ANNUAL RESEARCH REPORT

for

2018

California Tomato Research Institute

SUMMARY VERSION

Published as an industry service by the Members of the California Tomato Research Institute, Inc.

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Welcome, this report marks the 50th year of continuous crop research sponsored by the contributing members of the California Tomato Research Institute (CTRI).

The primary function of the CTRI is to identify production challenges and opportunities and to fund projects which research and development can address. Funding is through tonnage assessments ($0.07/paid ton) from its voluntary grower members. Decisions are governed by its Board; made up of growers. With the aim of building and maintaining an effective, robust and dynamic research agenda CTRI management promotes durable coalitions between growers, allied industry and researchers. Since 1968, when the CTRI was founded, over 600 research projects have been supported. These projects have primarily focused on improving field production, particularly in the areas of: pest management (250+ projects); variety development, pre-breeding and variety evaluation (150+ projects); agronomics (100+ projects); market development and process quality (75+ projects); and automation (25+ projects). Figure 1 charts our long running research categories over time.

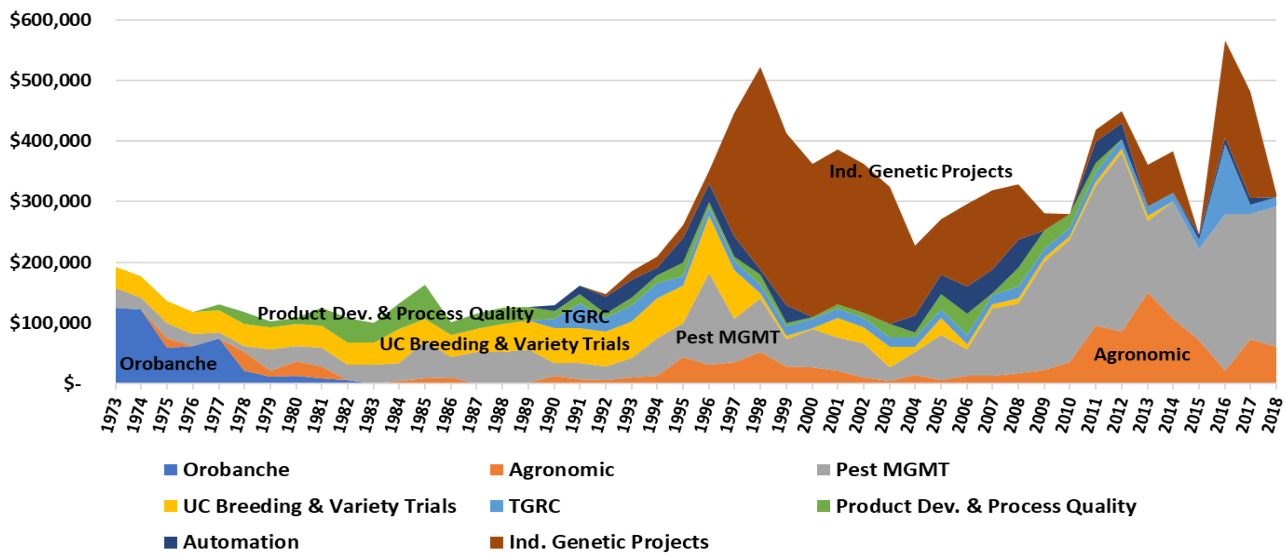


Figure 1. Expenditure by category through time (1973-2018)

As evidenced by a membership which represents over two thirds of the paid tons in 2018 (see Figure 2) and 50 years of historical expenditures, the CTRI has invested significantly (over 11 million USD) into the future of the processing tomato industry in California. These investments have come not only in the form of short term projects with results which can be immediately implemented in commercial fields (side-by-side crop protection product testing as an example) but also in the form of long term projection of industry need (continued annual TGRC commitment). Past experience highlights the reality that there is significance in not only what the CTRI chooses to fund from year to year but also in how we, alongside the industry, leverage those findings in two key ways: 1. To make the in-field changes which will continue to drive the industry forward incrementally and 2. To maintain and build the network of growers, processors, allied industry and researchers globally to cultivate and extend the next idea which will give us more than incremental change.

In the following pages we report on these efforts from 2018.

Additional resources for growers and allied industry can be found on the pages of www.tomatonet.org and by joining the industry email alert system also found on the home page of www.tomatonet.org.

Please do not hesitate to direct any and all questions related to this report or the work of the Institute to Zach Bagley at zach@tomatonet.org or 530-405-9469.

MEMBERSHIP & ASSESSMENT HISTORY

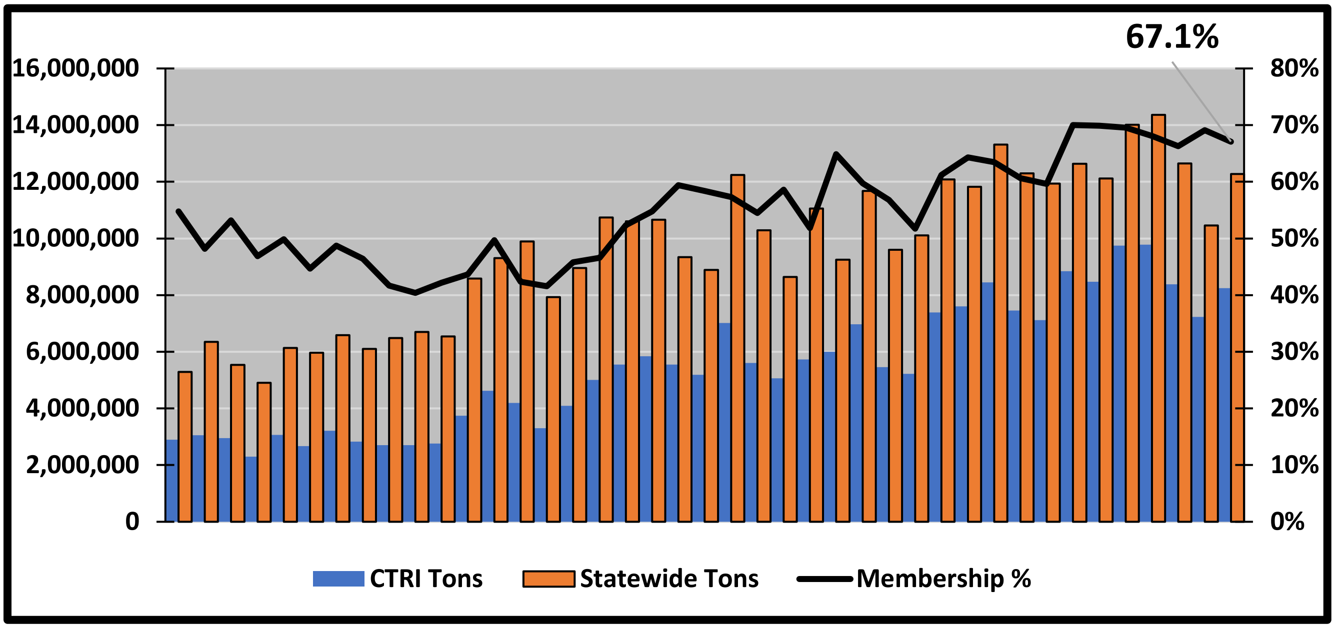
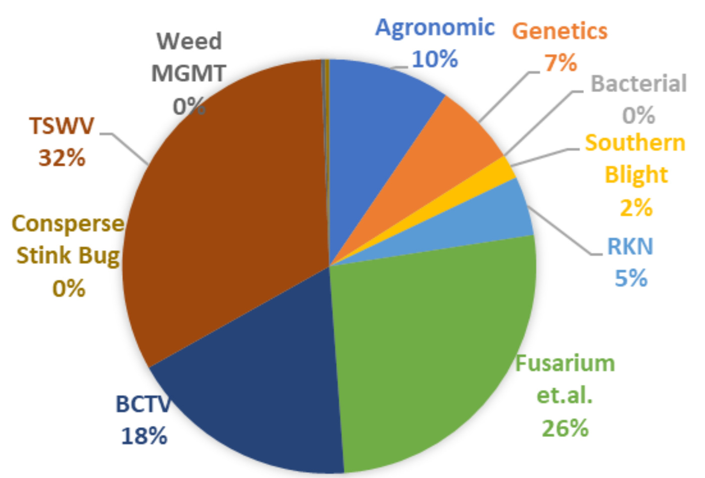


Figure 2. Membership & Assessment through time (1978-2018)

2018 RESEARCH - DOLLAR ALLOCATION

2018 Actual Allocations		
Category	Funding	%
Agronomic	$ 30,000	10%
Genetics	$ 20,440	7%
Bacterial	$ -	0%
Southern Blight	$ 6,000	2%
RKN	$ 14,600	5%
Fusarium et.al.	$ 82,710	26%
BCTV	$ 56,783	18%
TSWV	$ 102,282	33%
Weed MGMT	$ -	0%
Consperse Stink Bug	$ -	0%
TOTALS	$ 312,815	100%



California Tomato Research Institute

2018 CTRI FUNDED RESEARCH PROJECTS

2018 TOTAL FUNDING: $312,815

Agronomic/Water/Nutrient Management			**$**	**30,000**
2017 Start	Effects of irrigation and management practices on soil health and crop properties of processing tomatoes	Kate Scow	$	30,000
Germplasm and Variety Development			**$**	**20,440**
1991 Start	C. M. Rick Tomato Genetics Resource Center	Roger Chetelat	$	15,000
2016 Start	Wild tomato genome sequence analysis to discover novel genes for water stress tolerance	Dina St. Clair	$	5,440
Pathogen and Nematode Management			**$**	**262,375**
2014 Start	Evaluation of Chemical Control of Bacterial Speck	Gene Miyao	$	-
2018 New	Monitoring Southern Blight prevelance in Colusa County	Amber Vinchesi	$	6,000
2011 Start	Evaluation of Alternative Nematicides for the Control of Root-Knot Nematodes of Processing Tomatoes	Joe Nuñez	$	14,600
2018 New	Effect of deficit irrigation on Fusarium wilt and other root infecting pathogens in California tomato crops	Johanna Del Castillo	$	7,000
2017 Start	Tracking down Typhoid Mary: Rotation crops as hidden hosts of Fusarium oxysporum f. sp lycopersici race 3, the cause of Fusarium wilt in tomato	Cassandra Swett	$	12,360
2018 New	Putting the right varieties in the right places: Rapid Fusarium wilt diagnosis, soil detection and environmental risk assessment strategies to inform variety selection and reduce disease risk	Cassandra Swett	$	46,400
2018 New	The doppelganger dilemma: Improving resources for rapidly differentiating diverse tomato crown rot and wilt diseases	Cassandra Swett	$	16,950
2016 Start	Can vector-borne diseases be managed in commercial fields using ethylene inhibitors	Clare Casteel	$	26,000
2016 Start	Reducing insect virus vectors of Beet Curly Top Virus in processing tomatoes through soil health management	Amelie Gaudin	$	30,783
2018 New	Proximal remote sensing as a diagnostic tool to detect Tomato Spotted Wilt Virus in Western flower thrips	Christian Nansen	$	15,000
2017 Start	The resistance-breaking strain of Tomato spotted wilt virus in the Central Valley of California: Survey, genetic variability, improved detection and screening for resistance	Bob Gilbertson	$	79,903
2018 New	Relative susceptibility of processing tomato varieties to Tomato spotted wilt virus under commercial conditions in Central California	Tom Turini	$	7,379
Weed Control and Management			**$**	**-**
2015 Start	Automatic Vision Guided Weed Control System for Processing Tomatoes	David Slaughter	$	-
2018 New	Market development and paths forward for automation technologies in the processing tomato industry - UCD MBA IMPACT	Daria Costello	$	-
2018 TOTALS				**$312,815**

EFFECTS OF IRRIGATION AND MANAGEMENT PRACTICES ON SOIL HEALTH AND CROP PROPERTIES OF PROCESSING TOMATOES

KATE SCOW

Project Title: Effects of irrigation and management practices on soil health and crop properties of processing tomatoes

Project Leader: Kate Scow, Professor, Dept. of Land, Air and Water Resources, 3236 Plant & Environmental Sciences, One Shields Ave. University of California, Davis, CA 95616. 530-752-4632; kmscow@ucdavis.edu

Cooperating Personnel: David Viguie, Dustin Timothy & Viguie Farms, Davis, CA; Frank Muller, Muller Ranch, Woodland, CA; Robert Payne, Payne Farms, Woodland, CA; Danny Royer, Bowles Farming Company, Los Banos, CA; Scott Park, Park Farming Organics, Meridian, CA; Tony Turkovich, Button & Turkovich Ranch, Winters, CA; Steve Meek, J.H. Meek & Sons, Inc., Woodland, CA; Rich Collins, Collins Farm, Davis, CA; Israel Herrera, University Farm Facilities, Davis, CA; Scott Schmidt, Farming D, Five Points, CA; Kevin Ruble, Woolf Farming and Processing, Huron, CA

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: The goal of this survey was to identify and characterize soil chemical, physical, and biological parameters on northern and central CA tomato farms, and assess how these parameters impact tomato crop management, health, and yields. We also evaluated different irrigation and fertility management strategies in processing tomato systems using a Land Use System (LUS) economic model to quantify and evaluate tradeoffs associated with those strategies. Our objectives were to:

- Identify relationships between soil health properties, irrigation history, agricultural management practices and inputs, and tomato yields/quality.
- Identify relationships between particular management practices (e.g., SSDI management, compost inputs, cover cropping, crop rotation, etc.) and how these impact soil health indicators and soil fertility, ultimately impacting productivity.
- Evaluate impacts of irrigation management and potential strategies to improve soil health (e.g. cover crops, compost) on farm economics by quantifying tradeoffs related to water use, labor inputs, and crop performance.

SUMMARY: Increasing adoption of drip irrigation during the 2000s was accompanied by a dramatic increase in processing tomato yields statewide. Despite its widespread use, there is still more to learn about unanticipated impacts of SSDI in processing tomatoes and also how to best optimize management on both conventional and organic farms. We hope to address this gap by collecting data on SSDI and management practices in conventional and organic processing tomatoes from farms throughout the state, which will be used to evaluate soil health. Information on soil biological communities and their activities is rare and difficult for farmers to access because of the costs of lab analyses and their lack of availability in typical soil analysis laboratories. This study will combine common soil tests used on-farm with new soil biological indicators, and this information will be used to help tomato growers understand: 1) soil biological activity on their farms, 2) how their management practices interact with soil microbial community functions, and 3) how soil microbial communities may be impacting tomato crop management and growth. By aggregating data across farms we will be able to better understand the trends of tomato yields and what practices may help mitigate potential declines and support farm resilience.

It is well known that properties of soils and climates differ markedly between the Sacramento and San Joaquin Valley. Not surprisingly these differences were also related to regional differences in soil health indicators. In general, organic matter contents in the Sacramento Valley soils were greater than those in San Joaquin Valley soils. In the Sacramento Valley, a slight negative relationship was observed between soil organic matter content and tomato yields, but in the San Joaquin Valley, tomato yields increased with increasing organic matter (Figure 1). Soil microbial biomass was similar in the two regions despite differences in soil organic matter content. Soil organic matter provides microbes with a source of carbon, which microbes feed upon for energy; therefore, it was expected that a larger soil organic matter pool would support a larger soil microbial community. Organic matter was also positively correlated with soil P and K, implying that P and K availability to tomato plants increases with increasing soil organic matter, in general. Some of the differences in soil properties between regions included: 1) lower Ca:Mg ratio (1.2:1) in Sacramento Valley, compared to a 3.2:1 ratio in San Joaquin Valley, 2) higher soil P concentrations in Sacramento Valley, 3) higher soil K concentrations in San Joaquin Valley, and 4) higher soil cation exchange capacities (CEC) in San Joaquin Valley. While few of the soil health indicators showed relationships with length of time the farm was under SSDI, one such positive relationship was observed in San Joaquin Valley soils with soil sodium (Na) concentrations increasing with time in SSDI (Figure 2). This relationship was not observed in Sacramento Valley soils. Sodium could be an indicator of salt buildup over time with SSDI in the San Joaquin Valley, though there was no relationship between soil sodium levels and tomato yields based on data available so far. Soil organic matter's ability to increase the CEC could help mitigate sodium buildup over time in SSDI systems, representing a potential benefit of increasing soil organic matter in San Joaquin Valley soils.

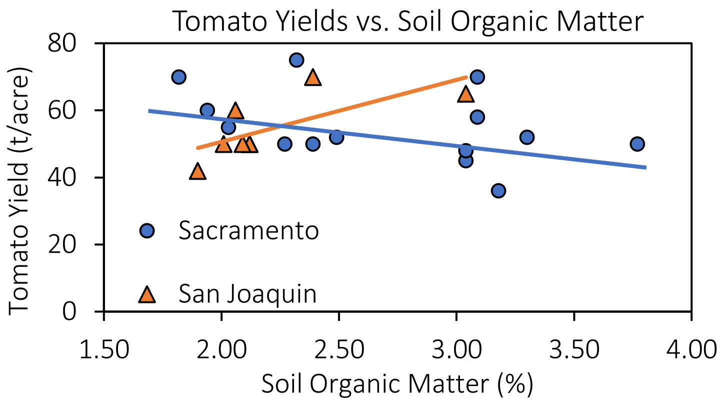


Figure 1. Estimated 2018 tomato yields on surveyed fields in the Sacramento (blue circles; blue line) and San Joaquin (orange triangle; orange line) Valleys versus soil organic matter content.

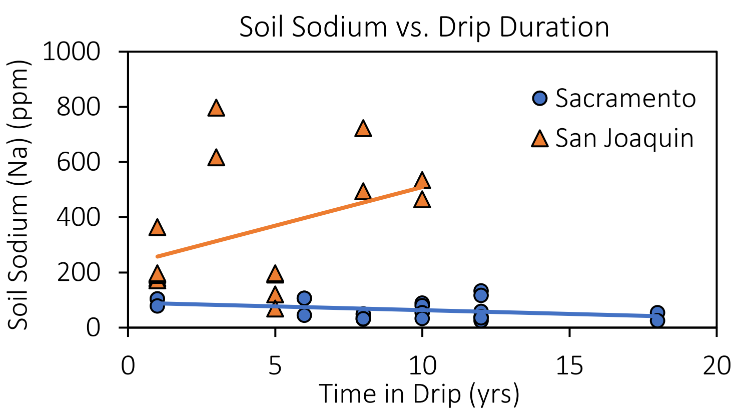


Figure 2. Soil test sodium on surveyed fields in the Sacramento (blue circles; blue line) and San Joaquin (orange triangle; orange line) Valleys versus years under SSDI.

Lastly, we found a logarithmic relationship between the MBN:nitrate ratio and soil nitrate levels, with an inflection point around 15 to 20 ppm nitrate. This point could be interpreted as representing where the MBN:nitrate ratio stops being as responsive to increasing soil nitrate concentrations. This finding could be important for fertigation management of nitrate because it implies that low uptake efficiency in tomato may occur in situations when fertilization injections are too low, e.g. resulting in soil nitrate levels lower than 20 ppm. This interesting relationship, showing a dependency of fertilizer inputs on the soil microbial biomass concentration, is novel and will be explored further in future research.

ONGOING ANNUAL SUPPORT OF THE TOMATO GENETICS RESOURCE CENTER
ROGER CHETELAT

Project Title: C.M. Rick Tomato Genetics Resource Center

Project Leader: Roger T. Chetelat, Geneticist, Dept. of Plant Sciences, University of California, Davis

SUMMARY:

Acquisitions: The TGRC acquired two new accessions this year, both long storage, delayed ripening varieties from Spain. In addition, we rescued three accessions of *S. ochranthum* that had never been successfully grown for seed increase. Obsolete or redundant accessions were dropped. The current total of number of accessions maintained by the TGRC is 4,344.

Maintenance and Evaluation: Over 1,050 cultures were grown for various purposes, of which 561 were for seed increase, including 92 wild species accessions. Germination tests were run on 707 seed lots. Progeny tests were performed on 122 stocks of male-steriles, trisomics, and other segregating lines or accessions with unexpected phenotypes. 197 stocks were grown for introgression of the S. sitiens genome. Other stocks were grown for research on interspecific reproductive barriers. All plants grown for seed regeneration were tested for PSTVd; no positive plants were found. Newly regenerated seed lots were split, with one sample stored at 5° C to use for filling seed requests, the other stored in sealed pouches at -18° C to better maintain long term seed viability. 86 seed samples were sent to the USDA and 25 to the Svalbard Global Seed Vault for long term backup storage.

Distribution and Utilization: A total of 6,946 seed samples representing 2,032 different accessions were distributed in response to 330 requests from 256 researchers and breeders in 31 countries; at least 32 purely informational requests were also answered. The overall utilization rate (i.e. the number of samples distributed relative to the number of accessions available) was 160%. Information provided by recipients indicates our stocks continue to be used to support a wide variety of research and breeding projects. Our annual literature search uncovered 90 publications that mention use of TGRC stocks.

Documentation: New images of mutants and wild species were uploaded. Passport data on new accessions was added. Revised guidelines for seed germination, pollen collecting, and maintenance of wild species were posted on our website. Seed request records and passport information on seed samples submitted for off-site back up were provided to the USDA for uploading to their GRIN-Global database.

Research: The TGRC continued research on the mechanisms of interspecific reproductive barriers and on introgression of the S. sitiens genome. We published a paper on a previously unknown mechanism for pollen recognition and rejection by flowers of the wild species S. pennellii. We completed development of a set of introgression lines that capture ca. 95% of the genome of S. sitiens in the background of cultivated tomato.

Project Title: Wild tomato genome sequence analysis to discover novel genes for water stress tolerance

Project Leader: Dr. Dina St. Clair, Professor, Plant Sciences Department, University of California, Davis

Cooperating Personnel: Dr. Ming Cheng Luo, Research Geneticist, Plant Sciences Department, University of California, Davis; and Amy Groh, Ph.D. graduate student, St. Clair research group

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: For 2018, our main goal was to identify and assemble the DNA sequences of the *S. habrochaites* genome sequence that correspond specifically to wild tomato chromosome 9. Our specific objectives were to: (1) complete hybrid scaffolding of PacBio sequences (contigs) with the BNG optical map of wild tomato, (2) compare super-scaffold sequences of wild tomato to the cultivated tomato reference genome, and complete pseudomolecule assembly for each chromosome.

SUMMARY: Water stress caused by limited water availability reduces productivity of tomato plants and negatively impacts fruit yields. Cyclic, prolonged droughts in California are adversely affecting water availability for irrigated agriculture. Breeding for "climate resilient" crops that can maintain productivity with less water is a strategy to help increase sustainability of production into the future. Wild tomato (*S. habrochaites*) is highly tolerant to various abiotic stresses, including limited water, unlike susceptible cultivated tomato (*S. lycopersicum*). Wild tomato can serve as a source of valuable genes for breeding tolerance to water stress and water use efficiency into cultivated tomato. Identification of genes from *S. habrochaites* that control traits associated with water stress tolerance and water use efficiency will enable targeted marker-assisted breeding of tomato cultivars that are productive with less water.

Our prior research on mapping of traits associated with water stress tolerance in wild tomato indicate that a defined region on chromosome 9 from *S. habrochaites* contains genes that control water stress tolerance and water use efficiency (Arms et al. 2015; Lounsbery et al. 2016; Arms et al. 2017). Although we determined the chromosome 9 regions associated with each of the traits, the identity of the genes is not revealed with genetic mapping. Fortunately, gene discovery is facilitated by whole genome sequencing. By obtaining genome sequence of wild *S. habrochaites*, it is feasible to determine the genes and/or gene regulatory elements in the wild tomato chromosome 9 regions controlling water stress tolerance and water use efficiency. These genes and regulatory elements would be ideal, specific targets for transfer from wild to cultivated tomato. Identification of the desirable wild genes enables efficient marker-assisted breeding of cultivated tomato. The overall goal of enabling marker-assisted breeding of tomato cultivars that are productive with less water will be accomplished ultimately by making this information available to breeders for use in commercial cultivar breeding.

With CTRI support in 2017, we obtained whole genome sequence data for *S. habrochaites* on the PacBio sequencer. With CTRI support in 2018, we assembled this large data set of small DNA sequences with a step-by-step process (see details below) into the 12 chromosomes of wild tomato, including our target, chromosome 9.

We have completed genome sequencing and genome assembly of the wild tomato genome of *S. habrochaites* LA1778 into 12 chromosomes and identified chromosome 9. All of the sequence data and genome analysis results are safely stored on UCD computers and external hard drives.

To achieve the overall goal of enabling marker-assisted breeding of cultivars that are productive with less water, it will require the identification and validation of wild tomato genes on chromosome 9 controlling traits associated with water stress tolerance and water use efficiency. Towards that end goal, we intend to leverage the data and results from this project in proposal(s) to USDA-NIFA and other funding sources to seek support to continue the research.

EVALUATION OF CHEMICAL CONTROL OF BACTERIAL SPECK

GENE MIYAO

Project Title: Evaluation of Chemical Control of Bacterial Speck

Project Leader: Gene Miyao, Farm Advisor, UC Cooperative Extension, 70 Cottonwood St., Woodland, CA 95695, emmiyao@ucanr.edu, 530-666-8732

Cooperating Personnel: Bryan Pellissier, field superintendent, UC Davis Plant Pathology Department Alexa Sommers-Miller, research assistant, UC Davis Plant Pathology Department Jesus Martinez Rodriguez, UCCE- Yolo lab assistant, UC Davis student. Gitta Coaker lab at UC Davis produced inoculum for the test. Joe Muller and Sons, Woodland (earlier-years cooperators in commercial fields). Ag Seeds and TS&L have each provided transplants for the trials over the years. Processing Tomato Advisory Board- fruit quality evaluations.

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: The goal was simple: identify a more effective chemical control combination to tank mix with copper for bacterial speck control. Include biological materials in the evaluations. Plant genetic resistance to bacterial speck has been widely overrun by a resistant pathogen population.

SUMMARY: Because disease pressure (severity) was low, these trial results have limited value to make a strong comparative judgement on reliable treatments under perhaps even modest disease pressure conditions.

Disease level, fruit yield, quality and culls, Plant Pathology Armstrong facility, UC Davis, 2018.

	Material (product/ac)	5-May diseased plants %	fruit biomass tons/A	marketable yield tons/acre	PTAB color	PTAB Brix	PTAB pH	% pink	% green	% mold
1	non treated control	54	102	85	21.1	4.48	4.42	17	15	2
2	copper (Kocide 3000) 1.75 lbs	42	110	87	21.8	4.20	4.46	12	20	1
3	copper plus Dithane 1.75 & 2 lbs	34	102	87	21.8	4.10	4.46	12	13	2
4	Actigard(0.75 oz) with copper	25	111	93	21.8	4.25	4.46	13	15	1
5	Oxidate with copper 1:100 @25 gpa	40	103	86	21.8	4.20	4.45	14	14	2
6	Regalia (3 qrt) with copper	47	103	90	21.4	4.40	4.44	12	11	2
7	Stargus MBI 110 (2 qrts) with copper	51	101	82	21.3	4.18	4.46	12	17	2
8	Serenade Opti (3 lbs) with copper	26	109	89	21.8	4.28	4.43	16	17	1
9	Agri-Mycin 17	47	101	81	21.6	4.10	4.47	11	18	1
10	non treated control	66	103	82	21.9	4.43	4.43	14	19	2
	LSD 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS
	F value	1.59	0.94	0.52	1.05	1.58	1.73	1.46	0.47	0.24
	% CV	47	8	12	2	5	1	25	50	65
	Group comparison									
	nontreated control vs.	60	102.4	83.2	21.5	4.5	4.42	15.4	17.2	1.6
	any chemical program	39	104.8	86.9	21.6	4.2	4.45	12.6	15.6	1.5
	Probability	0.01	NS	NS	NS	0.01	0.01	0.03	NS	NS

Project Title: Monitoring Southern Blight prevelance in Colusa County

Project Leader: Amber Vinchesi, Ph.D., Area Vegetable Crops Advisor Colusa, Sutter and Yuba counties, University of California Cooperative Extension, 100 Sunrise Blvd., Suite E, Colusa, CA 95932, 530-458-0575, acvinchesi@ucanr.edu

Cooperating Personnel: Cassandra Swett, Ph.D., Cooperative Extension Specialist Vegetable and Field Crop Pathology, UC Davis; Sarah Light, Area Agronomy Advisor Colusa, Sutter and Yuba counties, University of California Cooperative Extension; Mumma Brothers; T&P Farms; Vann Brothers

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL:

- Monitor southern blight disease development in fields in Colusa County previously planted to tomatoes (in 2017), known to have the pathogen.
- Monitor southern blight spread in Colusa County tomato fields in close proximity to fields monitored in Objective 1.

SUMMARY: We were successful in the aim of our study and able to recover southern blight sclerotia in fields throughout Colusa County and demonstrate southern blight increases over the growing season with rotational crops. This gives us the opportunity to study southern blight levels over time.

Our original goal was to determine whether southern blight is a growing problem in Colusa County and screen fields for southern blight sclerotia levels. The conditions in 2017 were ideal for disease development, but this was not the case in 2018. Southern blight requires specific conditions for development to occur. This year, southern blight was not a large issue for tomato growers, and remains a disease that is a problem in our area only when environmental conditions are ideal for development. Due to 2018 being a cooler year compared to 2017, we did not expect a large amount of southern blight development. However, Vinchesi had one farm call that resulted in a southern blight diagnosis in 2018. This was an organic tomato field in the Sutter Basin with seepage issues. Southern blight is favored by moisture and the stressed plants were more predisposed to disease.

The nine fields monitored may be critical for future trials to improve management methods, especially if future growing seasons resemble 2017. At this time, we do not plan to repeat this project next year, but southern blight remains present in Colusa County and has the potential to cause losses for specific growers in the Sacramento Valley in future years.

Field	Time 0	Time end-of-season	Time 0	Time end-of-season	Crop		Notes
	Average sclerotia levels/100 g soil		Total # sclerotia/total amount of soil		2017	2018	
1	0.60	0.29	3/500g	3/1050g	Tomato	Corn	
2	0.00	1.57	0/1100g	22/1400g	Tomato	Corn	
3	0.00	N/A	0/600g	N/A	Tomato	Cucumber	
4	2.30	0.29	7/300g	4/1400g	Tomato	Corn	
5	0.00	0.95	0/400g	10/1050g	Wheat	Corn	
6	0.67	0.86	2/300g	0/1400g	Tomato	Corn	Southern blight ID uncertain at Time 0
7	0.30	0.50	2/600g	7/1400g	Tomato	Sunflower	Southern blight ID uncertain at Time 0
8	0.00	0.00	0/600g	15/1750g	Tomato	Sunflower	
9	0.40	0.86	2/500g	21/2450g	Canary bean	Sunflower	

Project Title: Evaluation of Alternative Nematicides for the Control of Root-Knot Nematodes

Project Leader: Joe Nunez, Vegetable/Plant Pathology Advisor-Emeritus, UC Cooperative Extension, 1031 So. Mount Vernon Ave., Bakersfield, CA 93307. Office: 661-868-622, fax: 661-868-6208, Email: jnunez@ucdavis.edu

Cooperating Personnel: Alex Putman, Extension Specialist, UC Riverside

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: An over reliance of any one particular nematicide product would likely lead to a loss of that product. With the demise of the MI gene it is of utmost importance keep these new products performing at their highest level for as long as possible. We need learn how to best use these new nematicides in a rotation program to maintain their efficacy. New products, especially biological, come along each year and these need to be screened to learn if they show any promise as true nematicides.

Objectives 1: Conduct small plot field trials to evaluate the rotation of Nimitiz, Vellum, DP1 and Vydate.
Objective 2: Conduct small field trials to evaluate the efficacy of any new nematicides that may be available for testing with particular regards to biological products.

SUMMARY: Root knot nematodes (RKN) are a major pest of processing tomatoes grown in California. Most commercially grown processing tomato varieties now incorporate the MI gene to provide a single gene resistance to RKN. However, each year incidences of moderate to severe RKN injury seem to occur more frequently. Some failure of the MI gene can be attributed as being due to resistance buildup to this single mode of resistance by RKN to this gene. Other instances of failure of processing tomatoes with the MI gene are still debatable but may be due to high soil temperatures.

The trials were both planted at the root knot nematode nursery maintained at the UCCE Shafter Research farm. We have had many trials with excellent results over the past several years at this location. However this year we saw very little to no root knot nematode infections. We did not harvest the two plots or the similar trials we conducted on carrots due to the lack of nematode infection.

Because of the lack of RKN pressure in the dedicated nematode trialing blocks the below is information captured in the 2017 trials:

We were able to conduct several nematicide trials with processing tomatoes in 2017. We obtained significant differences in infection in several of the trials we conducted but several trials also did not have enough nematode pressure to make any conclusions. This was especially true for the biological nematicide trial.

Conventional Nematicides: In comparing Nimitz, Velum and DuPont's new nematicide Salibro side by side we saw significant reduction in nematode injury as compared to the non-treated control. All three nematicides have shown to be reliable and consistent performers.

The treatments were as follows:
1. Control
2. Velum 6.5 fl oz/A = 0.4 ml/plot
3. Nimitz 5 pts/A 7-10 days before planting = 5.4 ml/plot
4. Salibro 30.7 fl oz/A = 2.1 ml/plot

Treatment 3 was applied on 4/24/17 and the others applied at planting on 5/1/17. Only a single application pre-plant or at planting was applied for each treatment. Five roots per plot were harvested the week of 8/7/17 and evaluated for rootknot nematode galling. Roots were rated on a scale of 1 to 10 with 1 being no visible galling and 10 the roots being over 90% galled.

Treatment	Rating
1. Control	8.0 A
2. Velum	3.6 B
3. Nimitz	1.4 B
4 Salibro	2.5 B
Probability=	0.0019
%CV=	54.48
LSD $_{P=0.05}$	2.905

Biological Nematicides: A trial was also conducted to determine the efficacy of several biological products for root knot nematode control.

Treatments were as follows:

1. Control
2. Emune Plus @ 2 gal/A at planting followed every 3 weeks
3. H2H 6-1-0 @ 20 gal/A followed 4 weeks later at same rate
4. H2H 1-1-0 @ 20 gal/A followed 4 weeks later at same rate
5. Promax @ 2 gal/A at planting followed every 3 weeks
6. Ultra Grow @ 1 gal/A every 3 weeks

The trial was conducted at the western end of the root knot nematode nursery at the UCCE Shafter research farm which did not have enough nematode pressure which resulted in little to no galling on the roots. Data was therefore not collected from the biological segment of the trial.

Pictures of Roots from Tomato Nematicide Trial:

Figure 1. Control

Figure 2. Nimitz at 5 pt/A pre-plant

Figure 3. DuPont at 30.7 fl oz/A pre and post application

Figure 4. Velum at 6.5 fl oz/A pre-plant

Project Title: Effect of deficit irrigation on Fusarium wilt and other root infecting pathogens in California tomato crops

Project Leader: Cassandra Swett, Cooperative Extension Specialist, Department of Plant Pathology, One shields Ave, University of California, Davis, CA, 95616, phone: 530-902-0094, email: clswett@ucdavis.edu.

Initial Project Leader: Johanna Del Castillo, Post-doctoral Researcher, Department of Plant Pathology, One shields Ave, University of California, Davis, CA, 95616, phone: 517-894-7576, email: jdelcastillo@ucdavis.edu. (Took a job in May of 2018; Dr. Swett became project leader)

Cooperating personnel: Amélie Gaudin, Assistant Professor of Agroecology, Department of Plant Sciences, One shields Ave, University of California, Davis, CA, 95616, phone: 530-650-5101, email: agaudin@ucdavis.edu.
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SUMMARY: Recommendations for deficit irrigation strategies in processing tomato have been developed based on the physiological effects on plant growth which influence yield, but there may also be indirect effects on yield which are equally important. One of the main ways that deficit irrigation can indirectly effect yields is by influencing diseases. We undertook to conduct a preliminary assessment of the impacts of deficit irrigation on tomato diseases and understand the role that soil management plays in influencing these interactions. In this study we found that the effects on different diseases are not necessarily all the same. Stress-induced diseases such as Fusarium wilt appeared to be enhanced under deficit irrigation, while soil moisture-induced diseases such as crown rots appeared to be suppressed with irrigation deficit (Figure 1). TSWV also appeared to be slightly suppressed under deficit irrigation. We also found a disorder (likely pathogenic) of unknown etiology, which was enhanced under deficit irrigation. Looking at total fungal endophyte community diversity, taxa diversity was consistently lower at 100% ET and increased under irrigation deficit. This was most notable in the organic plots, with an increase from 2 taxa at 100% ET to 16 taxa at 25% ET. Across all analyses, there were rarely significant differences between 100% and 75% ET. The main differences between irrigation treatments were typically apparent at 50% and 25% ET. These are both considered extreme and may not be used in agricultural settings; further studies looking at practiced methods can give a more realistic picture of how current irrigation practices are influencing diseases.

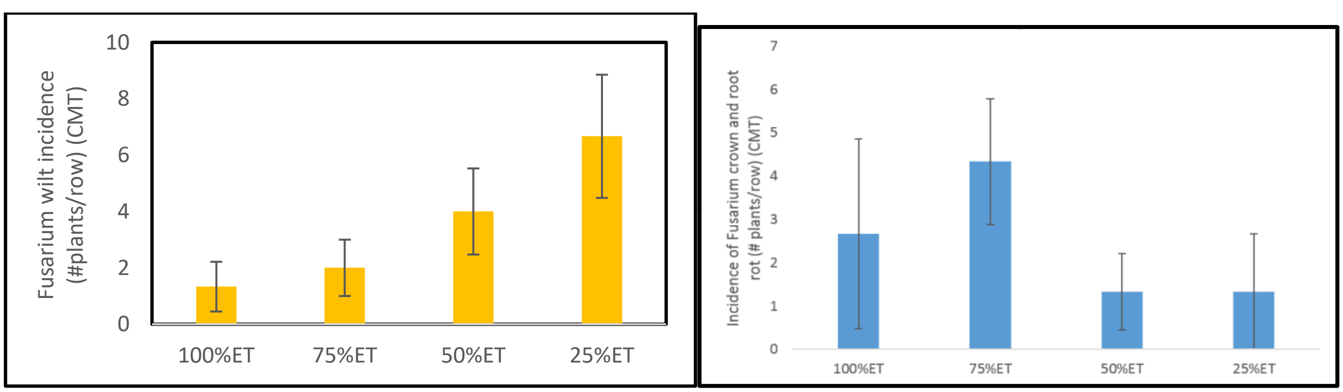

Figure 1. Effects of irrigation on Fusarium wilt (CMT, mid-season) and Fusarium crown and root rot (CMT, late season). CMT: Conventional management treatment

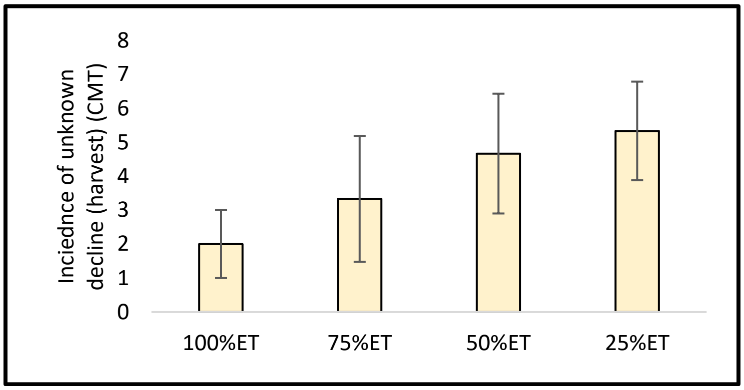

Figure 2. (L) Symptoms of plants suffering from this unknown decline and (R) effect of deficit irrigation on this unknown decline based on the number of plants with unknown decline symptoms in the conventional plots at harvest.

We hypothesized that soil management methods could influence disease and interactions between disease and irrigation. This was generally the case, but the effect of the treatment was the opposite of the expected, in which diseases were consistently higher in soils managed using organic methods, which are generally thought to be suppressive to pathogens and beneficial in improving soil moisture. We did find that diversity of fungal root endophytes was higher in the organic plots (30 taxa) compared to the conventional plots (23 taxa) and that diversity under deficit irrigation was much greater in the organic (23 taxa) compared to conventional plots (8 taxa), but whether these additional microbes are beneficial, harmful or neutral remains to be seen. Analyses by the Gaudin lab indicate that plant nutrient levels were much lower under organic management, likely because compost-based nutrients are not as effectively assimilated under drip irrigation. If plants were nutrient stressed, this could have also predisposed them to disease.

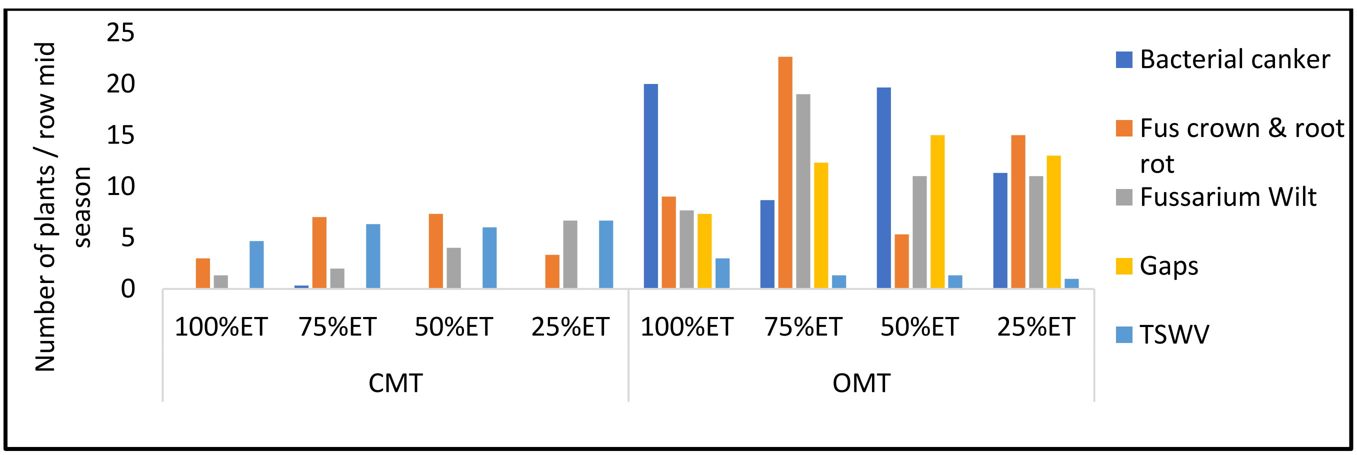

Figure 7. Disease incidence in organic and conventional plots across the four irrigation treatments.

The overall goal of this line of research is to enable use of deficit irrigation by identifying indirect yield-reducing effects on diseases and developing management strategies to avoid these effects. This study served its intended purpose of generating questions and hypotheses based on field observations connecting together deficit irrigation and land use management methods with disease impacts. We aim to use generated pilot data and hypotheses to seek external funding to support further study addressing various questions: What are the deficit irrigation conditions that trigger Fusarium wilt? Can deficit irrigation help manage Fusarium crown and root rots by reducing soil moisture? Is there an effect of deficit irrigation on TSWV? What is the cause of the unknown decline and is it influenced by deficit irrigation? Why were diseases higher in organic plots and is this linked to poor nutrient uptake from compost under drip irrigation? Why is there greater root endophyte diversity in organic vs. conventional plots under deficit irrigation--Is increased diversity beneficial or harmful (mutualists or pathogens)?

TRACKING DOWN TYPHOID MARY: ROTATION CROPS AS HIDDEN HOSTS OF *FUSARIUM OXYSPORUM* F. SP *LYCOPERSICI* RACE 3, THE CAUSE OF FUSARIUM WILT IN TOMATO

CASSANDRA SWETT

Project Title: Tracking down Typhoid Mary: Rotation crops as hidden hosts of *Fusarium oxysporum* f. sp *lycopersici* race 3, the cause of Fusarium wilt in tomato

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SUMMARY: Our big-picture goal for this project is to develop informed crop rotation recommendations that reduce Fusarium wilt risk (both losses from Fol race 3 and potential race 4 emergence). Fusarium wilt, caused by *Fusarium oxysporum* f. sp. *lycopersici* (Fol) race 3, is a devastating and widely distributed disease capable of causing up to an estimated 98% plant loss (50-100% yield loss). Despite being present in the state for decades, survival biology has never been studied and we rely on a highly generic non-data-based recommendation to rotate out of tomato (with any crop) for at least 2 years. Following these recommendations, Fusarium wilt has been observed to develop at similar levels to past plantings starting in the first year back to tomato, suggesting that these recommendations are flawed. There is concern that crop rotations are not working because certain non-tomato rotation crops contribute to inoculum persistence as cryptic hosts, as has been found for other Fusarium wilt pathogens. By identifying which crops most significantly increase and reduce soil inoculum loads can allow us to develop informed crop rotation recommendations, with particular emphasis on avoiding host crops in the first year after tomato.

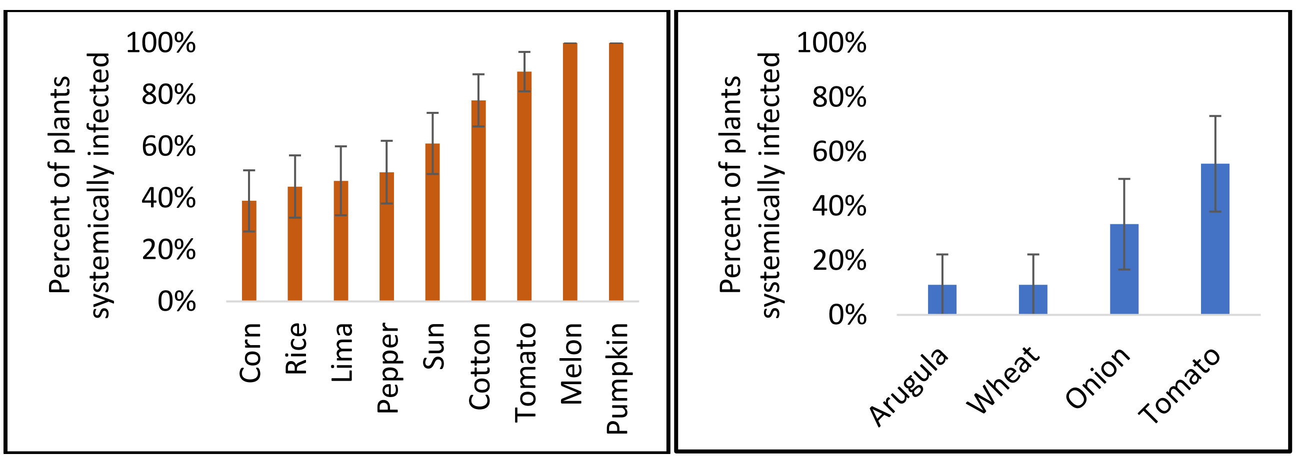

Figure 1. Percent of plants that Fol R3 colonized systemically, in warm season (L) and cool season (R) crop studies.

Based on host-status we have identified several putative **high-risk rotation** crops that should be avoided, at least in the first year out of tomato, specifically **cotton and cucurbit crops**, which are both common rotations with processing tomato in most counties (Figure 1). **Sunflower** also appears to be a moderate to high risk rotation. We have also identified several putative **low-risk rotation crops** that are better candidates for rotation. The lowest risk crops include all tested grasses—**corn, rice and wheat**—as well as **pepper and legumes** (Figure 1). Onion and brassica crops may also be low risk, but the data from the repeat trial is first needed, in order to validate statistically. Of note, Fol R3 survival during rice rotation may be influenced by flooding. We are working with Amber Vinchesi and Gene Miyao to evaluate survival of a Fol R3 (a nit mutant) in infected tomato tissue placed in flooded rice vs. a drip irrigated system. The most important next step is to determine how these different rotation crops contribute to soil inoculum loads. It's possible that some crops that are not extensively colonized still enable survival if tissue is slow to decompose; conversely, crops that are good hosts may not make significant inoculum contributions if the tissue rapidly breaks down or if the crop produces pathogen-inhibiting compounds. In addition, crops grown in the cool season may all be low risk if temperatures are too low to allow infection. We have initiated field studies to generate this information.

We also confirmed that F3 cultivars can host Fol and develop disease in artificially infested fields and determined that abiotic stressors such as salt can compromise disease resistance (Figure 2). We confirmed potential to contribute to inoculum loads by establishing that at least 10% of F3 plants in infested grower fields harbor Fol. We have determined that Fol R3 inoculum loads resulting from infested F3 tissue are similar if not higher than that resulting from infested F2 tissue (Figure 3). This suggests that planting F3 cultivars after an F2 outbreak, while effective in reducing disease losses, may not be effective in reducing inoculum loads and can pose a risk to race 4 emergence. However, we hypothesize F3 cultivars will vary in their contribution to inoculum loads due to variation in genetic background of quantitative traits, and some cultivars may be much lower risk. Further work is needed to evaluate consistency of host status across F3 genotypes, effect of pathogen dose and abiotic conditions on infection and evaluate relative contributions to inoculum loads in the field.

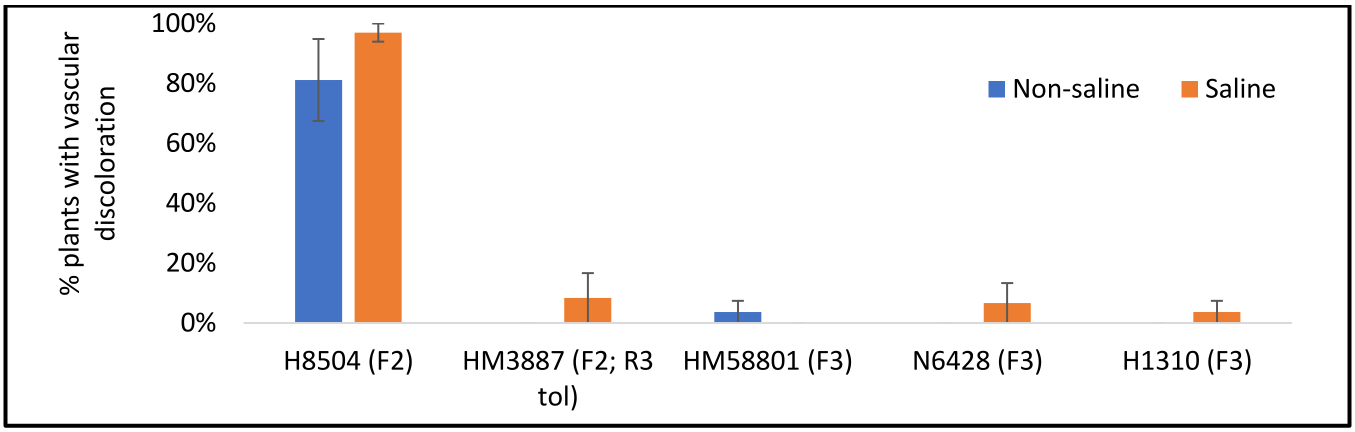

Figure 2. Incidence of systemic colonization in F3 cultivars based on presence of vascular discoloration.

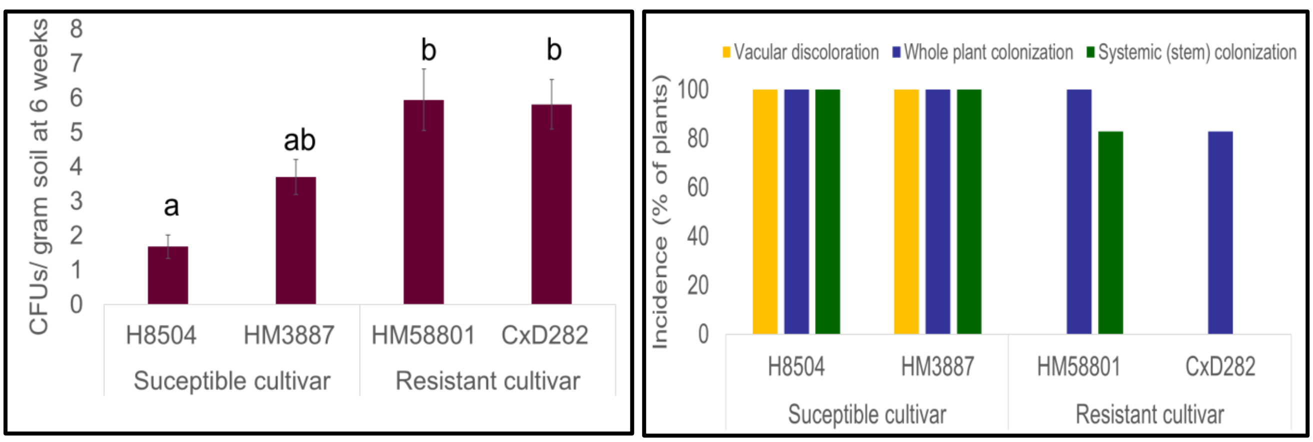

Figure 3. (L) Soil inoculum loads resulting from infestation of tissue of susceptible and resistant cultivars and (R) colonization incidence in tissue used in soil inoculum studies.

Project Title: Putting the right varieties in the right places: Rapid Fusarium wilt diagnosis, soil detection and environmental risk assessment strategies to inform variety selection and reduce disease risk

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Summary: At present there are no tools for assessing Fol race 3 soil inoculum loads, no rapid methods for diagnosing Fusarium wilt race 3 and limited information on environmental risks for Fusarium wilt. In this multi-year project we aim to provide molecular-based soil testing and disease diagnosis tools, and develop information on high risk environmental conditions that, together, can be used to mitigate Fusarium wilt risk. In this first year we initiated molecular marker development by (1) initiating creation of a validated genomic library of all *F. oxysporum* isolates present in tomatoes in California by sequencing the genomes of four Fol R3 isolates and one isolate each of Fol R1 and R2, (2) phenotyped 22 F. oxysporum isolates from tomato which will be added to the genomic library and used for marker validation, (3) for this same purpose, curated an additional 50+ *F. oxysporum* isolates from tomato including non-pathogenic isolates and additional Forl and Fol R1 and 2 isolates, which were under-represented in our collection.

We also evaluated inoculum risk thresholds for purposes of developing soil testing tools; initial studies have narrowed down the risk threshold level to less than 230 spores / g soil (medium inoculum level) but greater than 2.3 spores / g soil (low level) for a tolerant cultivar (Figure 1). Within this, we determined that soil salinity and deficit irrigation can both influence the inoculum risk threshold (Figure 2, 3). The effect of abiotic stress on disease development not surprisingly varied by cultivar, in which the effect on inoculum risk thresholds is more pronounced in tolerant cultivars; we also found that abiotic stress can trigger disease development in Fol R3 resistant cultivars. It would be very valuable to determine the precise conditions and mechanisms by which I3 expression is hindered, in order to mitigate these effects and preserve I3 efficacy. We did not see strong effects of abiotic stress on highly susceptible cultivars due to high levels of disease development—further studies at lower inoculum loads are needed to define inoculum risk thresholds and abiotic stress effects in a highly susceptible genetic background. In year two, we will expand our genomic DNA library and use this library to first identify conserved regions in all Fol R3 isolates and then evaluate which of these regions are not present in any other *F. oxysporum* strains.

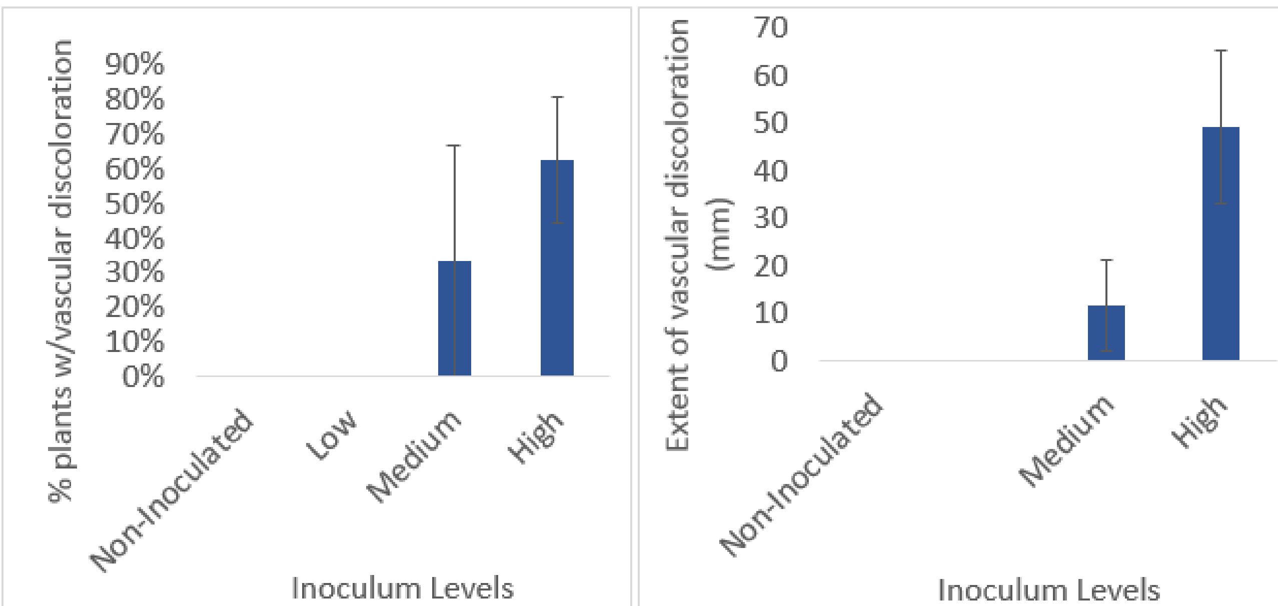

Figure 1. Evaluation of inoculum risk threshold, based on (L) Percent of plants with vascular discoloration extending into the stem (2cm above the crown) and (R) the extent to which discoloration spread up the stem (mm) 70 days post inoculation.

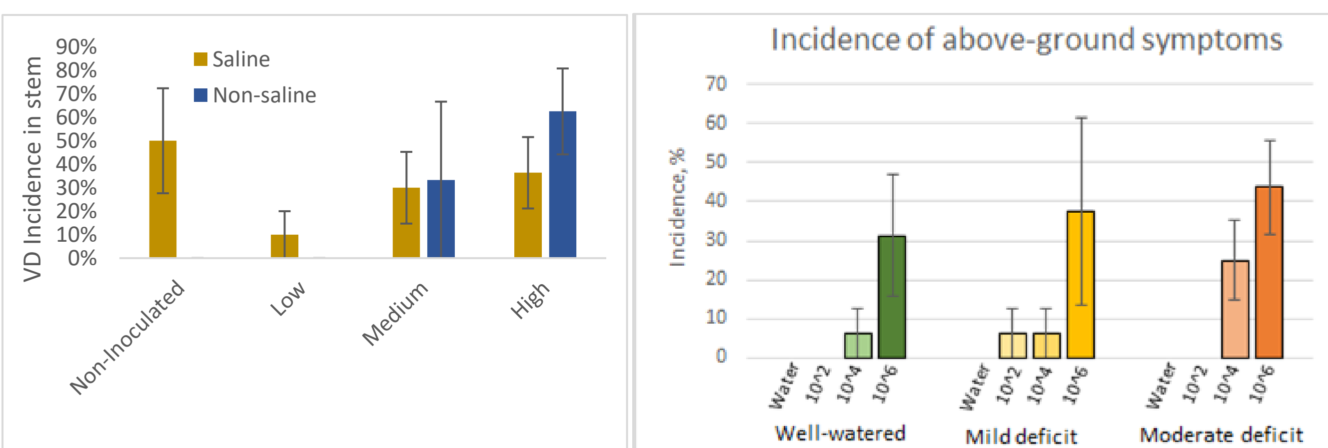

Figure 2. Inoculum risk threshold shifts as influenced by (L) salt (triggering disease at low, 10^2 spores/ml) and (R) deficit irrigation (increasing disease incidence at 10^4 spores/ml and triggering disease at 10^2).

Project Title: The doppelganger dilemma: Improving resources for rapidly differentiating diverse tomato crown rot and wilt diseases

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SUMMARY: With the loss of broad spectrum management strategies such as methyl bromide, disease-specific management methods such as resistant or tolerant cultivar use are increasingly important for management. Using these management tools requires accurate diagnosis to determine which disease or diseases are present in the field. Soil borne crown, root and wilt diseases of processing tomato are some of the most challenging to confidently identify in the field, due to overlapping symptoms and are often also challenging to diagnose in the lab. Based on interactions with advisors in 2017 and our own observations from conducting diagnoses, we identified several key challenge areas in making accurate diagnoses for crown, root and wilt diseases, including confusion regarding overlapping symptoms and lack of information on key diagnostic traits. This included confusion regarding overlap in crown rot and Fusarium wilt symptoms, as well as detection of a putative new Fusarium crown and stem rot disease, representing about 25% of crown rot received in 2017.

We have improved information for diagnosis by clarifying the following:

1. It appears unlikely that there is a strain of Fol R3 that is causing crown rot. Most samples where Fol was recovered from crown rot, were simply decaying from advanced Fusarium wilt. Thus, in diagnosing tomato diseases, we recommend only evaluating and submitting plants that are at an intermediate stage of decline. There were two Fol isolates that might cause rot, but the assay method was problematic and we are dubious of results (currently being repeated). Of note, isolates from our predecessor which were claimed to be Fol isolates that caused crown rot were neither Fol nor did they cause crown rot.

2. PCR diagnosis of Fol using the SIX genes, while reliable in consistently identifying Fol is problematic in that it also incorrectly identified several non-pathogenic isolates as Fol (false positives).

3. There is a new Fusarium pathogen, *Fusarium falciforme*, causing a disease with symptoms similar to Fusarium crown and root rot and Fusarium foot rot (depending on the stage of symptom development). We confirmed that this species can cause crown and stem rot (Figure 1) and have documented distribution on multiple farms across the state, from Fresno to Yolo county. Preliminary field trials indicate that this new Fusarium disease may cause unique symptoms, including whole canopy yellow and smaller leaves; <u>further studies</u> are needed to comprehensively characterize symptoms and name this disease. Preliminary field trials indicate that some cultivars may be tolerant to disease—<u>further work</u> is needed to develop tolerant cultivar recommendations, providing a rapid short-term management option.

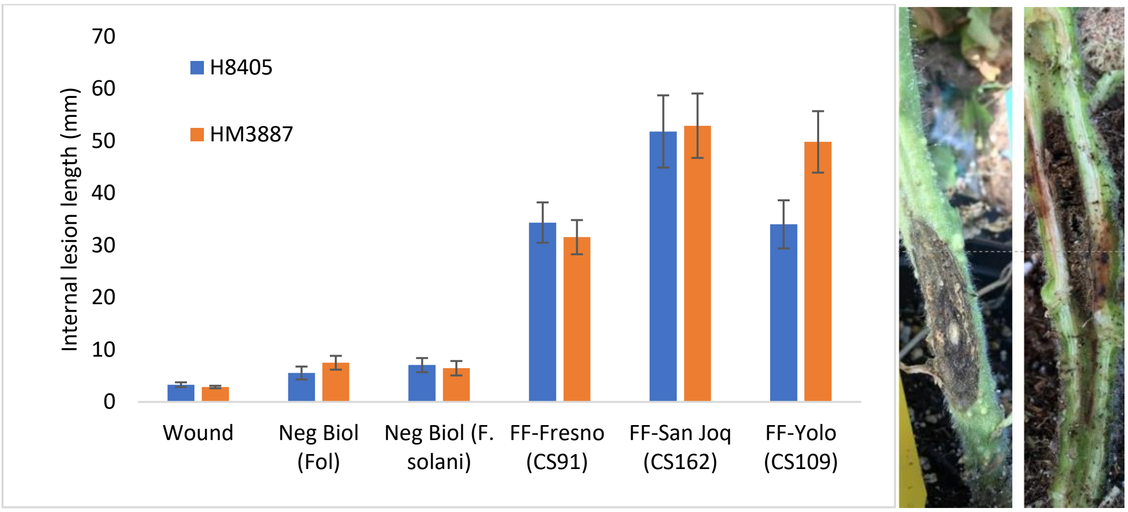

Figure 1. (L) Internal lesion length (mm) following inoculation by three *F. falciforme* (FF) isolates, in comparison to wound and negative biological controls (both Fol and F. solani) and (R) external and internal stem rot following *F. falciforme* inoculation.

4. To enable accurate field diagnosis by advisors and other practitioners, we developed a crown rot diagnostic guide and held a diagnostics workshop for farm advisors (which was very well received). We have distributed over 50 copies of the diagnostics guide at summer and fall meetings as well as presenting this guide as a talk--the preliminary version is available online. These efforts have been well received and have already started to improve disease diagnoses. For instance, advisors are now submitting samples tentatively (and often accurately) identified as *F. falciforme* to our diagnostics lab and the number of ambiguous Fol / Forl submission has reduced, resulting in clearer diagnoses.

5. Together with our regional farm advisor partners, we provided statewide diagnostics support to processing tomato producers. We diagnosed diseases on over 130 tomato samples and, new in 2018, we provided a molecular diagnostics confirmation of Fol. Our outputs included (1) the first detection of Fusarium wilt race 3 on tomatoes in Kern county (two reports); (2) detection of a potential bacterial canker outbreak*;* (3) detection of several possible Fol race 4 cases (Fusarium wilt in F3 cultivars) which we confirmed were NOT race 4 (all Fol R3); (4) data on incidence and distribution of the new Fusarium rot and decline disease, *F.* falciforme; (5) data on relative frequencies of different soil borne pathogens, which can provide insight into statewide priorities.

Project Title: Can vector-borne diseases be managed in commercial fields using ethylene inhibitors

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THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL:

The goal here is to develop novel and economically feasible control methods for vector-borne pathogens that can be used in current IPM systems for the tomato industry.

Objectives:
1) Evaluate the use of ethylene inhibitors (1-MCP and AVG) for management of vector-borne diseases in a *commercial field*
2) Investigate if ethylene inhibitors can be used to manage *Tomato spotted wilt virus*.
3) Examine agronomic impacts of ethylene inhibitor application in a *commercial field*.

SUMMARY:

Objective 1 & 2:
We examined the following six treatments in a commercial field (Byron, Contra Costa County): 1) no treatment control (no inhibitor, no insecticide), 2) insecticide treatment, 3) AVG treatment, 4) insecticide treatment and AVG treatment, 5) 1-MCP, or 6) insecticide treatment and 1-MCP treatment. For AVG and 1-MCP treatments chemicals were applied to tomato seedlings (cultivar HM 1892) in the greenhouse 24 hours before transplanting and 3 weeks after transplanting in the field (2 treatments per growing season). For insecticide treatments Admire Pro was applied the day after transplanting the seedlings to target leafhoppers, and the foliar spray Radiant was applied 4 weeks after transplanting to target thrips. Over the course of the growing season insect populations were surveyed with sweep nets for leafhoppers and sticky traps for Thrips. Ethylene inhibitors had minimal impacts on leafhopper and thrips populations, that varied over the course of the growing season (Fig. 1). For leafhoppers MCP-1 application significantly increased leafhopper populations early in the growing season, however late in the growing season MCP-1 application significantly decreased numbers compared to controls (Fig 1A). For thrips MCP-1 application significantly decreased thrips populations early in the growing season, however late in the growing season MCP-1 and AVG application significantly increased numbers compared to controls (Fig 1B).

We also recorded the number of symptomatic plants during the course of the growing season and collected a subsample of symptomatic plants from each plot to test for infection using PCR and RT-PCR. DNA and RNA were extracted from each sample and tested for BCTV and TSWV infection using PCR or RT-PCR. Application of MCP-1 significantly reduced virus infection early in the growing season, however there was no impact late in the season (Fig. 2).

Objective 3:
The week of Monday September 10th, a sub-section of each plot was hand-harvested to estimate the impact of the treatments on marketable yield, fruit maturity and culls, and on fruit quality (pH, soluble solids, and color). No significant impact for any treatments were observed.

Key Takeaway:
Our data suggests MCP-1 treatment offers some potential as a control for leafhoppers and BCTV, but may exacerbate thrips and/or TSWV outbreaks.

Fig. 1. A) Insect populations were monitored using sweep nets and B) Thrips population was monitored using sticky traps.

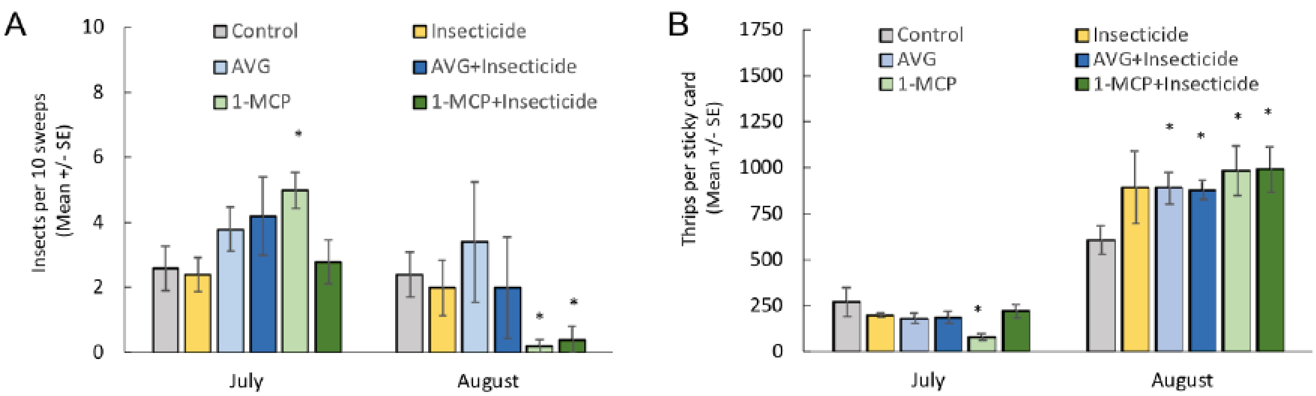
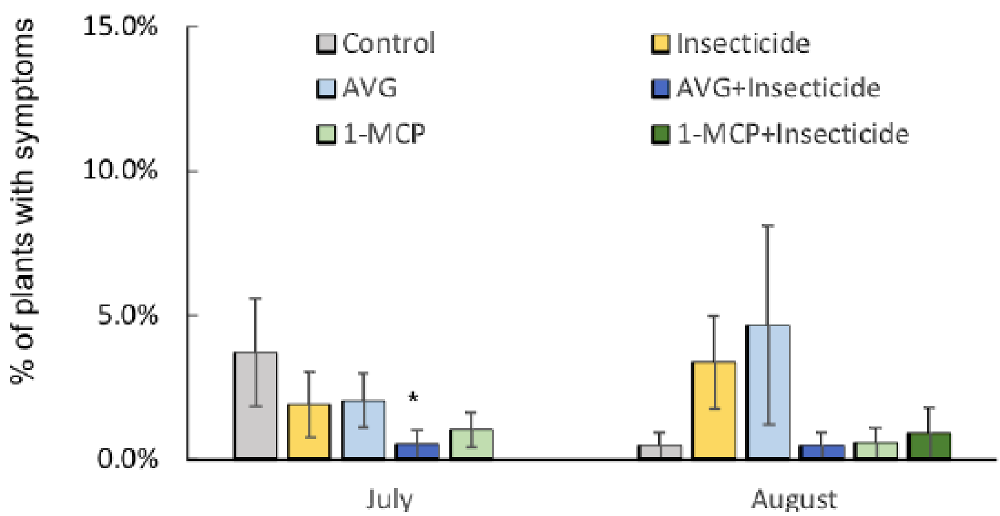


Fig. 2. Percentage of symptomatic plants confirmed with BCTV, TSWV or with both.



REDUCING INSECT VIRUS VECTORS OF BEET CURLY TOP VIRUS IN PROCESSING TOMATOES THROUGH SOIL HEALTH MANAGEMENT

AMÉLIE GAUDIN

Project Title: Reducing insect virus vectors of beet curly top virus in processing tomatoes through soil health management

Project Leaders:
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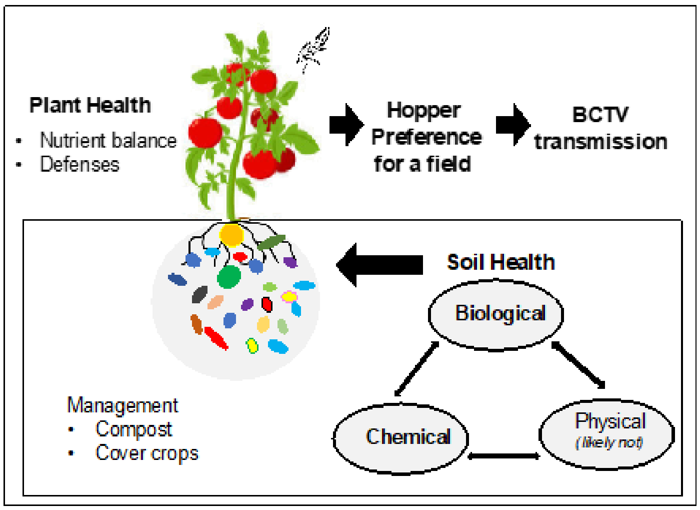
Cooperating Growers: Russell Ranch, Israel Herrera, Winters, CA; Muller Ranch, Frank Muller, Woodland, CA; Park Farming Organics, Scott Park, Meridian, CA; Fong Farm, Woodland, CA; Red Rock Ranch, John Diener, Five Points, CA; Frank Coehlo, 2031 E Washington Rd, El Nido, CA

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: This project aimed at developing a novel approach to integrated pest management of beet leafhopper (*Circulifer tenellus*) in processing tomato fields.

Objectives

1) Assess the impact of soil health and its components on tomato attractiveness and susceptibility to insect virus vectors of beet curly top virus (BCTV) in commercial fields in Yolo county;
2) Identify key rhizosphere interactions and their shift with management.

SUMMARY: Taken together our results suggest that soil management practices used in organic production increase plant health and ability to resist plant pests via microbial mediated increased in Salicylic acid levels. We are currently leveraging CTRI funding to write more comprehensive grants to pinpoint which management practices improve plant resistance to insects and develop potential biomarkers to screen fields for the rhizosphere microbes of interest. CTRI support has been instrumental to be able to better understand the potential of healthier soils to decrease tomato attractiveness and susceptibility to insect virus vectors of BCTV and whether there is room to improve current IPM strategies. This will advance the processing tomato industry and its sustainability while adding novel scientific knowledge about the role of plant defense, aboveground diversity, crop nutrition and belowground soil and rhizosphere microbes in this process.



PROXIMAL REMOTE SENSING AS A DIAGNOSTIC TOOL TO DETECT TOMATO SPOTTED WILT VIRUS IN WESTERN FLOWER THRIPS
CHRISTIAN NANSEN

Project Title: Proximal remote sensing as a diagnostic tool to detect tomato spotted wilt virus in Western flower thrips

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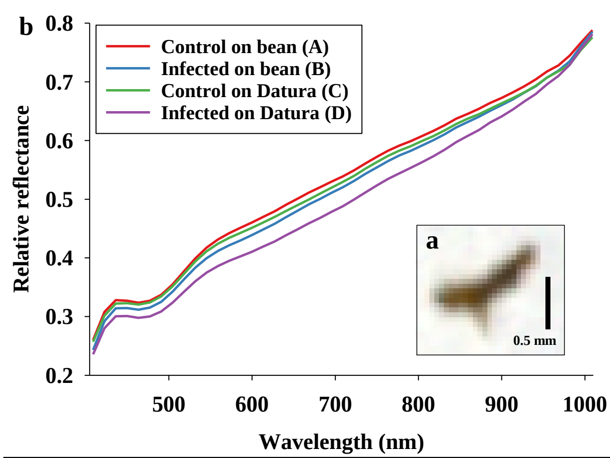
THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: This project falls within the category of pest management, and the project goal is to demonstrate that advanced hyperspectral imaging can be used to develop a diagnostic tool of tomato spotted wilt virus (TSWV) in Western flower thrips (WFT) (*Frankliniella occidentalis*). The specific project objectives are:

1. Obtain WFT with and without TSWV (two strains) reared on green beans and WFT with and without TSWV which had been transferred to *Datura* plants.
2. Subject WFT individuals under objective 1 to PCR for detection confirmation of TSWV.
3. Acquire proximal remote sensing data from WFT individuals listed under objective 1.
4. Develop reflectance based classification algorithm based on data from objectives 1 and 2.
5. Obtain WFT without TSWV after being reared on different host plants (tomato, zinnia, marigold, alfalfa, and soybean).
6. Acquire proximal remote sensing data from WFT individuals listed under objective 5.
7. Use data from objective 5 to assess the classification reflectance based classification algorithm from objective 4 – by examining its robustness of host plant induced variation on reflectance traits acquired from individual WFTs.

SUMMARY: A reflectance based diagnostic tool to detect TSWV and other crop pathogens could greatly improve the ability to manage risks of severe TSWV outbreaks in tomato and other specialty crops by enabling fast and cost-effective monitoring of sampled WFT populations. Results so far are very promising. That is, Fig. 1b shows the average reflectance profiles from the four treatments, and it is seen that TSWV infection caused a reduction in reflectance values, especially when Western flower thrips were transferred to Daura. Using forward stepwise selection in a linear discriminant analysis, we selected nine spectral bands with the highest contribution to a discriminant classification model of infection (combining treatments A and C versus B and D), and a spectral band near 1000 nm provided the strongest contribution. The confusion matrix (Fig. 1C) shows that about 14% of control specimens were misclassified as infected, while only 3% of infected were misclassified as control. Thus, the overall classification accuracy was about 93%. We also examined the relative effect of host plant (combining treatments A and B versus C and D). In this analysis, the spectral band with highest contribution to the most of the linear discriminant analysis was near 670 nm. The confusion matrix shows that about 15% of bean specimens were misclassified as Datura, and that about 21% of Datura specimens were misclassified as bean specimens. Thus, the overall classification accuracy was about 79%. In summary, we have demonstrated that reflectance-based classification of Western flower thrips with/without TSWV has considerable potential as a possible diagnostic tool.

Fig. 1. Diagnostics of tospovirus in Western flower thrips



c

Confusion matrix (infection)

	Control	Infected
Control	86.05	13.95
Infected	2.78	97.22
Overall accuracy= 92.63		

Confusion matrix (host)

	Bean	Datura
Bean	85	15
Datura	20.51	79.49
Overall accuracy= 82.24		

THE RESISTANCE-BREAKING STRAIN OF TOMATO SPOTTED WILT VIRUS IN THE CENTRAL VALLEY OF CA: SURVEY, GENETIC VARIABILITY, IMPROVED DETECTION AND SCREENING FOR RESISTANCE

BOB GILBERTSON

Project Title: The resistance-breaking strain of Tomato spotted wilt virus in the Central Valley of California: Survey, genetic variability, improved detection and screening for resistance

Project Leaders: Robert L. Gilbertson, Professor of Plant Pathology, Department of Plant Pathology, UC Davis

Cooperating Personnel: Maria Rojas, Project Scientist, Department of Plant Pathology, UC Davis; Diane Ullman, Professor of Entomology, Department of Entomology, UC Davis; Sulley Ben-Mahmoud, Postdoctoral Researcher, Department of Entomology, UC Davis; Martha Mutschler-Chen, Plant Breeder, Department of Plant Breeding and Genetics, Cornell University; and Tom Turini, Farm Advisor, UC Cooperative Extension, Fresno, CA

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: The main goal of this project is understand the potential threat posed to the processing tomato industry by the newly emerged RB-TSWV strain of TSWV (RB TSWV), and to develop strategies to minimize the impact of this virus.

Objectives:

- Monitoring for the distribution of RB-TSWV in Fresno and other counties during the winter and in early and late-planted tomatoes in 2018.
- Evaluate the response of a range of potentially resistant tomato germplasm to the RB-TSWV with mechanical inoculation and perform a field trial to test the potential of these varieties to prevent RB-TSWV infection.
- Develop a molecular tool for the rapid identification of RB-TSWV.
- Complete the full-length sequences of the California RB- and WT-TSWV isolates and compare these sequences to determine genetic variability between these strains.
- Examine the current TSWV IPM program to make any needed revisions and to develop additional strategies to help prevent the spread of RB-TSWV in processing tomato production in the Central Valley of California.

SUMMARY:

The emergence of RB-TSWV in California was perhaps not unexpected as this has previously occurred in other regions of the world. Indeed, it shows that while deployment of disease resistance is the most desirable approach for disease management, it demonstrates the genetic capacity of pathogens to break (overcome) resistance. In processing tomatoes in California, this has occurred previously with other diseases, including bacterial speck, where race 1 of *Pseudomonas syringae* pv. *tomato* overcame the *Pto* gene and RB forms of root knot nematode overcame the *Mi* gene. This phenomenon also shows the importance having multiple management practices in place for diseases, ideally implemented through an IPM program.

Because RB-TSWV strains breaking Sw-5 resistance in tomato had been previously described and the 'MP effector' of the TSWV was previously identified, we were able to quickly confirm that similar changes were present in the RB-TSWV that emerged in California. We then developed an efficient mechanical inoculation procedure to inoculate tomatoes with RB-TSWV. Using this test it was demonstrated that this RB-TSWV strain could infect and cause spotted wilt in the major Sw-5 varieties grown in California. To better understand the biology and spread of RB-TSWV it is important to have rapid and effective tools for detection. The development of the one-step RT-PCR test was based on our knowledge of the genetic sequence of the California RB-TSWV strain and eliminated the need for costly and time-consuming sequencing to confirm the presence of RB-TSWV. The RT-PCR test for RB-TSWV was extensively used in 2018 (a total of 261 samples were processed) and substantially reduced the time to provide results to growers and PCAs.

The survey and testing for RB-TSWV in 2018 revealed numerous findings about RB-TSWV, including some that are directly related to disease management. The failure to detect RB-TSWV in weeds in the winter survey, including the known weed host sowthistle, was consistent with previous results with RB-TSWV and WT-TSWV that the virus does not extensively infect winter weeds. As previous CTRI-funded research showed that thrips population are extremely low in the winter, this time period represents a weak point in the cycle of the virus that can be exploited even further by sanitation efforts. The finding that RB-TSWV infected the winter bridge crop lettuce in Fresno in 2018, revealed a likely inoculum source for tomatoes in 2018 and reinforced the importance of such sources in the epidemiology of the disease. In Merced County, radicchio can serve as a winter bridge crop and efforts to manage thrips populations and harvest and plow radicchio fields before planting of tomatoes was associated with a dramatic reduction of spotted wilt in tomato. Finally, previously supported CTRI research also has demonstrated that thrips pupae can persist in soil through the winter and that some emerging adults are likely to be carrying the virus and serve as initial inoculum sources. As these thrips are difficult to predict and manage, it further emphasizes the need to implement thrips management early in the season.

The 2018 surveys of processing tomato fields for spotted wilt revealed good news in that the pattern of disease development was similar to that observed with WT-TSWV in previously funded CTRI research. That is, the disease begins slowly, takes time to build-up and occurs at highest incidences in late-planted crops, often in combination with other problems, sometimes associated with the vine decline syndrome. This is important because RB-TSWV was the predominant strain detected in plant samples with spotted wilt collected early and late in the growing season in 2018. This was not unexpected as the vast majority of varieties grown had Sw-5. Furthermore, RB-TSWV had expanded to new areas in Fresno and Kings Counties and was detected for the first time in Kern County. Taken together with the capacity of RB-TSWV to infect lettuce and peppers, our results indicate that RB-TSWV has become the dominant strain in major processing tomato regions and will likely continue to be a problem. On the other hand, RB-TSWV has not been detected in the Northern Counties (Colusa, Solano and Yolo), and finding of spotted wilt-like symptoms in some processing tomato fields in these counties was shown to be caused by AMV, a virus that causes symptoms that can be confused with those caused by TSWV. Although these results indicate that spread of RB-TSWV to Northern Counties has not yet occurred, it seems important to monitor fields to detect any introductions as early as possible.

Fortunately, losses in processing tomatoes due to RB-TSWV were minimal in 2018. However, the fact that this strain can break the resistance associated with the *Sw-5* gene in all processing tomato varieties tested indicates the potential for losses in years when thrips populations are high early in the season or there is high levels of initial inoculum. Therefore, it is important to search for sources of resistance that can be used to protect the Sw-5 gene, which could still be providing some degree of resistance to RB-TSWV (see results of the field plot study). In 2018, we evaluated a number of potential sources of resistance, including commercial varieties reported to possess resistance to RB-TSWV strains in Europe, a variety from Italy reported to possess resistance to RB-TSWV in Italy (cv. Manduria), a wild tomato species (*S. sitiens*) and acyl sugar tomato lines that repel thrips and may not allow TSWV transmission. Depending on the material, two approaches were used, a field trial at the Westside Field Station and the mechanical transmission test in the greenhouse. In these tests, none of the materials showed high levels of resistance (i.e., such as that observed for Sw-5 varieties inoculated with WT-TSWV). Most of the ISI materials, cv. Manduria and the wild species were very susceptible. However, two materials did show some promise in terms of lower levels in infection, the ISI cv. 25033 and the acyl sugar line AL6/As+Sw-5. Also, in preliminary thrips transmission tests, we found similar results to the mechanical transmission tests; this suggests that we can use the mechanical transmission test for screening materials for resistance. We hope to purse these lines further in 2019 as well as search for more robust resistance to RB-TSWV in other sources.

The determination and comparison of the complete genetic sequences of a California RB- and WT-TSWV strain indicated that these strains were closely related and that the RB-TSWV was not an exotic introduced strain. However, it was also clear that these strains did not differ only in the NSm gene, where the RB phenotype has been mapped, and that there was substantial differences in another gene, the NSs. Interestingly, the NSs protein is the effector for the *Tsw* gene in pepper, which confers resistance to TSWV. What these data suggest is that the evolution of the RB strain has been more complex and may have involved mutations in the NSm gene as well as acquisition of the NSs gene, most likely via recombination. Moreover, because the sequence of the NSs gene of RB-TSWV was most identical to that of an isolate from North Carolina, it suggests that greater levels of genetic diversity may have existed in TSWV populations in California than were previously recognized. It is not clear if the RB-TSWV NSs gene plays a role in resistance breaking, but the sequence could be useful for developing improved diagnostic tests such as a loop-mediated amplification test (LAMP).

Finally, we believe that our results indicate that although RB-TSWV is clearly emerging as the predominant strain in major processing tomato regions of California, effective management can be obtained using the some modifications of the previously developed IPM program. This would include more extensive weed sanitation efforts in the winter and early spring as well as monitoring and thrips management in potential bridge crops. Early and effectively timed thrips management efforts are critical for delaying the appearance of TSWV and may help reduced incidences in late-planted crops. Where practical, e.g., in fresh market crops, monitor fields early and remove/rogue infected plants will delay the appearance of viruliferous adult thrips. The long-term solution will be identifying and introgressing resistance to RB-TSWV.

VARIETAL RESPONSE TO RESISTANCE-BREAKING *TOMATO SPOTTED WILT VIRUS*
TOM TURINI

Project Title: Varietal response to resistance-breaking *Tomato spotted wilt virus*

Project Leader: Tom Turini, Fresno County Cooperative Extension Vegetable Crops Advisor, 559-375-3147, taturini@ucanr.edu

Cooperating Personnel: Scott Stoddard, Cooperative Extension in Merced and Madera Counties, Vegetable Crops Advisor/County Director; Brenna Aegerter, San Joaquin County Cooperative Extension, Vegetable Crops Advisor; Robert Gilbertson, UC Davis Department of Plant Pathology, Professor

THE MAIN *GOAL* AND THE *OBJECTIVES* UNDER THAT GOAL: Quantification of relative susceptibility of processing tomato varieties to Tomato spotted wilt virus. Strain present in varieties with and without Sw5 resistance

SUMMARY: The single gene resistance (Sw5) to *Tomato spotted wilt virus* (TSWV) used in commercial processing tomatoes has been widely deployed in the Central San Joaquin Valley and many of the varieties recently developed have this resistance. However, in 2016, a resistance breaking strain was detected in Fresno County. In 2017, it was detected in Merced and Contra Costa Counties. In 2018, the resistance breaking strain was detected in Kings and Kern Counties. A total of six variety trials conducted by TS&L and Ag Seeds were evaluated for expression of TSWV. Thirty-four entries consistently appeared in these trials and Analysis of variance was performed on the disease ratings. In addition, representative samples were collected from entries. There was a great deal of variability in terms of the ratings. Some differences were statistically significant (LSD P=0.05), but there would be a great deal more confidence if it were possible to rate additional trials during the next season. Interestingly, samples from the trial evaluated in 2017 that were from varieties lacking Sw5 were infected by the wild type strain (the strain of TSWV that is not breaking resistance). However, in 2018, all samples either with or without Sw5 tested positive for the resistance-breaking strain. This, along with other observations in summer of 2018 regarding the presence of the resistance-breaking strain in tomatoes without resistance and other hosts, suggests that the resistance breaking strain is becoming very common in production areas in Fresno and Merced Counties. Management of TSWV in areas in areas in which the resistance-breaking strain has been documented, should not be limited to the use of resistant varieties. A combination of sanitation, thrips management and site selection should be used to minimize risk posed by the plant resistance-breaking strain of TSWV.

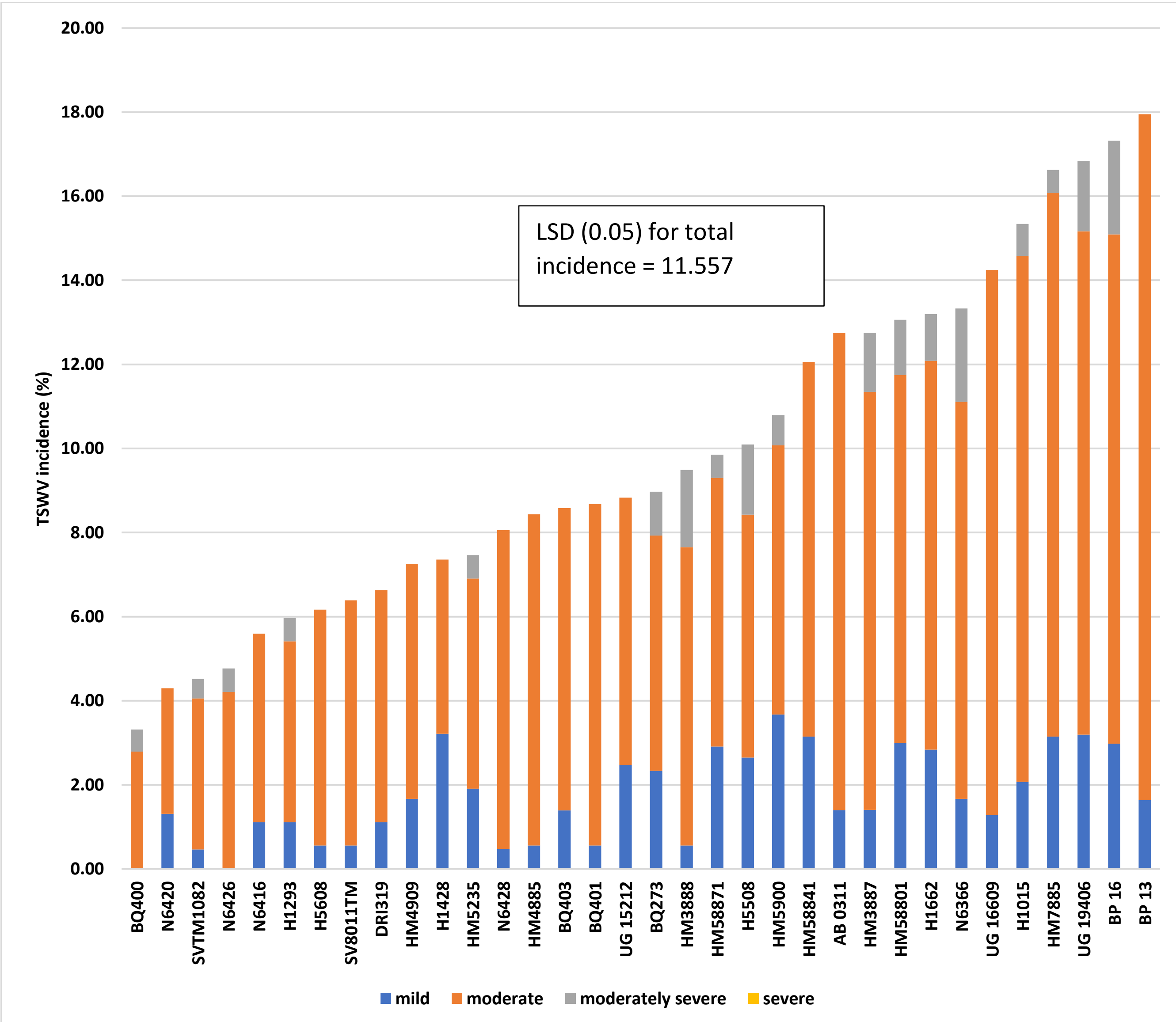
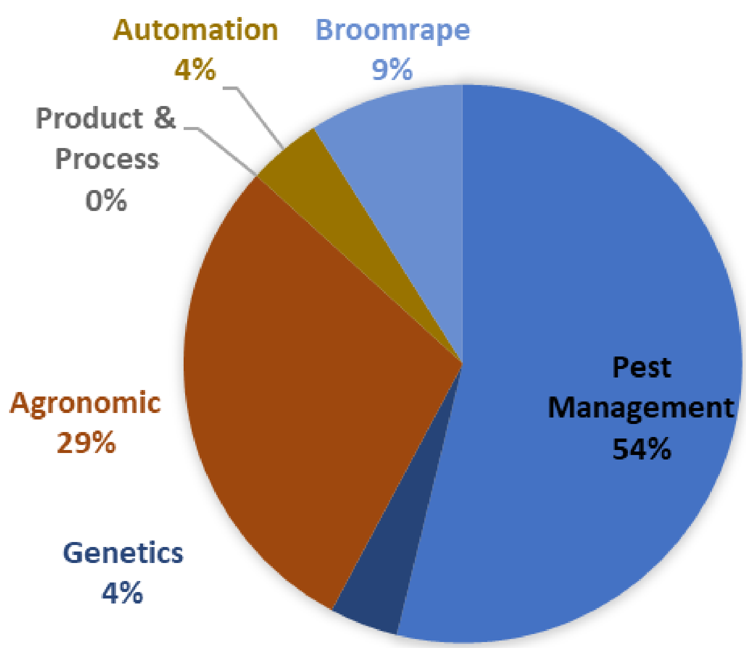


Figure 1. Levels of Tomato spotted wilt virus symptom incidence in commercial variety trials conducted in Fresno and Merced Counties in 2017 and 2018.

2019 BOARD APPROVED RESEARCH - PROJECT LIST

2019 CTRI FUNDED RESEARCH PROJECTS				
2019 TOTAL FUNDING: $376,736				
Agronomic/Water/Nutrient Management			$	109,156
2017 Start	Effects of irrigation and management practices on soil health and soil salinity in processing tomatoes	**Kate Scow**	$	35,479
2019 New	Optimizing Potassium Fertilizer Uptake Efficiency while Minimizing Costs in Processing Tomato	**Nicole Tautges / B. Aegerter**	$	34,279
2019 New	Effects of soil management on processing tomato associations with mycorrhizal fungi	**Rachel Vannette / A. Gaudin / C. Casteel**	$	33,998
2019 New	Influence of Compost Application Rates and Timing on Nitrogen Management and Processing Tomato Productivity and Quality	**Zheng Wang / A. Fulford**	$	5,400
Germplasm and Variety Development			$	29,499
1991 Start	C. M. Rick Tomato Genetics Resource Center	**Roger Chetelat**	$	15,000
2019 New	Optical sorting (machine vision, machine learning, and robotics) to classify tomato seeds	**Christian Nansen / M. Imtiaz**	$	14,499
Insect and Invertebrate Management			$	32,390
2011 Start	Evaluation of Alternative Nematicides for the Control of Root-Knot Nematodes of Processing Tomatoes	**Jaspreet Sidhu / J. Nuñez**	$	2,000
2019 Restart	Consperse Stink Bug IPM Update	**Tom Turini**	$	30,390
Pathogen Management			$	170,323
2018 Start	Putting the right varieties in the right places: Rapid Fusarium wilt diagnosis and soil detection	**Cassandra Swett**	$	25,500
2018 Start	Developing effective crop rotation strategies for Fusarium wilt management	**Cassandra Swett**	$	24,600
2019 New	Efficacy of F3 cultivars - understanding F3-Fol R3 interactions & monitoring race 4 emergence	**Cassandra Swett**	$	5,000
2019 New	Cultivar-based control strategies Fusarium crown and root rot diseases of tomato / disease diagnostics support	**Cassandra Swett**	$	19,500
2019 New	Eval. of Fusarium wilt survival in the Sac. Valley as influenced by rotational crops of flooded rice and dry-farmed crops	**Amber Vinchesi**	$	5,500
2019 New	Screening varietal resistance for management of southern blight in processing tomatoes	**Jaspreet Sidhu / J. Nuñez / Alex Putman**	$	14,385
2017 Start	The resistance breaking strain of TSWV in CA processing tomatoes: Monitoring, improved detection and screening for resistance	**Robert Gilbertson / N. McRoberts**	$	70,104
2018 Start	Varietal response to resistance-breaking Tomato spotted wilt virus	**Tom Turini**	$	5,734
Weed Control and Management			$	35,368
2019 New	Pre-emptive development of management strategies for branched broomrape in CA tomato systems	**Mohsen Mesgaran / B. Hanson**	$	33,868
2019 New	Evaluation of weed control in tomatoes comparing finger weeders to standard cultivation	**Amber Vinchesi**	$	1,500
2019 TOTALS			$	376,736

Category	Funding		%
Pest Management	**$**	**202,713**	**54%**
Fusarium et al.	$	80,100	
TSWV	$	75,838	
Consperse Stink Bug	$	30,390	
Southern Blight	$	14,385	
RKN	$	2,000	
Genetics	**$**	**15,000**	**4%**
Agronomic	**$**	**109,156**	**29%**
Product & Process	**$**	**-**	**0%**
Automation	**$**	**15,999**	**4%**
Seed Sorting	$	14,499	
Weeding Technology	$	1,500	
Broomrape	**$**	**33,868**	**9%**
TOTALS	**$**	**376,736**	**100%**



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