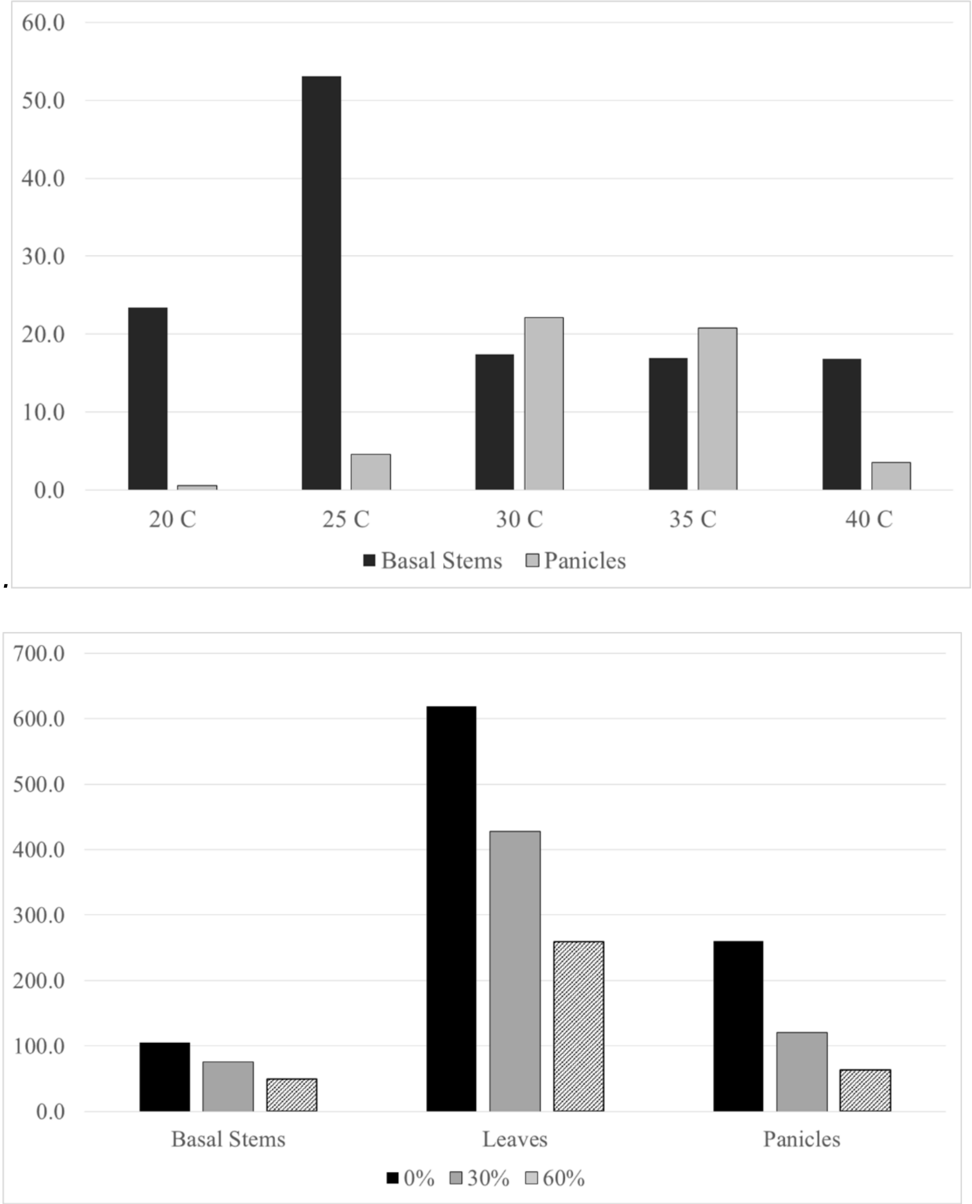


Figure 12. Junglerice stem and panicle production (number), averaged over 6 populations, in response to temperature at 28 days after initiation of the treatments (top) and junglerice stem, leaf, and panicle production (number), averaged across accessions and locations, in response to shade at 28 days after initiation of the treatments (bottom) (Sosnoskie, Ceseski, Parry, Shrestha, Hanson).