Grapevine leafroll and red blotch diseases:
applying science to management

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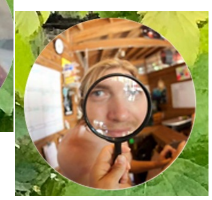
Funding:
American Vineyard Foundation, Viticulture Consortium West
CDFA PD/GWSS Program
USDA-NIFA-SCRI
Napa County Wine Grape Pest & Disease Control District

University of California Cooperative Extension

A Tradition of Stewardship
A Commitment to Service





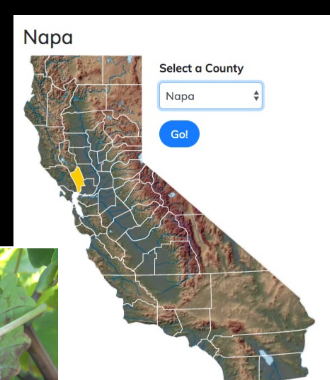


1

Consequential grapevine viral diseases in California

Leafroll disease


Red blotch disease

University of California Cooperative Extension

2

What is the significance of red blotch and leafroll diseases to California grape growers?

Acute impacts

Grapevine red blotch disease

Decreased transpiration (-40%) & carbon assimilation (-40%)
Decreased photosynthesis
Inefficient water conduction
Elevated glucose (+40%) in leaves

Decreased TSS (-20%), anthocyanin (-20%), flavonol (-20%), yeast assimilable nitrogen; Elevated TA
Wines with: "Thin mouthfeel, green & grainy tannins, suppressed fruit"; "less body and aftertaste, lower intensity of black and red fruit character, increased acidity and intensity of vegetal character

Grapevine leafroll disease

reduced yield & anthocyanin
delayed sugar accumulation

Al Rwahnih et al. 2015. Plant Disease 99: 895
Blanco-Ulate et al. 2017. J. Exper. Botany 68: 1225- 1238
Bowen et al. 2020. AJEV 71: 308-318
Girardello et al. 2019. J. Agric. Food Chem 67: 5496-5511
Guidoni et al. 2000. Acta Horticulturae 526: 445-452
Lee et al. 2009. Food Chem 117: 99-105
Martínez-Lüscher et al. 2019. J Agric Food Chem 67: 2437-2448
Woodrum et al. 1984. Vitis 23: 73-83

3

What is the significance of red blotch and leafroll diseases to California grape growers?

Long-term impacts

Impaired water & nutrient translocation & carbohydrate storage affects growth, fruitfulness, cold tolerance

Impaired translocation of systemic insecticides results in suboptimal vector (and pest) management

Interactions with other viruses (GVA)
Poor healing of graft union (table grape)

Lower salability and market demand for fruit from infected vines; suboptimal fruit contracts and negotiating power

Management costs and logistics
Labor implications

Al Rwahnih et al. 2015. Plant Disease 99: 895
Blanco-Ulate et al. 2017. J. Exper. Botany 68: 1225- 1238
Bowen et al. 2020. AJEV 71: 308-318
Girardello et al. 2019. J. Agric. Food Chem 67: 5496-5511
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Woodrum et al. 1984. Vitis 23: 73-83

4

What is the significance of red blotch and leafroll diseases to California grape growers?

Survey results (2019, 2020)

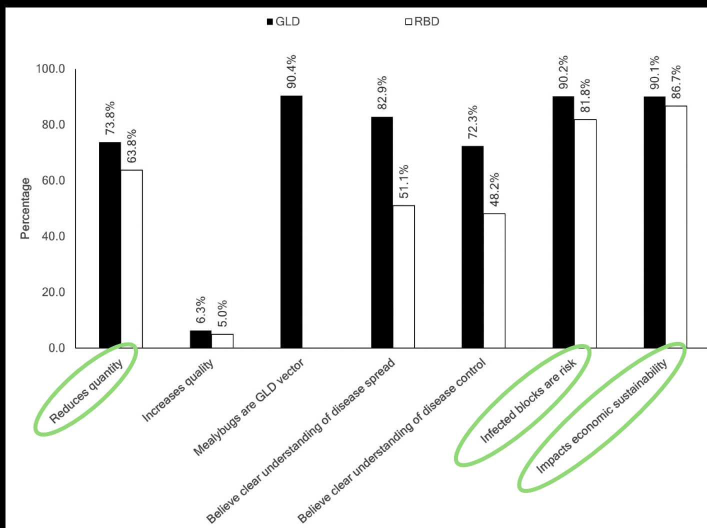


FIGURE 7
Respondents that answered "true" to statements about grapevine leafroll disease (GLD) and grapevine red blotch disease (RBD) ($n =$ 136 to 143 for each statement).

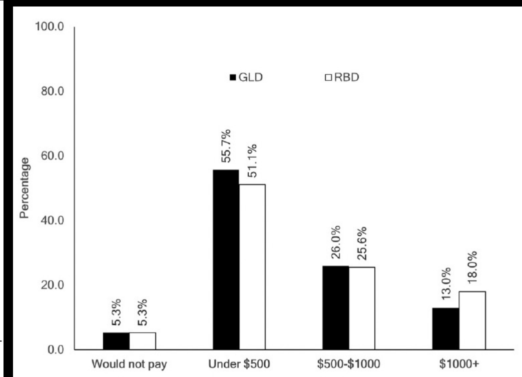


FIGURE 6
Respondents that would pay select cost brackets (per acre) for a control program for grapevine leafroll disease (GLD) ($n = 131$) and grapevine red blotch disease (RBD) ($n = 133$). Note:

Hobbs et al. 2022. doi 10.1094/PHYTOFR-07-21-0045-R

5

Are there regional differences? [perceptions & impacts]

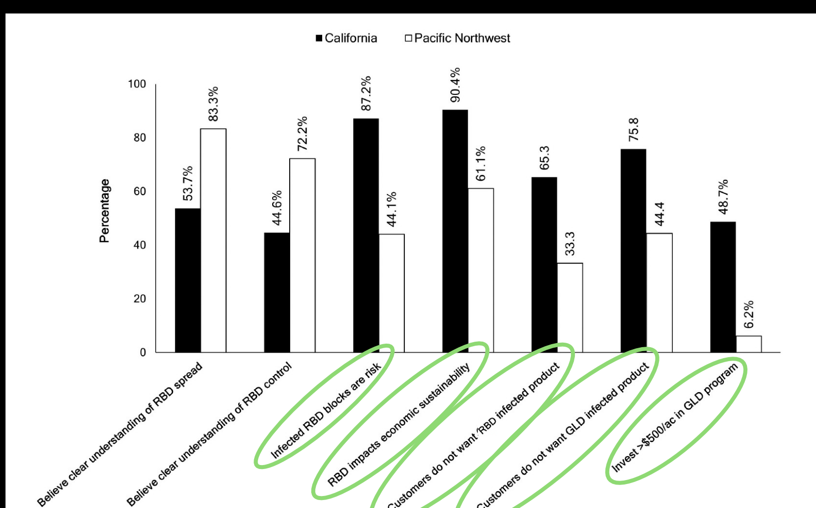


FIGURE 9
Regional differences in responses between California and the Pacific Northwest. Respondents in California found it harder to sell products infected with grapevine leafroll disease (GLD; $P = 0.009$) or grapevine red blotch disease (RBD; $P = 0.005$); believed vineyard blocks with RBD are a risk to neighboring vineyards ($P < 0.000$) and that RBD impacts the economic sustainability of the industry ($P = 0.001$); were willing to invest more than $500/ac in a management program ($P = 0.007$). Respondents in the Pacific Northwest thought there was a clear understanding of how RBD spreads ($P = 0.003$) and how to control it ($P = 0.029$).

Local expertise & outreach programs can address regional differences

Hobbs et al. 2022. doi 10.1094/PHYTOFR-07-21-0045-R

6

Are there regional differences? [biology & ecology]

Vector species composition

Grape mealybug	Obscure mealybug	Vine mealybug
Geographic origin Nearctic	Geographic origin Neotropic	Geographic origin Palearctic
1.5 generations/year	2-3 generations/year	4-8 generations/year



Photos: KM Daane

Daane et al. 2012. 10.1007/978-94-007-4032-7_12

7

Are there regional differences? [biology & ecology]

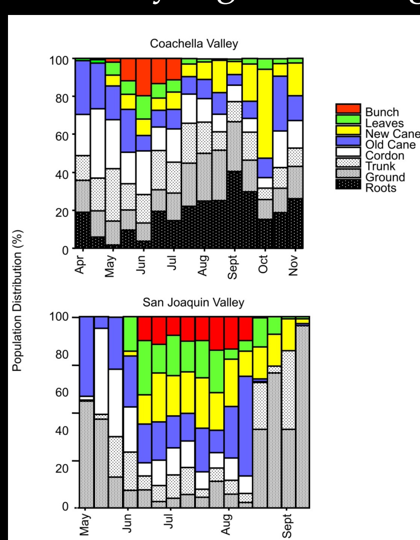
Mealybug biology & behavior

1.5 generations/year

4-8 generations/year

2-3 generations/year

Do mealybugs colonize grapevine roots?



In CA, only vine mealybug

Only in certain growing regions
Coachella: common on roots
southern Kern: on roots in winter
northern Kern: at ground level, occasionally on roots
Fresno: at ground level, not roots
North Coast: not on roots

Why on roots?
avoid heat, sandy soil, young vines
ant species (*Formica perpilosa*)

Daane et al. 2012. 10.1007/978-94-007-4032-7_12

8

Are there regional differences? [ecology]

Red blotch & vector species composition

CA (Napa Co.) vineyard

GRBD incidence 2017: 9% 2018: 13.8%

TABLE 1
Grapevine red blotch virus (GRBV) detection in insects trapped on yellow sticky cards in a diseased *Vitis vinifera* 'Cabernet Sauvignon' vineyard in California in 2017 and 2018 in which limited spread of GRBV was observed

		GRBV detection[a]					
		2017		2018		Cumulative	
Family	Genus, species	*n*	%	*n*	%	*n*	%
Membracidae	*Spissistilus festinus*	2/3	67	0/2	0	2/5	40

NY (Suffolk Co.) vineyard

No change in GRBD incidence 2014-2018

TABLE 2
Grapevine red blotch virus (GRBV) detection in insects trapped on yellow sticky cards in a diseased *Vitis vinifera* 'Merlot' vineyard in Suffolk County, New York in 2017 and 2018 in which no spread of GRBV was observed

		GRBV detection[a]					
		2017		2018		Cumulative	
Family	Genus, species	*n*	%	*n*	%	*n*	%
Membracidae	*Acutalis* sp.	0/11	0	0/4	0	0/15	0
	Entylia sp.	1/7	14	1/30	3	2/37	5
	Campylenchia sp.	0/1	0	–	na	0/1	0
	Stictocephala sp.	0/3	0	–	na	0/3	0

Cieniewicz et al. 2019. Phytobiomes 3: 203-211

9

Are there regional differences? [ecology]

Red blotch & vector species composition

Entylia carinata in Missouri vineyards

Table 2 Abundance of treehoppers (Membracidae) and leafhoppers (Cicadellidae) at monitoring sites in four commercial Missouri vineyards in 2018 and 2019. Samples were collected weekly from budbreak to harvest in 2018 and from budbreak to veraison in 2019. "Inside" refers to insects trapped on sticky cards placed in interior vineyard rows. "Outside" refers to insects trapped on sticky cards placed along the edge habitats surrounding vineyards. Selected species of insects were tested using standard PCR for grapevine red blotch virus.

	2018 Inside	2018 Outside	2018 Total	2019 Inside	2019 Outside	2019 Total	Number of individuals tested	Number of positive aggregate samples/ total samples tested	Percent of insects tested positive[a]
Membracidae	5742	2361	8103	2426	391	2817	1168	2/77	0.17-1.28
Spissistilus festinus	0	0	0	0	0	0	0	0/0	0
Micrutalis calva	5619	1902	7521	2410	349	2759	1086	0/54	0
Entylia carinata	123	438	561	15	38	53	55	2/11	3.6-27

Stictocephala spp. in artificial transmission system western Canada

Table 1. Insects collected for use in the artificial transmission system (ATS), taxonomic IDs of a subset of collected insects, and ATS PCR results.

Generic name	Superfamily, Family	Total assessed in ATS	Taxonomically identified species	Total ID'd	PCR +ves
Treehopper	Membracoidea, Membracidae	82	*Campylenchia rugosa*	21	0
			Stictocephala basalis	1	**1**
			Stictocephala bisonia	58	**8**
			Stictocephala wickhami	1	0
			Stictocephala brevitylus	1	0

Kahl et al. 2021. 10.1080/07060661.2021.1930174
LaFond et al. 2022.10.5344/ajev.2022.21056

10

Are there regional differences? [ecology] Red blotch disease

Disease pressure, vector incidence, surrounding landscape, cultivar

11

Are there regional differences ? [ecology] Leafroll disease

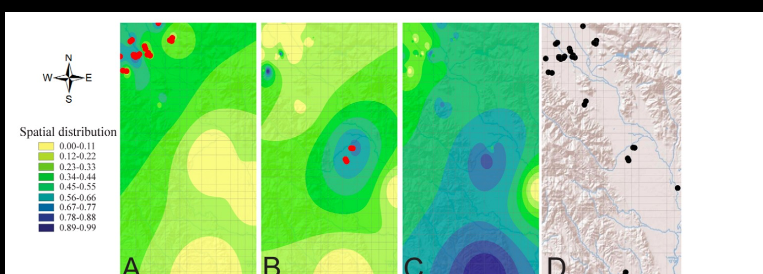
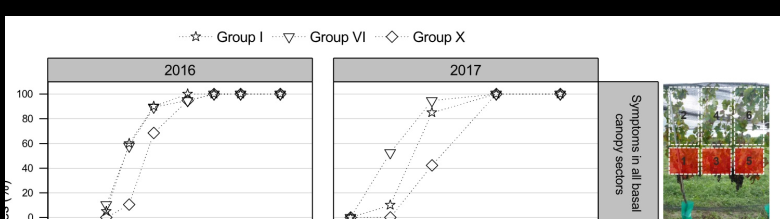


Figure 3. Geospatial and clustering analyses of GLRaV-3 variants in the Napa Valley. Images A through C illustrate results for GLRaV-3a, -3b and -3c, respectively; spatial distribution patterns for each variant are shown using interpolation data. The colored gradient and the corresponding values for spatial distribution represent the proportion for a given GLRaV-3 variant compared to the total number of GLRaV present in the tested block. The red dots indicate localities with statistically supported high incidence ($p<0.01$) of a particular variant in relationship to the remaining sample set. Image D shows all blocks positive for at least one GLRaV-3 variant. Each grid box represents 1 km^2.
doi:10.1371/journal.pone.0026227.g003



Genetic variants of GLRaV-3

Differences in distribution & symptom expression

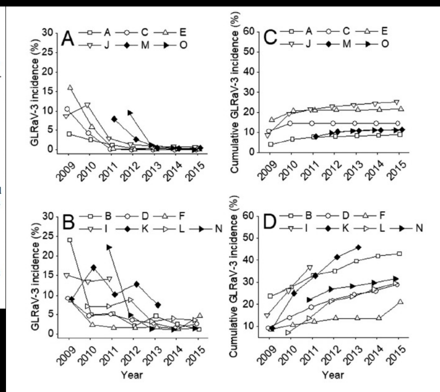
Sharma et al. 2011. 10.1371/journal.pone.0026227
Chooi et al. 2022. 10.3390/v14071348

12

Are there regional differences? [ecology] Leafroll disease

Disease pressure, vector species & population density

Fig. 3 Percent annual grapevine leafroll-associated virus 3 (GLRaV-3) incidence (graphs **a** and **b**) and cumulative GLRaV-3 incidence (graphs **c** and **d**) in the 13 study vineyards, 2009 to 2015. In group 1 vineyards (graphs **a** and **c**), GLRaV-3 incidence reduced to <1% where it was sustained for at least two consecutive years up until 2015. In group 2 vineyards (graphs **b** and **d**), GLRaV-3 control was either ineffective (I and K) or annual virus incidence was >1% (B, D, F, L, and N). Data included the planting of replacement vines and the addition of vineyards L, M, N, and O after 2009. Data from each vineyard in 2009 included cumulative numbers of vines that will have acquired GLRaV-3 in the interval between initial planting and the commencement of this study



Bell et al. 2018. J. Plant Path 100:399-408

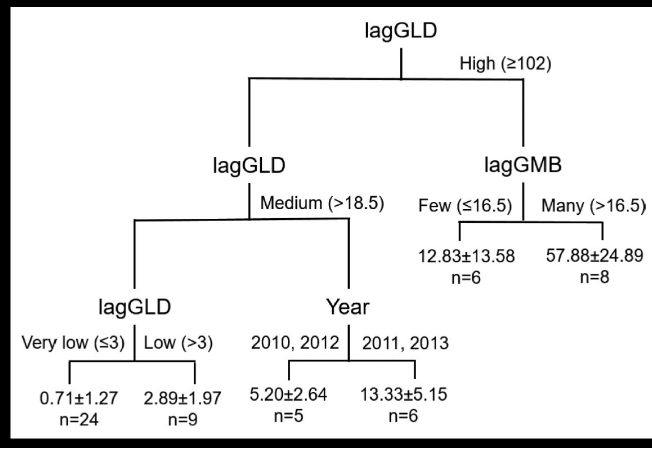


Fig. 1. Classification and regression tree analysis on the effects of prior leafroll disease (lagGLD), mealybug (*Pseudococcus maritimus)* population (lagGMB), and study year on the number of new leafroll disease cases. Variables at nonterminal nodes and the accompanying values to the left and right denote the thresholds that define the arrangement of partitions. Values listed in terminal partitions equate to the mean number of new leafroll disease cases (±SE) and number of block-year observations (*n*, out of 58 total) falling into each partition. Descriptors 'High' to 'Very low' and 'Many' versus 'Few' are intended to characterize broadly relative values for partitions with respect to prior leafroll disease and mealybug abundance, respectively. Partitions further to the left represent block-years for which prior leafroll disease was lower, which corresponded with fewer new diseases cases. For mealybug abundance, lower values (to the left) equated to fewer new cases of disease in some blocks, and the years 2010 and 2012 had fewer cases of new disease than 2011 and 2013 for some blocks.

Cooper et al. J Econ Entomol 2018. 111: 1542-1550

13

Challenges & opportunities for *individual* and *collective* action

- Adoption is a dynamic process (short, medium, long-term solutions)
- Main factors affecting adoption: Technical (knowledge), Economic, Social-behavioral
- Harness peer-learning networks & participatory research to positively influence adoption
- Outreach: active learning, multimedia resources tailored for audience, trusted information
- Communication, consensus-building, and collaboration skills support adoption
- Flexibility to customize disease management tools to the situation

Research

Adoption of Best Management Practices for Grapevine Leafroll and Red Blotch Diseases: A Survey of West Coast Growers

Malcolm B. Hobbs[1] | Selena M. Vengco[1] | Stephanie L. Bolton[2] | Larry J. Bettiga[3] | Michelle M. Moyer[4] | Monica L. Cooper[1,†] |

Information transfer among grape producers in the western United States on pest and disease management

Sarah R. Lowder[1,2], Michelle M. Moyer[3], Monica L. Cooper[4], Jay W. Pscheidt[2], Walter F. Mahaffee[5]

Research Article

Meeting the Challenge of Viral Disease Management in the US Wine Grape Industries of California and Washington: Demystifying Decision Making, Fostering Agricultural Networks, and Optimizing Educational Resources

Malcolm B. Hobbs,[1] Selena M. Vengco,[1] Stephanie L. Bolton,[2] Larry J. Bettiga,[3] Michelle M. Moyer,[4] and Monica L. Cooper[1]

Perspectives towards collective action for pest and disease management in vineyards in the western US

Sarah R. Lowder[1,2], Michelle M. Moyer[3], Monica L. Cooper[4], Jay Pscheidt[2], Walter F. Mahaffee[5]

Hobbs et al. 2022. 10.1094/PHYTOFR-07-21-0045-R
Hobbs et al. 2023. 10.1155/2023/7534116
Lowder et al. 2023. 10.1094/PHYTOFR-07-23-0082-R
Lowder et al. 2023. 10.1094/PHYTOFR-07-23-0081-R

14

Grapevine leafroll disease management

Plant material

Technical

Economic

Social

Diseased vine mapping & removal

Mealybug (vector) detection & management

15

Leafroll disease management
Plant material

Ideal: plant material free-from pathogens + pests
Is that reasonable & achievable?

Support for certification & government assistance
Certification programs (nursery standards & regulation)
Hot water dip & plant inspections for vine mealybug

Government assistance programs: reduce application burden
Public-private partnerships for pest detection (local scale)

16

Leafroll disease: vector detection & management

Vineyard mealybugs (& soft scale) are vectors of GLRaV-3

Longtailed

Photos: KM Daane

17

Leafroll disease management

Mealybug (vector) detection & management

Challenges

Uncertainty around MB as vector

Understand life cycle and seasonality

Determine when/if to treat

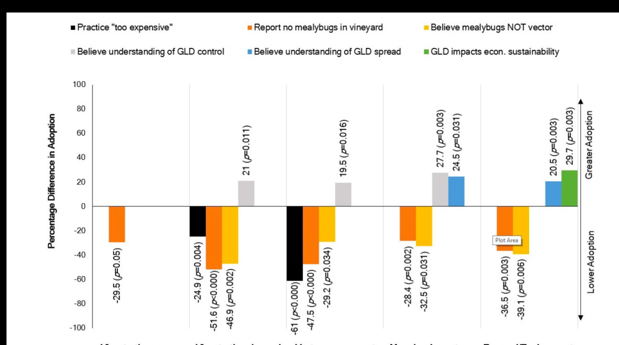


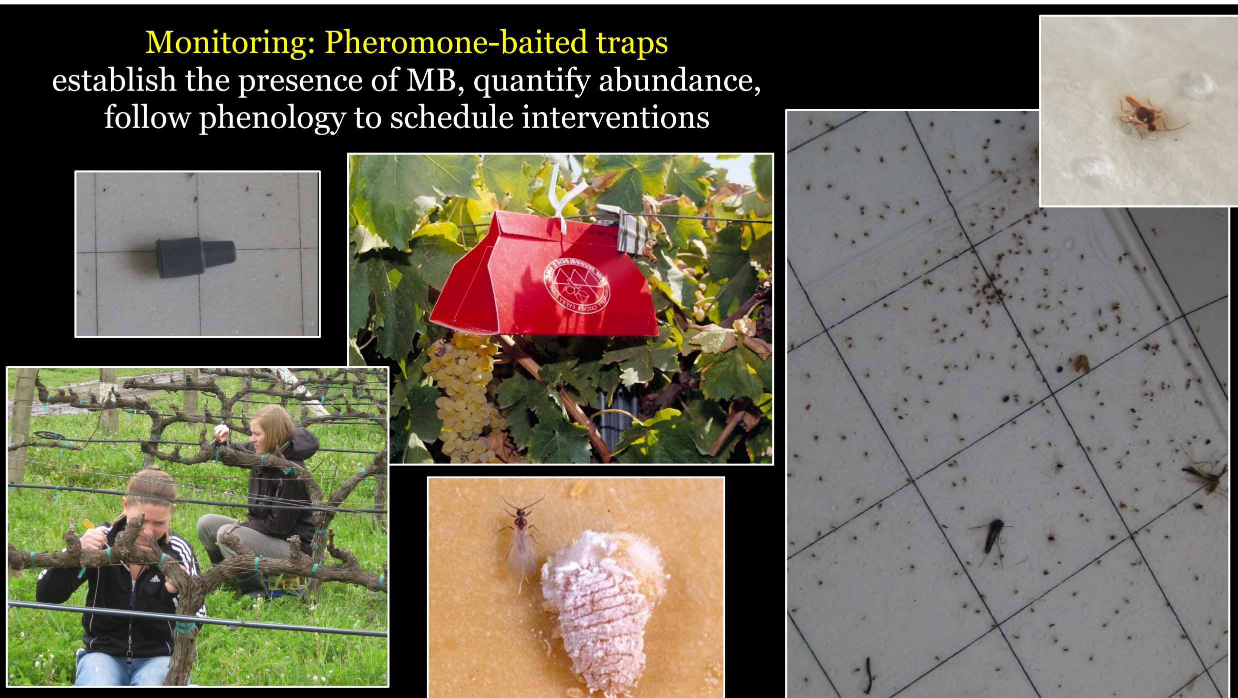
FIGURE 4

Difference in adoption among respondents of grapevine leafroll disease (GLD) management based on perceived costs and reported knowledge of disease ecology. Only significant comparisons are displayed. For vector management, “too expensive” refers to the cost of mealybug monitoring.

18

Monitoring: Pheromone-baited traps

establish the presence of MB, quantify abundance, follow phenology to schedule interventions



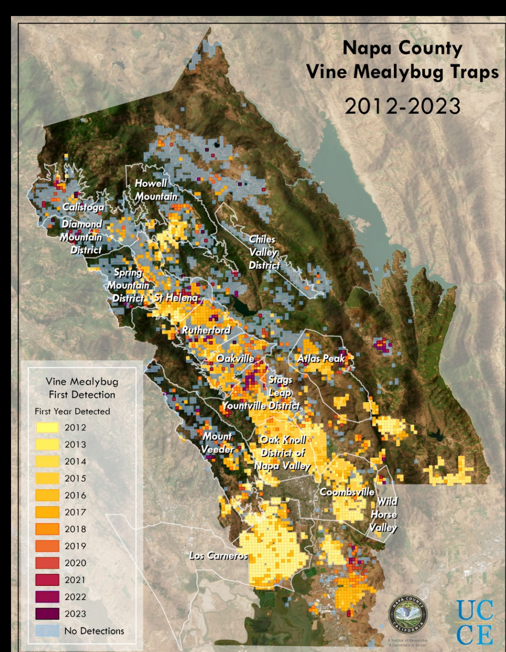
19

Regional trapping

Napa County Pest & Disease Control District

Public-private partnership
Grower self-assessment

VMB detection trapping since 2012



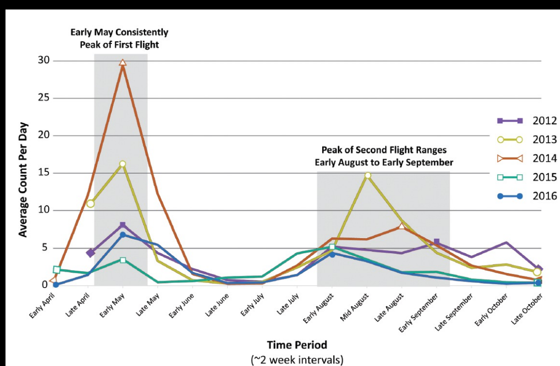
20

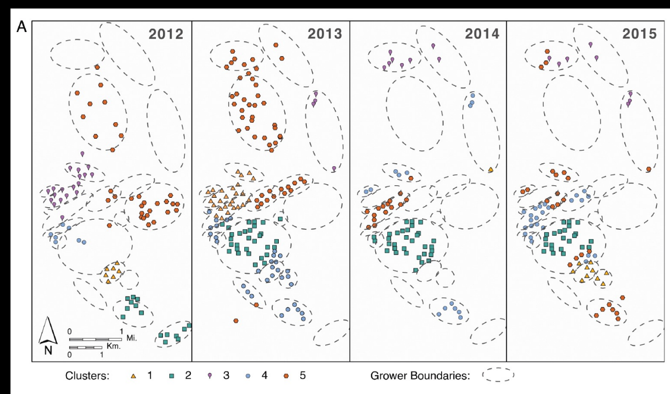
Regional trapping: grower groups

Napa neighbors coordinate grape mealybug trapping (2012-2016)

Improved understanding of seasonal life cycles

Regional patterns demonstrate impact of individual & collective action





MacDonald et al. 2021. J Econ Entomol. 10.1093/jee/toab091

21

Regional trapping: grower groups

WASHINGTON WINE INDUSTRY FOUNDATION

Eastern Washington & Oregon (2023)

Neighbors sharing grape mealybug trap data

WASHINGTON STATE UNIVERSITY

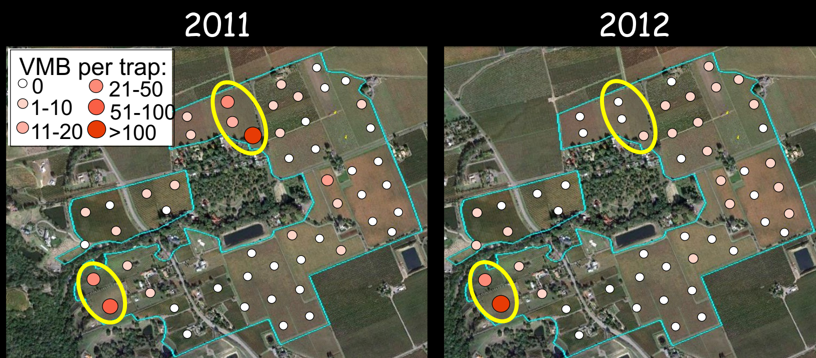
STOP THE SPREAD: EFFECTIVE OPTIONS FOR MANAGING LEAFROLL
JANUARY 24, 2023 - JANUARY 25, 2023 …and Feb 29, 2024 (webinar)

22

Mating disruption for vine mealybug

Regional programs suppress spread of VMB + LR3
Preventative tool in high-risk VMB areas
Sustained (multi-year) applications

Application method (dispenser, flowable)
Dispenser density & longevity



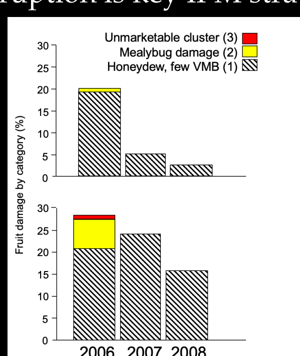
Hogg et al. 2021. 10.1016/j.cropro.2021.105735
Daane et al. 2020. 10.3390/insects11090635

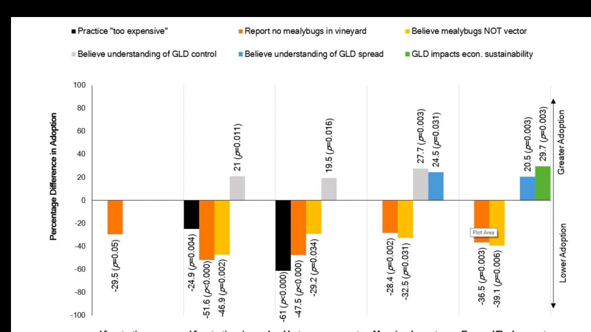
23

Summary & major achievements: vector detection and management

Mealybugs are vectors of LR3
Improved understanding of transmission biology (field + lab)
Develop & deploy management practices
Tools to detect and quantify vector incidence
Improved understanding of mealybug phenology
Regional trends in population & seasonal phenology
Data-sharing & collaboration across neighborhoods and regions

Mating disruption is key IPM strategy for VMB





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Hobbs et al. 2022. 10.1094/PHYTOFR-07-21-0045-R

24

Leafroll disease management: Diseased vine mapping and removal

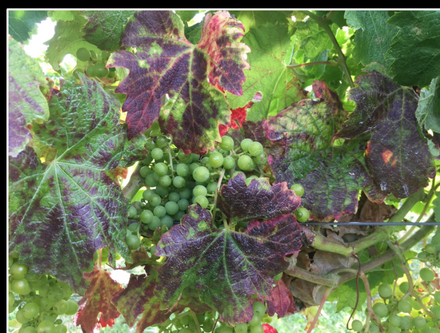
Challenges (2009)

Roguing perceived as ineffective

Leafroll disease "persisting" despite roguing

Financial inputs

Labor & technical skills & tools to map, remove, replant or re-develop



25

Roguing: Applied and participatory research

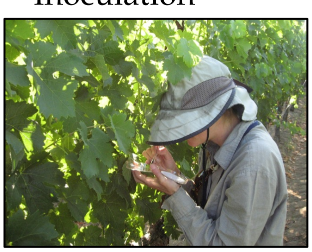
Control of Grapevine Leafroll Disease Spread at a Commercial Wine Estate in South Africa: A Case Study

Gerhard Pietersen,[1]* Nico Spreeth,[2] Tobie Oosthuizen,[2] André van Rensburg,[3] Maritza van Rensburg,[3] Dwayne Lottering,[3] Neil Rossouw,[3] and Don Tooth[3]

Knowledge sharing: diseased vine removal is critical management strategy

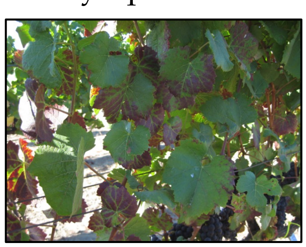
I. **Field trial** in commercial vineyard

Inoculation



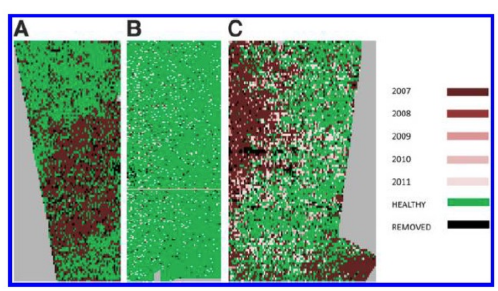
1-year

Symptoms



Blaisdell et al. 2016. *EJPP* 146: 105-116

II. **Grower-validated**: early adopters of vine removal shared successes

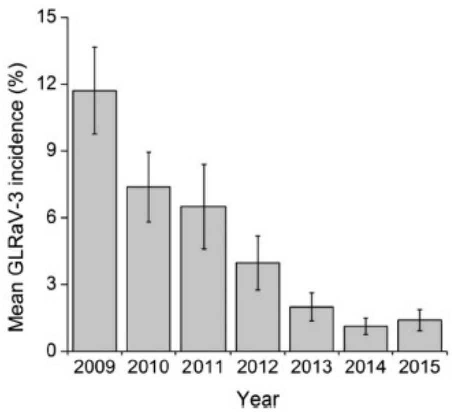


Arnold et al. 2017. *Phytopathology* 107: 418-426

26

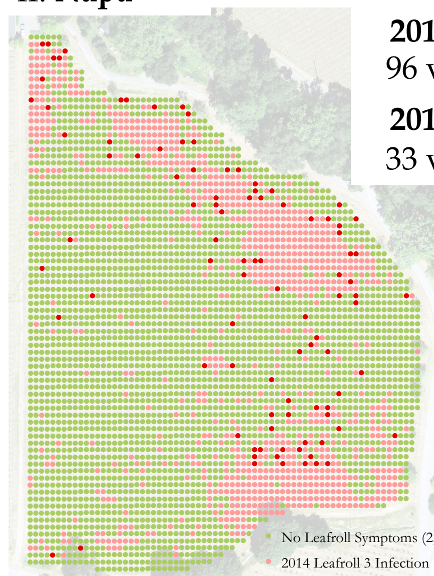
Roguing: A multi-year strategy

I. **New Zealand**



Bell et al. 2018. *J. Plant Path.* 100: 399-408.

II. **Napa**



2014-15
936 vines

2015-16
96 vines

2016-17
33 vines

27

Challenges to mapping and removal

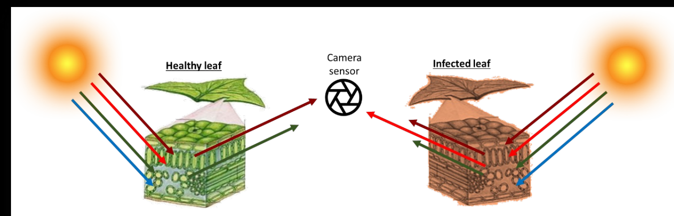
Expertise to distinguish visual symptoms–train & mentor staff
Mapping is labor-intensive & detail-oriented—protocols & record-keeping
Balance mapping with other activities (harvest)
Implement consistent mapping, vine removal & replant
Use diagnostic assays to confirm visual symptoms

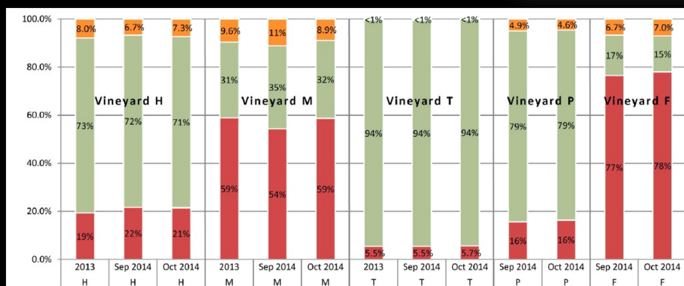
Site	2021 Mapped	Vines Removed	% Remaining
1	107	40	63%
2	98	60	39%
3	373	356	5%

28

Decision-support tools

Airborne hyperspectral imaging for LR-3





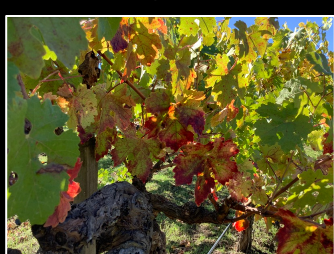
	2013 H	Sep 2014 H	Oct 2014 H	2013 M	Sep 2014 M	Oct 2014 M	2013 T	Sep 2014 T	Oct 2014 T	Sep 2014 P	Oct 2014 P	Sep 2014 F	Oct 2014 F
Image/ Ground Conflict	8.0% 304	6.7% 256	7.3% 279	9.6% 213	11.1% 247	8.9% 197	0.5% 28	0.5% 32	0.2% 12	4.9% 314	4.6% 297	6.7% 198	7.0% 208
Agree - Non GLRaV-3	72.7% 2778	71.6% 2736	71.2% 2721	31.5% 698	34.5% 766	32.5% 720	94.1% 5758	94.0% 5751	94.1% 5761	79.4% 5075	79.0% 5050	16.7% 494	15.0% 442
Agree - GLRaV-3	19.3% 739	21.7% 829	21.5% 821	58.9% 1307	54.3% 1205	58.7% 1301	5.5% 334	5.5% 337	5.7% 347	15.7% 1001	16.3% 1043	76.6% 2260	78.0% 2302

MacDonald et al. 2016. http://dx.doi.org/10.1016/j.compag.2016.10.003

29

Machine learning-VirusVision

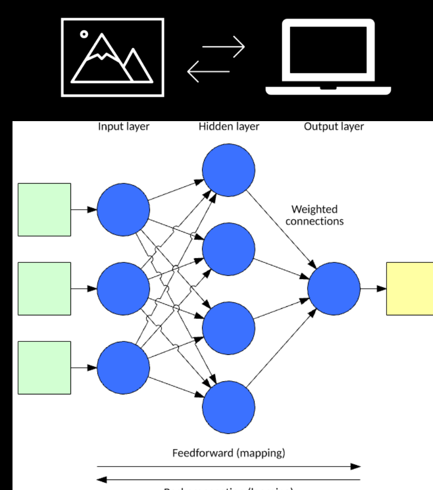
4,675 images contributed by industry & UCCE team


Red blotch


Spider mite


Abiotic (girdle)


healthy



30

Machine learning-VirusVision

University of California Cooperative Extension

tule — A part of cropx

1 Home screen

2 Continuous image collection

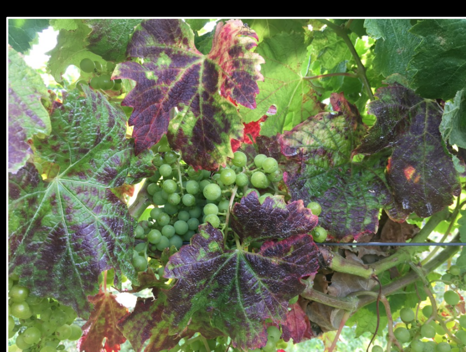
3 Confidence rating
Leafroll
Red blotch
"Other"
Asymptomatic

31

Putting it all together: implementation guidelines

Economic studies
25% disease incidence threshold
Below threshold: rogue + replant
Above threshold: redevelop block

Field studies & modeling
More nuanced (site-specific)



P. calceolariae
V. Bell

P. maritimus

32

Field studies & modeling
New Zealand (2009-2015)

Initial disease incidence	Vector abundance *P. calceolariae* (citrophilus mealybug)
0.4%	**Low abundance** 6 MB per 100 leaves 2% leaf infestation
5%	**Moderate abundance** 26 MB per 100 leaves 7% leaf infestation
10%	**Highly abundant** 75 MB per 100 leaves 21% leaf infestation
15%	
20%	

Roguing is optimal response

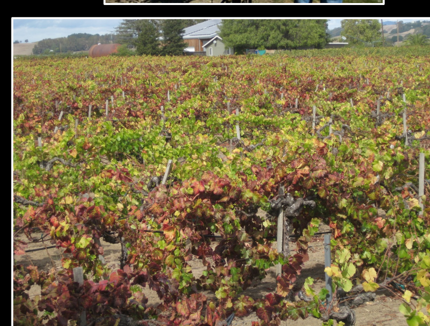
moderate & high MB abundance
Roguing is more expensive + less effective
Additional interventions to reduce MB


Bell et al. 2018. J. Plant Pathol. 10.1007/s42161-018-0085-z
Bell et al. 2021. J Plant Pathol. 10.1007/s42161-020-00736-7

33

Field studies & modeling
Grape mealybug + GLRaV-3
Napa (2009-2016)



Mgmt. by disease incidence category

less than 1% GLD incidence
Pathogen originating outside the block
Regional monitoring + communication among neighbors
Rogue to reduce build-up of inoculum in the block
No clear role for insecticides (GMB)

1 to 20% GLD incidence
Roguing & Insecticides

greater than 20% GLD incidence
Roguing effective (reduces inoculum)
Insecticide did not reduce spread (in the target block)

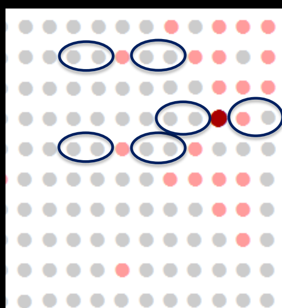
Cooper et al. 2018. J. Econ. Entomol. 10.1093/jee/toy124
MacDonald et al. 2021. J Econ Entomol. 10.1093/jee/toab091

34

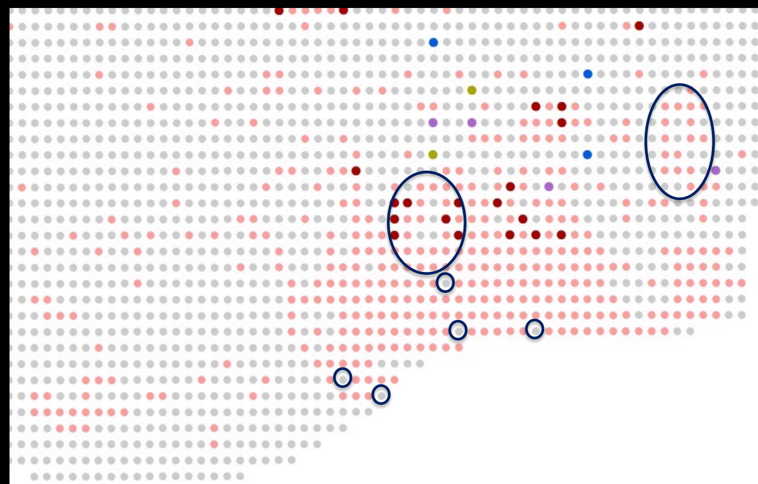
Spatial roguing

Grape mealybug + GLRaV-1
Finger Lakes, NY (2009-2016)

Remove infected vine and two in-row neighbors on each side



Useful in high incidence areas (disease hot spots)



Hesler et al. 2022. AJEV. 10.5344/ajev.2022.22004

35

Summary & major achievements for leafroll disease management

Challenges (2009)

Uncertainty surrounding GLD management
Questioned mealybugs as vectors
GLD not universally recognized as problem
No widespread commitment to management

2010-2023

Economic, Technical, Social Aspects of Adoption

Comprehensive program & dedicated resources for research (2010-2016) & outreach (2017-2023)
Participatory research (disease ecology & transmission biology)
Neighborhood groups
Peer networking, information-sharing, proof of concept
Similar experiences across regions reinforces management and adoption
South Africa, California, New York, New Zealand, Israel
Vector detection & interventions (insecticide, biocontrol, mating disruption)

36

Information exchange, educational resources & agricultural networks

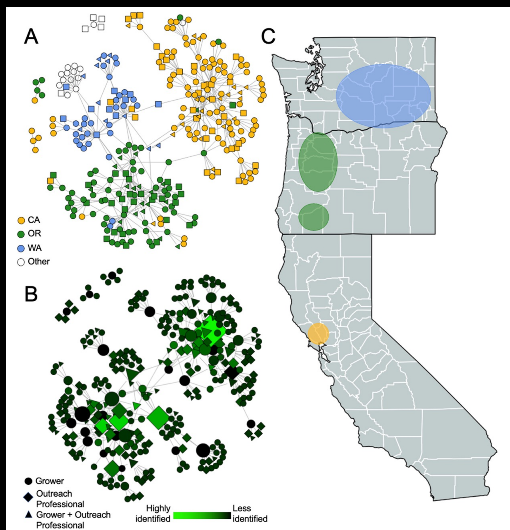


Figure 2. Communication networks. (A) Undirected sociogram showing communication between grape growers discussing pest and disease management in vineyards with actors colored and shaped by location and professional role. (B) A directed network sociogram with the influencers, or those who were highly identified by others in the network, are shown in blue. Actors were sized by their degree centrality, where larger circles indicates that the actor identified and/or was identified my more actors. All network layouts created using Fruchterman and Reingold algorithm (Handcock et al. 2008). (C) The regions of focus from the western US highlighted by ovals; participants from outside of these regions were not excluded.

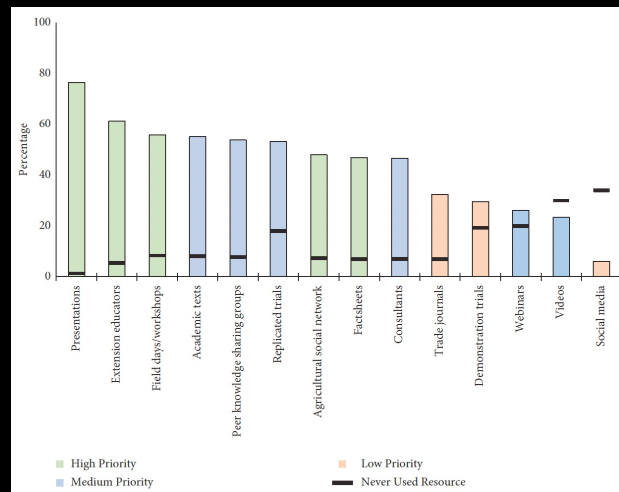


FIGURE 1: Percentage of respondents ($n = 145$) who accessed resources and rated highly useful for grapevine viruses. Resources were defined as (1) formal presentations; (2) direct contact with extension educators; (3) field days and interactive workshops; (4) academic texts; (5) informal grower meetings and discussions; (6) replicated research trials; (7) informal social network; (8) factsheets, newsletters, booklets, and pamphlets; (9) paid consultants; (10) trade journals; (11) in-house demonstration trials; (12) webinars; (13) educational videos; and (14) social media. The ratings and content analysis were used to categorize resources as high, medium, and low priority, which was judged by evaluating their reach, persuasiveness, and impact.

Hobbs et al. 2023. 10.1155/2023/7534116
Lowder et al. 2023. 10.1094/PHYTOFR-07-23-0081-R

37

Leafroll disease in Napa (2023)

Leafroll is low incidence

Red blotch disease is challenging

"I would rather have LR3 than red blotch, because I know how to manage LR3."

38

Grapevine red blotch disease

39

2008-2012

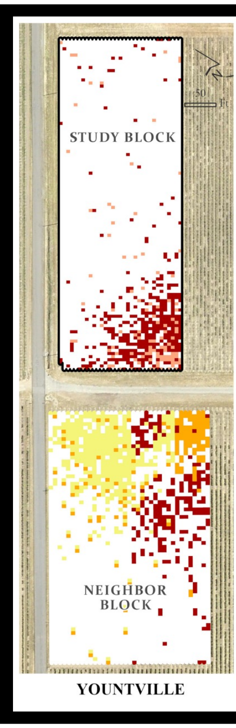
Spread patterns associated with plant material

Primary spread

40

Currently…

Vector-mediated, secondary spread
Within & between blocks & neighbors



41

Red blotch disease management

Diseased vine mapping & removal

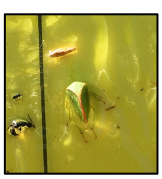
Plant material

Technical

Economic

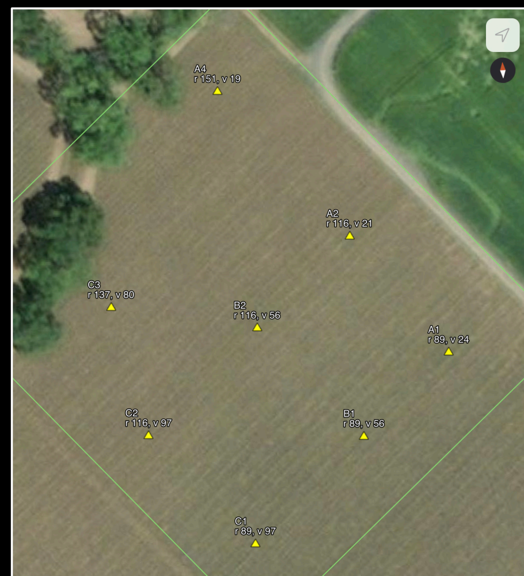
Social

Vector detection & habitat



42

Vector detection & management

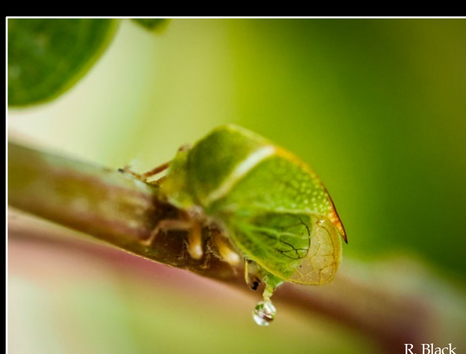


43

Threecornered alfalfa hopper (TCAH)

Spissistilus festinus
Membracidae (treehopper)

Historically considered an incidental pest of grapevine


R. Black

44

Threecornered alfalfa hopper (TCAH)

Historic geographic range
southern & SE USA
Now more widely distributed in CA

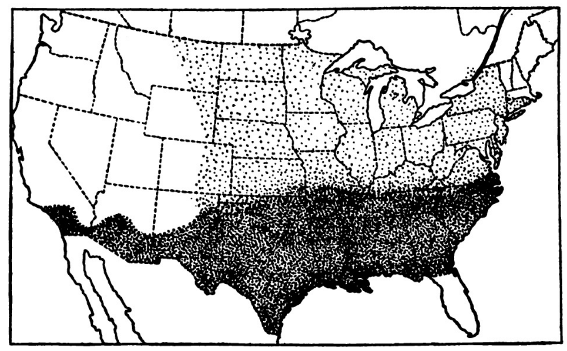
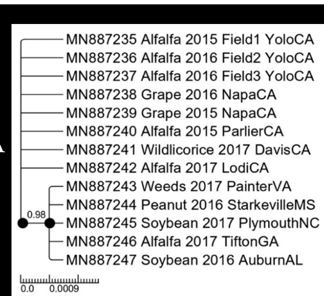


FIG. 1.—Map showing distribution of the three-cornered alfalfa hopper (*Stictocephala festina*) in the United States. The densely dotted area shows region of injurious infestation; the sparsely dotted area shows region of occurrence in limited numbers. Original.

Two genotypes
CA & SE USA



Reproductively compatible

Table 1. Fecundity of individual *Spissistilus festinus* mating pairs on detached *Phaseolus vulgaris* trifoliates.

Parent Pair [a]	Replicate [b]	Observed [c]	Average [d]
CA Only	1	94	50.6
	2	35	
	3	58	
	4	43	
	5	23	
SE Only	1	1	54.2
	2	70	
	3	63	
	4	82	
	5	55	
CA Male + SE Female	1	55	52
	2	1	
	3	52	
	4	80	
	5	31	
	6	93	
SE Male + CA Female	1	3	46.8
	2	88	
	3	42	
	4	32	
	5	69	

[a] Individual parental pair maintained on excised *P. vulgaris* trifoliates. [b] Detached chamber containing an individual *P. vulgaris* trifoliate. [c] Number of resultant nymphs. [d] Average number of resultant nymphs for each parental pair.

Cieniewicz et al. 2020. 10.3390/insects11020080
Flasco and Fuchs. 2023. 10.3390/insects14100831
Wildermuth 1915. J Agric Research 3(4): 343-362

45

Transmission assays in greenhouse and vineyard

Spissistilus festinus
Membracidae (treehopper)

TABLE 2. Transmission of grapevine red blotch virus (GRBV) on excised *Phaseolus vulgaris* and *Vitis vinifera* leaves after acquisition by *Spissistilus festinus* on infected *P. vulgaris* during various acquisition access periods

		Experiment 1[b]		Experiment 2		Experiment 3		Total[c]	
Virus recipient tissue	AAP[a]	Petiole[d]	Leaf	Petiole	Leaf	Petiole	Leaf	*N*	%
P. vulgaris	2	0/2	0/2	nt	nt	nt	nt	0/4	0
	4	0/2	0/2	nt	nt	nt	nt	0/4	0
	6	6/7	7/7	6/8	8/8	nt	nt	27/30	90
	12	nt	nt	nt	nt	7/8	7/8	7/8	88
V. vinifera	6	5/5	5/5	nt	nt	nt	nt	5/5	100

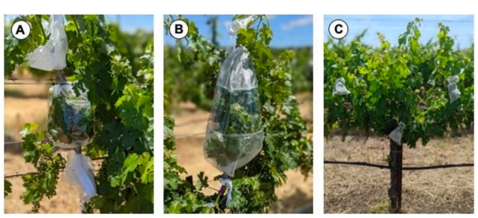


Figure 1. Distinct sleeve configurations used in transmission assays of grapevine red blotch virus by *Spissistilus festinus* in a 'Cabernet Sauvignon' vineyard. (**A**) A peppermint candy sleeve configuration allowing for cohorts of 10 *S. festinus* to feed on a restricted area of a shoot, (**B**) A tootsie roll sleeve configuration in which cohorts of 20 *S. festinus* were confined to an entire shoot, and (**C**) A lollipop sleeve configuration in which two *S. festinus* were allowed to feed on a single leaf on a middle–middle–bottom arrangement. Other lollipop sleeve configurations included middle–middle–top, top–middle–bottom, and middle–middle–middle.

Sleeve Configuration	2020 [a]		2021 [b]		2022 [c]		Total [d]		Total [f]
	NY [e]	CA	NY	CA	NY	CA	NY	CA	
Tootsie roll [g]	0/10	n/a	0/4	0/6	n/a	n/a	0/14	0/6	0/20
Peppermint candy [h]	n/a	n/a	0/11	0/15	n/a	n/a	0/11	0/15	0/26
Lollipop [i]	n/a	n/a	0/5	n/a	5/11	1/20	5/16	1/20	6/36
Total [j]	0/10		0/41		6/31		6/82		

Table 1. Transmission of grapevine red blotch virus (GRBV) to grapevines in a New York and a California vineyard by *Spissistilus festinus* using various sleeve configurations for inoculation after a two-week acquisition period on infected *Phaseolus vulgaris* plants.

Flasco et al. 2021. 10.3390/v15040927
Flasco et al. 2023. 10.3390/v15040927

46

Other treehopper vectors?

Tortistilus albidosparsus

Entylia carinata in Missouri vineyards

Table 2 Abundance of treehoppers (Membracidae) and leafhoppers (Cicadellidae) at monitoring sites in four commercial Missouri vineyards in 2018 and 2019. Samples were collected weekly from budbreak to harvest in 2018 and from budbreak to veraison in 2019. "Inside" refers to insects trapped on sticky cards placed in interior vineyard rows. "Outside" refers to insects trapped on sticky cards placed along the edge habitats surrounding vineyards. Selected species of insects were tested using standard PCR for grapevine red blotch virus.

	2018 Inside	2018 Outside	2018 Total	2019 Inside	2019 Outside	2019 Total	Number of individuals tested	Number of positive aggregate samples/ total samples tested	Percent of insects tested positive[a]
Membracidae	5742	2361	8103	2426	391	2817	1168	2/77	0.17-1.28
Spissistilus festinus	0	0	0	0	0	0	0	0/0	0
Micrutalis calva	5619	1902	7521	2410	349	2759	1086	0/54	0
Entylia carinata	123	438	561	15	38	53	55	2/11	3.6-27

Stictocephala spp. in artificial conditions

western Canada

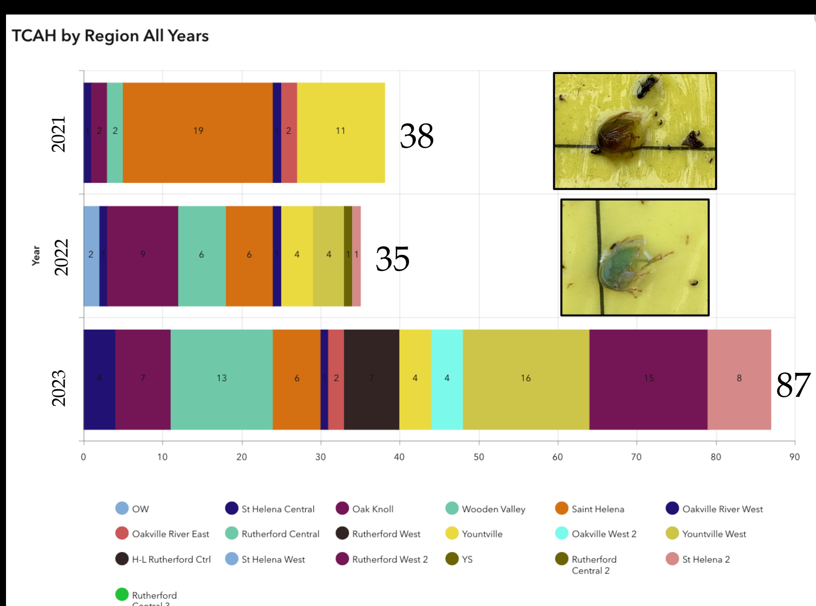
Table 1. Insects collected for use in the artificial transmission system (ATS), taxonomic IDs of a subset of collected insects, and ATS PCR results.

Generic name	Superfamily, Family	Total assessed in ATS	Taxonomically identified species	Total ID'd	PCR +ves
Treehopper	Membracoidea, Membracidae	82	*Campylenchia rugosa*	21	0
			Stictocephala basalis	1	**1**
			Stictocephala bisonia	58	**8**
			Stictocephala wickhami	1	0
			Stictocephala brevitylus	1	0

Kahl et al. 2021. 10.1080/07060661.2021.1930174
LaFond et al. 2022.10.5344/ajev.2022.21056

47

Detection varies by site and by year



Traps: low input detection method compared to sweep sampling

Without an attractant, are they a reliable indicator of TCAH populations?

48

Threecornered alfalfa hopper (TCAH)

No reproduction on *V. vinifera*

Reproductive (breeding) hosts

Fabaceae (subfamily Faboideae) principally clover, vetch

Table 2 *Spissistilus festinus* feeding and oviposition hosts associated with vineyards.

Scientific Name	Common Name	Family	Feeding	Oviposition[a]	Relative preference[b]	Source
Daucus carota	Wild carrot	Apiaceae	XX		N/A	Preto et al. 2018
Senecio vulgaris	Common groundsel	Asteraceae	XX	XX	N/A	Preto et al. 2018
Taraxacum officinale	Dandelion	Asteraceae	XX	XX	<0.01	Preto et al. 2018
Brassica sp.	Mustard	Brassicaceae			N/A	Preto et al. 2018
Raphanus sativus	Daikon radish	Brassicaceae	XX		N/A	
Convolvulus arvensis	Field bindweed	Convolvulaceae	XX	XX	<0.01	Preto et al. 2018
Acmispon americanus	Spanish clover	Fabaceae	XX	XX	0.12	Preto et al. 2018
Lotus corniculatus	Birdsfoot trefoil	Fabaceae	XX	XX	0.26	Preto et al. 2018
Medicago lupulina	Black medick	Fabaceae	XX	XX	0.58	Preto et al. 2018
Medicago polymorpha	California burclover	Fabaceae	XX	XX	N/A	Wildermuth 1915
Pisum sativum	Magnus peas	Fabaceae	XX	XX	0.22	Preto et al. 2018
Trifolium alexandrinum	Berseem clover	Fabaceae	XX	XX	0.25	
Trifolium incarnatum	Crimson clover	Fabaceae	XX	XX	0.42	Preto et al. 2018
Trifolium repens	White Dutch clover	Fabaceae	XX	XX	0.06	Mitchell and Newsom 1984
Trifolium resupinatum	Persian clover	Fabaceae	XX	XX	N/A	Newsom et al. 1983
Trifolium subterraneum	Subterranean clover	Fabaceae	XX	XX	0.26	Preto et al. 2018
Vicia benghalensis	Purple vetch	Fabaceae	XX	XX	1.00	Preto et al. 2018
Vicia faba	Bell beans	Fabaceae	XX	XX	0.55	Preto et al. 2018
Vicia villosa ssp. *varia*	Woollypod vetch	Fabaceae	XX	XX	1.36	Preto et al. 2018
Eschscholzia californica	California poppy	Papaveraceae			N/A	
Kickxia elatine	Sharppoint fluvellin	Plantaginaceae			N/A	Preto et al. 2018
Plantago lanceolata	Buckhorn plantain	Plantaginaceae	XX		N/A	Preto et al. 2018
Avena sativa	California red oats	Poaceae			N/A	Preto et al. 2018
Bromus hordeaceus	Blando brome	Poaceae	XX	XX	0.06	Preto et al. 2018
Cynodon dactylon	Bermuda grass	Poaceae			N/A	Preto et al. 2018
Dactylis glomerata	Paiute orchardgrass	Poaceae			N/A	
Festuca arundinacea	Fawn tall fescue	Poaceae			N/A	
Festuca ovina spp. *duriuscula*	Hard fescue	Poaceae			N/A	
Festuca rubra	Creeping red fescue	Poaceae	N/A			
Hordeum vulgare	Barley UC 937	Poaceae	XX		N/A	
Lolium multiflorum	Annual ryegrass	Poaceae	XX	XX	0	
Lolium perenne	Perennial ryegrass	Poaceae	XX		N/A	
Poa pratensis	Kentucky bluegrass	Poaceae	XX		N/A	Preto et al. 2018
Secale cereale	Winter ryegrain	Poaceae	XX		N/A	
Sorghum sudanense	Piper sudangrass	Poaceae	XX		N/A	
Triticum x *secale*	Trios triticale	Poaceae	XX	XX	0	
Vulpia myuros var. *hirsuta*	Zorro fescue	Poaceae	XX		<0.01	
Fagopyrum esculentum	Buckwheat	Polygonaceae	XX	XX	0.03	

Kron & Sisterson. 2020. *AJEV*
doi: 10.5344/ajev.2020.19069

49

In-field TCAH host trial: Jun 28-Sep 20, 2023

Collaboration with Fuchs Lab, Cornell Univ.

Asteraceae
Prickly lettuce
Bristly oxtongue

Fabaceae
Burclover
Birdsfoot trefoil
Spanish clover

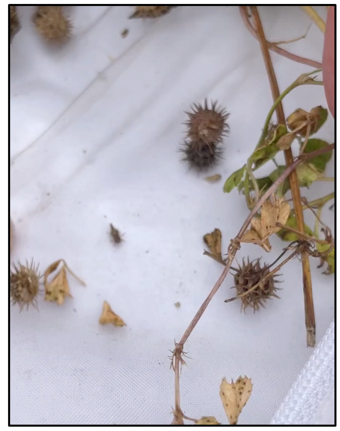
Plantaginaceae
Plantago
Fluvellin

Vitaceae
V. californica

50

In-field TCAH host trial: Jun 28-Sep 20, 2023

Species	Adult longevity	Nymphs	Notes
Asteraceae			
Prickly lettuce	1 to 4 weeks	No	
Bristly oxtongue	5 to 8 weeks	No	
Plantaginaceae			
Plantain	2 weeks	No	
Fluvellin	0 weeks	No	
Fabaceae			
Burclover	3 to 5 weeks	Yes	Most plants dead by week 6
Spanish clover	2 to 7 weeks	Yes	New adults emerged
Birdsfoot trefoil	1 week	No	
Vitaceae			
V. californica	5 weeks	Yes	New adults emerged



51

California burclover
Medicago polymorpha L.

along drive roads
& reservoirs

in vine rows &
row middles

52

Spanish clover
Acmispon americanus

ditches, roadside & drive roads
in row middles & vine rows






53

Patterns of disease spread near areas with weedy groundcover

Reservoirs, ditches, drive roads

54

Vegetation management & habitat manipulation

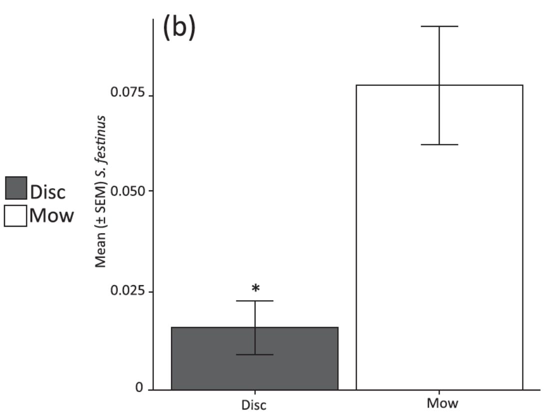
Pierce's disease and BGSS
Riparian revegetation
Target BGSS breeding hosts

Leguminous breeding hosts for TCAH

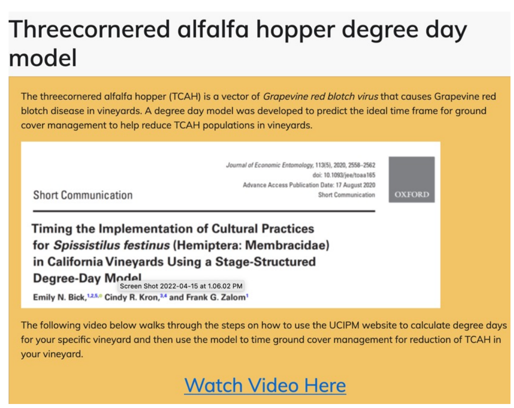
55

UC CE University of California Cooperative Extension

Vineyard cultural practices



Billings et al. 2021. 10.1093/jee/toab115



Threecornered alfalfa hopper degree day model

The threecornered alfalfa hopper (TCAH) is a vector of *Grapevine red blotch virus* that causes Grapevine red blotch disease in vineyards. A degree day model was developed to predict the ideal time frame for ground cover management to help reduce TCAH populations in vineyards.

Journal of Economic Entomology, 113(5), 2020, 2558–2562
doi: 10.1093/jee/toaa165
Advance Access Publication Date: 17 August 2020
Short Communication
OXFORD

Short Communication

Timing the Implementation of Cultural Practices for *Spissistilus festinus* (Hemiptera: Membracidae) in California Vineyards Using a Stage-Structured Degree-Day Model

Screen Shot 2022-04-15 at 1.06.02 PM

Emily N. Bick,[1,2,5] Cindy R. Kron,[3,4] and Frank G. Zalom[1]

The following video below walks through the steps on how to use the UCIPM website to calculate degree days for your specific vineyard and then use the model to time ground cover management for reduction of TCAH in your vineyard.

Watch Video Here

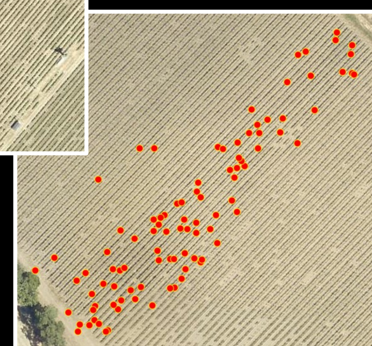
https://cesonoma.ucanr.edu/Integrated_Pest_Management685/Threecornered_alfalfa_hopper_degree_day_model/

56

Is limiting within-block habitat sufficient to reduce disease spread?

Breeding hosts in adjacent landscapes

Girdles observed in clean cultivated blocks



Rates of spread similar for blocks with permanent cover vs. cultivated

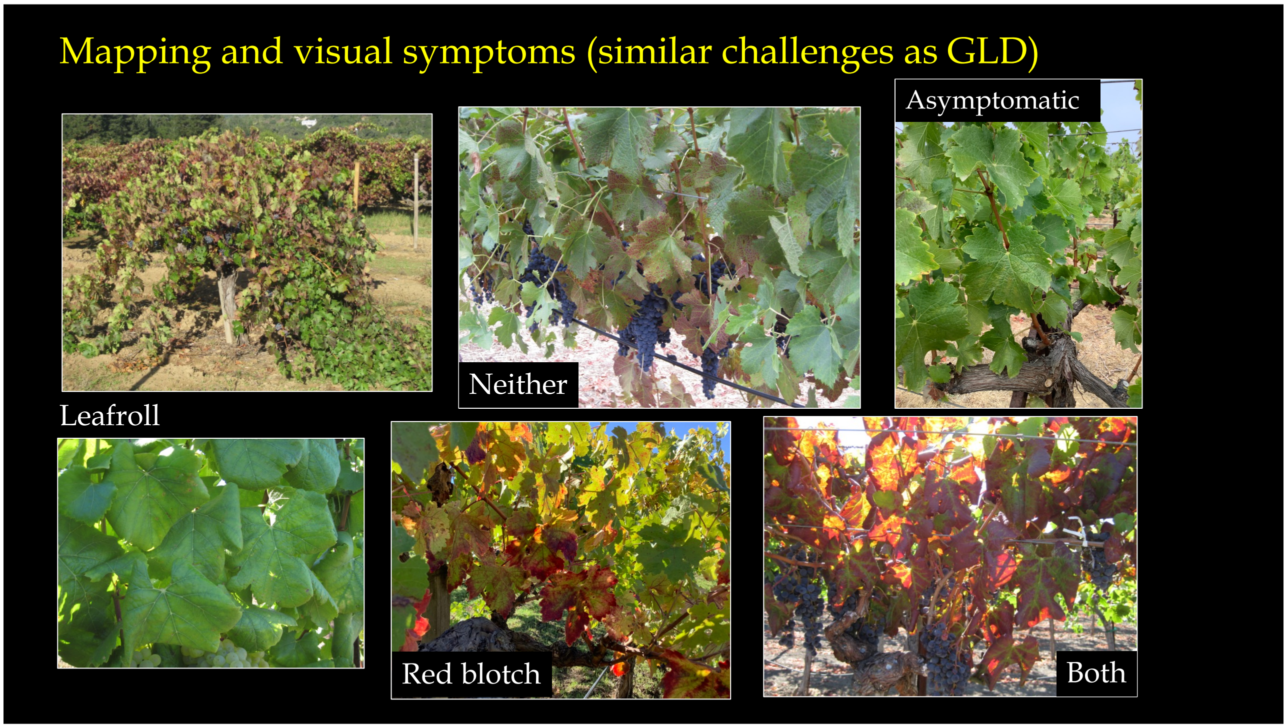
57

Poor understanding of *in-situ* insect ecology & transmission biology

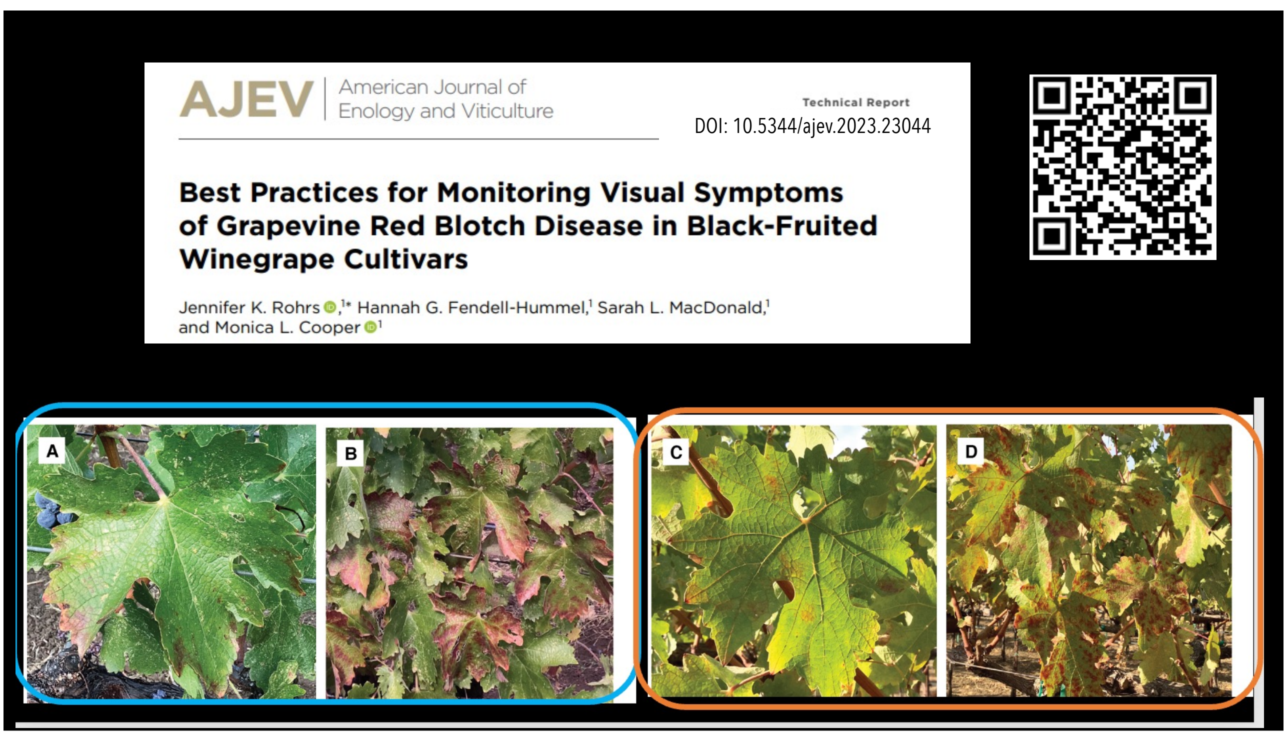
Seasonal ecology & movement
Host utilization

Feeding behavior on grapevine
Transmission biology
Transmission efficiency

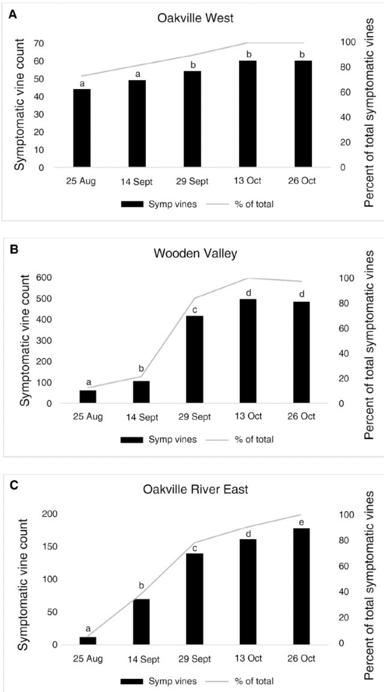
58


Mapping and visual symptoms (similar challenges as GLD)
Asymptomatic
Neither
Leafroll
Red blotch
Both

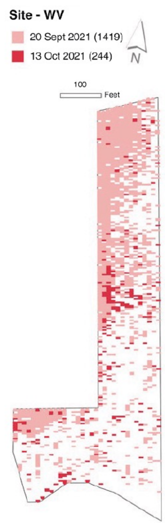
59


AJEV American Journal of Enology and Viticulture
Technical Report
DOI: 10.5344/ajev.2023.23044
Best Practices for Monitoring Visual Symptoms of Grapevine Red Blotch Disease in Black-Fruited Winegrape Cultivars
Jennifer K. Rohrs,[1*] Hannah G. Fendell-Hummel,[1] Sarah L. MacDonald,[1] and Monica L. Cooper[1]
A
B
C
D

60



Temporal trends & visual symptoms



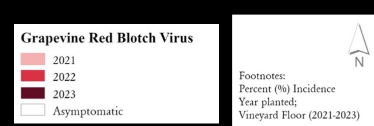
Variable between and within blocks
Optimize timing of symptom mapping

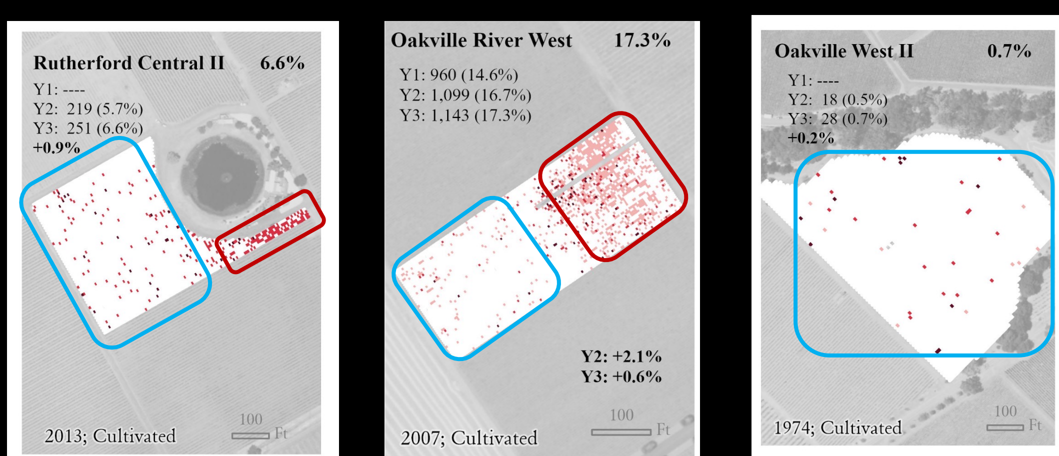
Rohrs et al. 2023. 10.5344/ajev.2023.23044

61

Spatial patterns and disease spread

Two spatial patterns
Aggregated
Random

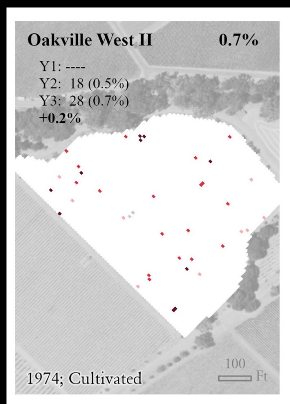


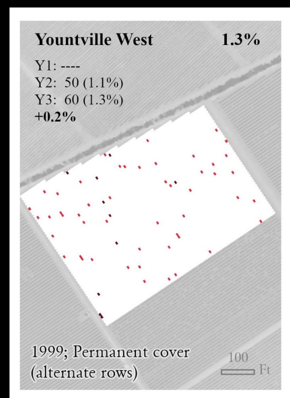


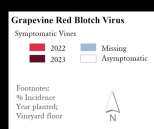
62

Manage random spread with vine-by-vine roguing

Maintain low inter-annual levels of disease

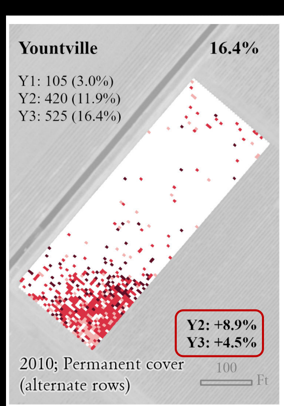


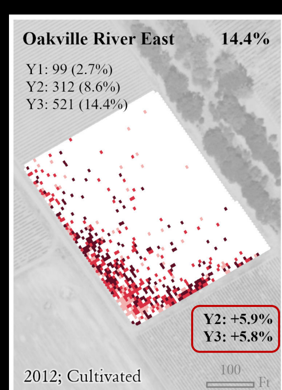


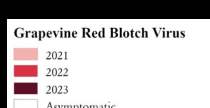


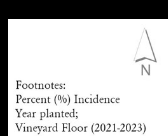
Optimize mapping to timing of symptom development

Vine-by-vine roguing has not reduced spread in aggregated areas









Follow consistent mapping & removal protocols

Site	2021 Mapped	Vines Removed	% Remaining
1	107	40	63%
2	98	60	39%
3	373	356	5%

Knowledge gap: **Incubation period**: time between inoculation & symptoms

Field trials established one-year incubation period for leafroll-3

Inoculation

1-year

Symptoms

Blaisdell et al. 2016. *EJPP* 146: 105-116

Unknown incubation period for GRBV affects management

Inoculation

?? Years
>16 months

Symptoms

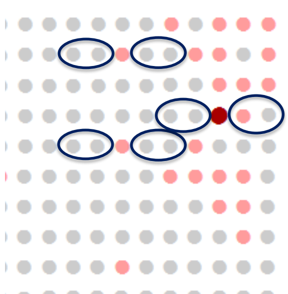
65

How to manage spread in aggregated areas?

Spatial roguing for leafroll

Grape mealybug + GLRaV-1
Finger Lakes, NY (2009-2016)

Remove infected vine and two in-row neighbors on each side



Hesler et al. 2022. AJEV. 10.5344/ajev.2022.22004

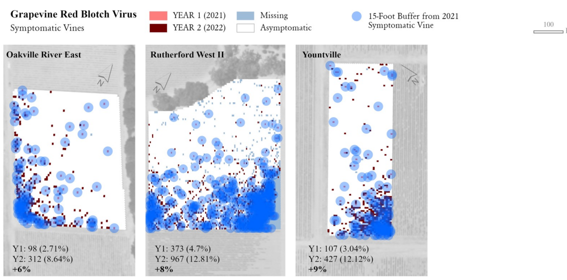
Will spatial roguing of aggregated infections work for **red blotch**?

What are the parameters?

66

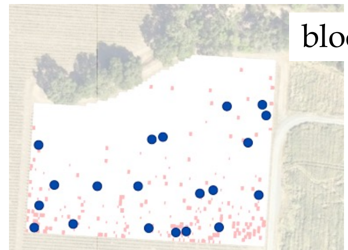
How to manage spread in aggregated areas?

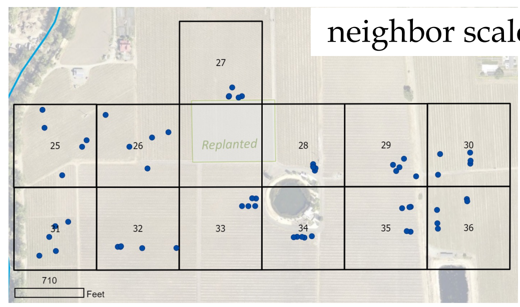
Buffer analysis to study roguing distances



trial & error in production blocks

Molecular ecology (genotyping)

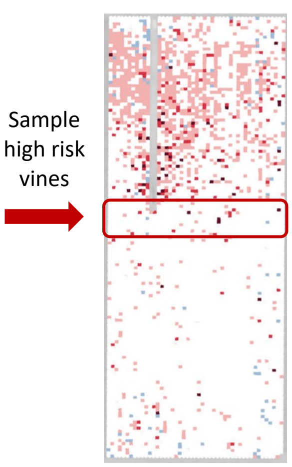




67

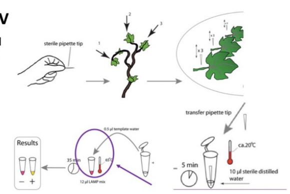
If we can detect pre-symptomatic vines, would that improve roguing outcomes?

Sample high risk vines



LAMP Assay for GRBV

The loop mediated isothermal amplification (LAMP) method is a point-of-use, DNA-based assay that has been developed for detection of grapevine red blotch virus (GRBV). LAMP is a rapid, colorimetric assay designed to be used "in-house" because it does not require special facilities, expensive equipment, or highly trained laboratory personnel.



Romero Romero et al. 2019. *Archives of Virology* 164: 1453-1457

https://ucceviticulturenapa.wixsite.com/uccevitnapa/lamp-assay

UC CE University of California Cooperative Extension

2023 Symptomatic (n=39)			2023 Asymptomatic (n=36)		
LAMP result 2022	+	-	LAMP result 2022	+	-
Trunk	25	14	**Trunk**	0	36
Cane	11	28	**Cane**	1	35
Petiole	2	37	**Petiole**	0	36

68

LAMP-GRBV (in-house diagnostic assay)

Opportunity for vineyard-winery collaboration

LAMP Assay for GRBV

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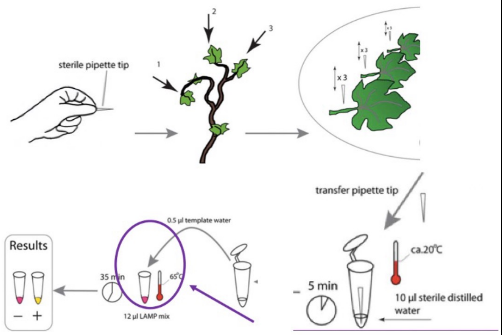

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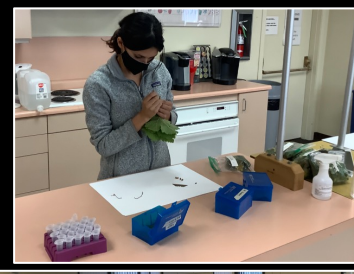
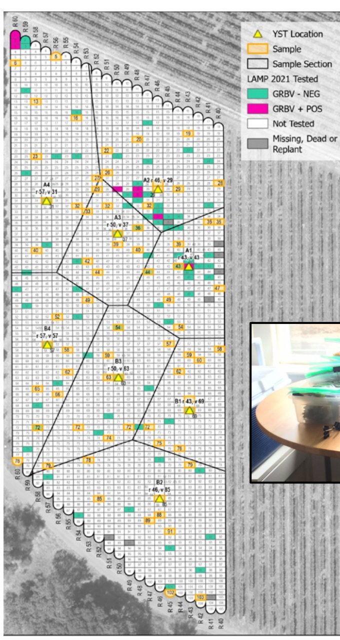
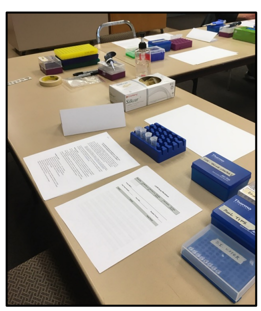


https://ucceviticulturenapa.wixsite.com/uccevitnapa/lamp-assay

69

Applications of LAMP-GRBV

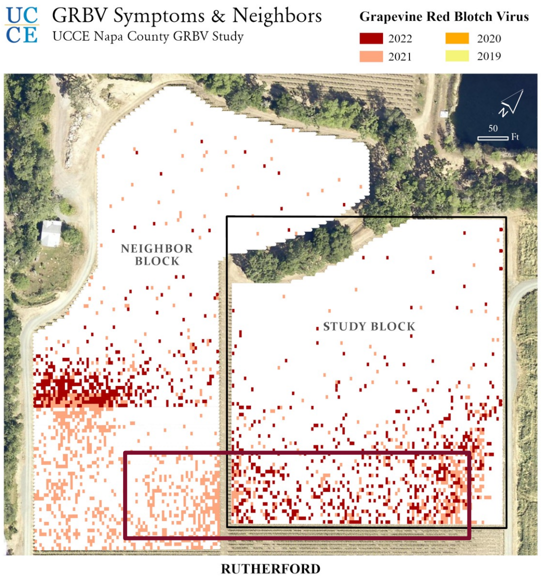




Sauvignon Blanc

70

Neighborhood Patterns



Neighboring blocks share GRBV issues

Coordinate with neighbors & develop regional strategies

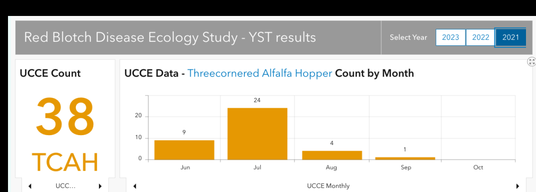
71

Regional monitoring

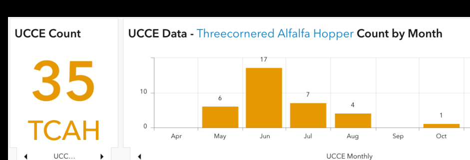
Technology for sharing & viewing data

https://ucceviticulturenapa.wixsite.com/uccevitnapa/data-dashboards

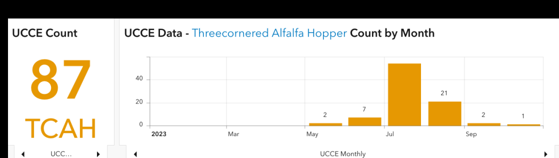
2021

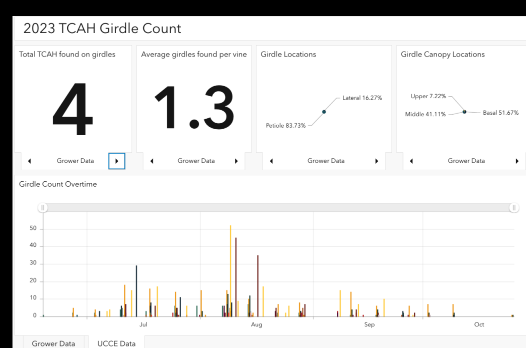


2022



2023





72

Positively influence adoption through improved communication & collaboration

Research

Adoption of Best Management Practices for Grapevine Leafroll and Red Blotch Diseases: A Survey of West Coast Growers

Malcolm B. Hobbs[1] | Selena M. Vengco[1] | Stephanie L. Bolton[2] | Larry J. Bettiga[3] | Michelle M. Moyer[4] | Monica L. Cooper[1,†] |

Information transfer among grape producers in the western United States on pest and disease management

Sarah R. Lowder[1,2], Michelle M. Moyer[3], Monica L. Cooper[4], Jay W. Pscheidt[2], Walter F. Mahaffee[5]

Research Article

Meeting the Challenge of Viral Disease Management in the US Wine Grape Industries of California and Washington: Demystifying Decision Making, Fostering Agricultural Networks, and Optimizing Educational Resources

Malcolm B. Hobbs,[1] Selena M. Vengco,[1] Stephanie L. Bolton,[2] Larry J. Bettiga,[3] Michelle M. Moyer,[4] and Monica L. Cooper[1]

Perspectives towards collective action for pest and disease management in vineyards in the western US

Sarah R. Lowder[1,2], Michelle M. Moyer[3], Monica L. Cooper[4], Jay Pscheidt[2], Walter F. Mahaffee[5]

Hobbs et al. 2022. 10.1094/PHYTOFR-07-21-0045-R
Hobbs et al. 2023. 10.1155/2023/7534116
Lowder et al. 2023. 10.1094/PHYTOFR-07-23-0082-R
Lowder et al. 2023. 10.1094/PHYTOFR-07-23-0081-R

73

Positively influence adoption through improved communication & collaboration

Needs assessment conducted in 2023 (survey & interviews)

74%

Voiced need for collaborative skills to advocate for GRBD management
Communication, negotiation, advocacy, leadership

Specific challenges

Convince other team members to rank GRBD as sufficiently important to act.
Clearly communicate impacts of GRBD to others.
Explain position to others with different job roles or in more powerful positions.
Gain buy-in from other stakeholders.
Diffuse interpersonal conflict and blame.
How to communicate with neighbors & create consensus.

74

Workshop series: Collaboration & Communication

These skills can increase team effectiveness
Decision-making quality & Productivity

Communicate information, negotiate, and advocate an idea effectively.

Build consensus and commitment to a decision.

Understand specific behaviors that lead to collaboration.

Move 'stuck' collaborations forward.

Respond to difficulties in collaborations.

"I did not realize that by being curious and asking questions in this way there could be a solution that I didn't know about that exists. Previously I did not think to ask questions in a [work] conversation, I just pushed my position which in hindsight wasn't very helpful".

Funded by a grant from the American Vineyard Foundation

75

Red blotch disease in Napa (2023)

"I would rather have LR3 than red blotch, because I know how to manage LR3."

Secondary spread patterns
Technical knowledge incomplete (vector & disease ecology)
Economics are challenging due to spatial scale of disease
Neighborhood cooperation needed

76

What have we learned about adoption & management of insect-vectored pathogens?

Economic, Technical (knowledge) and Social Factors influence adoption

Leafroll disease

Roguing is optimal response; vector management for large populations
Not a lack of knowledge, but lack of broader implementation, explained by

- Economic factors: too expensive, or fruit is under contract & buyer is not concerned about LR3
- *When buyers are looking for reasons to end a contract, they will target LR3 (and GRBD)*
- Social factors: question the science—overcome this with trusted, local expertise

Red blotch disease

Knowledge gaps result in uncertainty and unwillingness to adopt
Hard to convince people to do things when they can't be assured that their investment will have positive outcomes; Resources may be expended on low ROI practices
Closing knowledge gaps is critical: vector biology, disease ecology, management
Economic and social factors also come into play

- Neighborhood and regional collaboration
- Involve people & organizations across the supply chain

77

What have we learned about adoption & management of insect-vectored pathogens? [Leafroll, Red blotch, Pierce's disease]

Field studies of disease ecology

Important to close knowledge gaps in transmission biology & pathogen ecology

- Understand factors affecting disease spread and prioritize interventions

Field studies, controlled studies, and modeling are complementary
Similarities across regions (CA, New Zealand) reinforce outcomes

Participatory research engages growers in outcomes & adoption

Create shared learning opportunities & expertise in the community
Leverage network connections to share successes & create "new normal"

- Viticulturist previously had to plead with clients to manage LR3, now they request it

Invest time and resources: vector-transmitted diseases are complicated systems

Leafroll disease field research (2009-2020), outreach & education (2019-2023)
Red blotch disease field research (2013-ongoing), outreach & education (ongoing)

Strategic planning & evaluation of research & extension projects

Develop short, medium, and long-term solutions
No single solution—growers adapt various options & information to situational context
Don't over-emphasize long-term at the expense of short and medium-term projects

78

Thank you!

UCCE-Napa Viticulture Team
Sarah MacDonald, Malcolm Hobbs, Selena Vengco, Hannah Fendell-Hummel, Jennifer Rohrs

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79