



American Society of Agronomy  
California Chapter

*Co-sponsored by the California Plant Health Association*

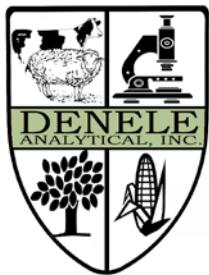
2015  
**CONFERENCE  
PROCEEDINGS**

*California Water: Balancing Quality  
and Quantity*

**February 4 & 5, 2015**

**Fresno Hotel and Conference Center  
2233 Ventura St.  
Fresno, CA**

# CONFERENCE SPONSORS:



*To download additional copies of the proceedings or learn about the activities of the California Chapter of the American Society of Agronomy, visit the Chapter's web site at: <http://calasa.ucdavis.edu>*

# **2015 California Plant and Soil Conference**

## **California Water: Balancing Quality and Quantity**

**WEDNESDAY, February 4 and THURSDAY, February 5, 2015**

**Fresno Hotel and Conference Center, 2233 Ventura Street, Fresno, CA**

**9:50 General Session Introduction:** Chapter President – Steve Grattan, Dept of Land Air and Water Resources

**10:00 – 10:45 Keynote Speaker:** Thomas Harter, UC Davis, Dept of Land, Air and Water Resources  
**The Future of Groundwater Use and Protection in California's Agricultural Regions**

### **DAY 1 (Wednesday, February 4) CONCURRENT SESSIONS: 10:55AM – 12:15PM**

<b>Session 1 – Professional Development</b>		<b>Session 2 – Water Re-use: Use of non-conventional waters for irrigation</b>	
10:55	Session Chairs: Scott Stoddard and Anne Collins Burkholder	10:55	Session Chairs: Sharon Benes and Steve Grattan
11:00	Exploring soil survey information with SoilWeb Apps, Toby O'Geen UC Davis, Dept of LAWR	11:00	Strategies for Irrigating with Saline Water, Blake Sanden, UCCE Kern
11:25	On-farm Research and Testing: Suggestions for Making a Good Evaluation, Scott Stoddard, UCCE Merced	11:25	Overview of recycled water quality and landscape plants, Nelda Matheny, HortScience Inc.
11:50	Fostering Effective Teams, Linda Marie Manton, UCCE Davis	11:50	Use of reclaimed municipal water for irrigation of vegetables: a grower's perspective, Dale Huss, Ocean Mist Farms (Castrville)

**LUNCH 12:15PM – 1:25PM**

### **DAY 1 (February 4) CONCURRENT SESSIONS: 1:30PM – 2:50PM**

<b>Session 3 – Pest Management</b>		<b>Session 4 – Water Management in the Face of Changing Supplies</b>	
1:30	Session Chairs: Anil Shrestha and Mark Sisterson	1:30	Session Chairs: Warren Hutching and Sharon Benes
1:35	Effects of drought conditions on weed control performance and herbicide fate, Brad Hanson, UC Davis, Dept of Plant Sciences	1:35	Weather prediction, Steve Johnson, Owner, Steve Johnson Meteorology
2:00	Drought-mediated effects on vector movement and pathogen spread: Insights to epidemiology of Xylella fastidiosa-elicited diseases, Rodrigo Krugner, USDA-ARS	2:00	Current groundwater supplies and subsidence risks, Ken Schmidt, Owner, Kenneth D. Schmidt & Associates
2:25	Botryosphaeria canker and blight of walnut and approaches for its management, Themis Michailides, UC Kearney Agricultural Research and Extension Center	2:25	The New California Groundwater Law Clarity or Uncertainty for Agricultural Water Users?, Sarge Green, CA State University, Fresno, CA Water Institute

**2015 California Plant and Soil Conference**  
**California Water: Balancing Quality and Quantity**

**WEDNESDAY, February 4 and THURSDAY, February 5, 2015**

**Fresno Hotel and Conference Center, 2233 Ventura Street, Fresno, CA**

**BREAK 2:50PM – 3:20PM**

**DAY 1 (February 4) CONCURRENT SESSIONS: 3:20PM – 4:40PM**

<b>Session 5 – Water Related Management Issues</b>		<b>Session 6 – Practical application of nitrogen management strategies</b>	
3:20	Session Chairs: Scott Stoddard and Dan Munk	3:20	Session Chairs: Karen Lowell and Richard Smith
3:25	Deficit irrigation of cotton, Bob Hutmacher, UC Davis, Dept of Plant Sciences	3:25	Panel discussion:  Practical issues in nitrogen management; Tim Hartz UC Davis, Dept of Plant Sciences; Danyal Kasapligil, Dellavalle Laboratory; Daniel Geisseler, UC Davis, Dept of LAWR
3:50	Subsurface irrigation of alfalfa: benefits and pitfalls, Dan Putnam, UC Davis, Dept of Plant Sciences	3:50	
4:15	Irrigation strategies for grapevines grown in the San Joaquin Valley: Comparison of table and wine grape vineyards, Larry Williams, UC Davis, Viticulture and Enology	4:15	

**EVENING SOCIAL – POSTER SESSION, WINE AND CHEESE RECEPTION, ETC. (5:30 pm  
Location TBD)**

**DAY 2 (Thursday, February 5) CONCURRENT SESSIONS: 8:30AM – 9:50AM**

<b>Session 7 – Manure/Compost/Organic Amendments</b>		<b>Session 8 – Salinity Response/Management</b>	
8:30	Session Chairs: Dan Munk and Karen Lowell	8:30	Session Chairs: Steve Grattan and Bob Hutmacher
8:35	Use of organic matter amendments in permanent crops – a grower oriented analysis, Dan Shellenberg and Patrick Brown, UCD Dept of Plant Sciences	8:35	Overview of CV Salts and development of salinity standards to protect irrigated crops, John Dickey, Ph.D. Principal Soil Scientist & Agronomist, PlanTierra LLC
9:00	Implications of timing on N release from organic amendments, David Crohn and Namratha Reddy, UC Riverside	9:00	Impact of salinity on pistachio rootstocks, Jessie Godfrey. PhD student. UC Davis
9:25	Composting to manage on-farm waste and improve soil health, Bob Martin, or Jocelyn Gretz, Rio Farms (King City)	9:25	Salinity stress in almond: How do the rootstocks, cultivars and ionic composition make a difference? Baris Kutman, Ph.D. Post doc. UC Davis

**BREAK: 9:50AM – 10:20AM**

**2015 California Plant and Soil Conference**  
**California Water: Balancing Quality and Quantity**

**WEDNESDAY, February 4 and THURSDAY, February 5, 2015**

**Fresno Hotel and Conference Center, 2233 Ventura Street, Fresno, CA**

**DAY 2 (February 5) CONCURRENT SESSIONS: 10:20AM – 11:40AM**

<b>Session 9 – Monitoring Options "Measure to Manage"</b>		<b>Session 10 – Management and mitigation of nitrate in crop production</b>		
10:20	Session Chairs: Bob Hutmacher and Steve Grattan		10:20	Session Chairs: Eric Ellison and Richard Smith
10:25	Imperial valley salinity management program, Khaled Bali, UCCE Imperial		10:25	Denitrification beds for removing nitrate from tile drain water; Tim Hartz, UC Davis Plant Sciences
10:50	Infrared Thermometry – Smartfield System Capabilities and Experiences, Tom Speed, Smartfield Technologies, Lubbock, TX		10:50	Fertilizer value of nitrate in irrigation water for lettuce production; Michael Cahn, UCCE Monterey
11:15	Discussing Irrigation Scheduling Principles with Producers- Are We Making it More Difficult than Necessary? Dan Johnson, State Water Management Engineer, USDA, NRCS		11:15	Managing Nitrogen in Perennial Crops, Patrick Brown, Saiful Muhammad and Sebastian Saa, UC Davis Plant Sciences

**BUSINESS MEETING and LUNCH**

**12 Noon – 1:45PM**

## Table of Contents

<b>Past Presidents .....</b>	001
<b>Past Honorees .....</b>	002
<b>2014-15 Chapter Board Members .....</b>	003
<b>Minutes – CA Chapter ASA 2014 Business Meeting .....</b>	004
<b>2015 Honorees .....</b>	009
<b>2015 Scholarship Recipient Essays .....</b>	016
<b>General Session .....</b>	021
<b>Session I. Professional Development.....</b>	030
Exploring soil survey information with SoilWeb Apps, Toby O'Geen UC Davis, Dept of LAWR	
On-farm Research and Testing: Suggestions for Making a Good Evaluation, Scott Stoddard, UCCE Merced	
Fostering Effective Teams, Linda Marie Manton, UCCE Davis	
<b>Session II. Water Re-use: Nonconventional Waters for Irrigation .....</b>	039
Strategies for Irrigating with Saline Water, Blake Sanden, UCCE Kern	
Overview of recycled water quality and landscape plants, Nelda Matheny, HortScience Inc.	
Use of reclaimed municipal water for irrigation of vegetables: a grower's perspective, Dale Huss, Ocean Mist Farms (Castroville)	
<b>Session III. Pest Management .....</b>	055
Effects of drought conditions on weed control performance and herbicide fate, Brad Hanson, UC Davis, Dept of Plant Sciences	
Drought-mediated effects on vector movement and pathogen spread: Insights to epidemiology of Xylella fastidiosa-elicited diseases, Rodrigo Krugner, USDA-ARS	
Botryosphaeria canker and blight of walnut and approaches for its management, Themis Michailides, UC Kearney Agricultural Research and Extension Center	
<b>Session IV. Water Management in the Face of Changing Supplies.....</b>	072

Weather prediction, Steve Johnson, Owner, Steve Johnson Meteorology

Current groundwater supplies and subsidence risks, Ken Schmidt, Owner, Kenneth D. Schmidt & Associates

The New California Groundwater Law: Clarity or Uncertainty for Agricultural Water Users?  
Sarge Green, CA State University, Fresno, CA Water Institute

**Session V. Water Related Management Issues..... 081**

Deficit irrigation of cotton, Bob Hutmacher, UC Davis, Dept of Plant Sciences

Subsurface irrigation of alfalfa: benefits and pitfalls, Dan Putnam, UC Davis, Dept of Plant Sciences

Irrigation strategies for grapevines grown in the San Joaquin Valley: Comparison of table and wine grape vineyards, Larry Williams, UC Davis, Viticulture and Enology

**Session VI. Practical Application of Nitrogen Management Strategies..... 099**

Panel discussion. Practical issues in nitrogen management:

Tim Hartz UC Davis, Dept of Plant Sciences

Danyal Kasapligil, Dellavalle Laboratory

Daniel Geisseler, UC Davis, Dept of LAWR

**Session VII. Manure/Compost/Organic Amendments..... 104**

Use of organic matter amendments in permanent crops – a grower oriented analysis, Dan Shellenberg and Patrick Brown, UC Davis Dept of Plant Sciences

Implications of timing on N release from organic amendments, David Crohn and Namratha Reddy, UC Riverside

Composting to manage on-farm waste and improve soil health, Jocelyn Gretz, Rio Farms (King City)

**Session VIII. Salinity Response/Management..... 116**

Overview of CV Salts and development of salinity standards to protect irrigated crops, John Dickey, Ph.D. Principal Soil Scientist & Agronomist, PlanTierra LLC

Impact of salinity on pistachio rootstocks, Jessie Godfrey. PhD student. UC Davis

Salinity stress in almond: How do the rootstocks, cultivars and ionic composition make a difference? Baris Kutman, Ph.D. Post doc. UC Davis

**Session IX. Monitoring Options: Measure to Manage.....** 131

Imperial Valley salinity management program, Khaled Bali, UCCE Imperial

Infrared Thermometry – Smartfield System Capabilities and Experiences, Tom Speed,  
Smartfield Technologies, Lubbock, TX

Discussing Irrigation Scheduling Principles with Producers- Are We Making it More Difficult  
than Necessary? Dan Johnson, State Water Management Engineer, USDA, NRCS

**Session X. Management and Mitigation of Nitrate in Crop Production .....** 141

Denitrification beds for removing nitrate from tile drain water; Tim Hartz, UC Davis Plant  
Sciences

Fertilizer value of nitrate in irrigation water for lettuce production; Michael Cahn, UCCE  
Monterey

Managing Nitrogen in Perennial Crops, Patrick Brown, Saiful Muhammad and Sebastian Saa,  
UC Davis Plant Sciences

**2015 Poster Abstracts .....** 154

**Notes .....** 171

**Plant and Soil Conference Evaluation Form .....** 170

## PAST PRESIDENTS

YEAR	PRESIDENT	YEAR	PRESIDENT
1972	Duane S. Mikkelsen	2010	Larry Schwankl
1973	Iver Johnson	2011	Mary Bianchi
1974	Parker E. Pratt	2012	Allan Fulton
1975	Malcolm H. McVickar	2013	Dave Goorahoo
1975	Oscar E. Lorenz		
1976	Donald L. Smith		
1977	R. Merton Love		
1978	Stephen T. Cockerham		
1979	Roy L. Bronson		
1980	George R. Hawkes		
1981	Harry P. Karle		
1982	Carl Spiva		
1983	Kent Tyler		
1984	Dick Thorup		
1985	Burl Meek		
1986	G. Stuart Pettygrove		
1987	William L. Hagan		
1988	Gaylord P. Patten		
1989	Nat B. Dellavalle		
1990	Carol Frate		
1991	Dennis J. Larson		
1992	Roland D. Meyer		
1993	Albert E. Ludwick		
1994	Brock Taylor		
1995	Jim Oster		
1996	Dennis Westcot		
1997	Terry Smith		
1998	Shannon Mueller		
1999	D. William Rains		
2000	Robert Dixon		
2001	Steve Kaffka		
2002	Dave Zodolske		
2003	Casey Walsh Cady		
2004	Ronald Brase		
2005	Bruce Roberts		
2006	Will Horwath		
2007	Ben Nydam		
2008	Tom Babb		
2009	Joe Fabry		

## PAST HONOREES

YEAR	HONOREE	YEAR	HONOREE	YEAR	HONOREE
1973	J. Earl Coke	1995	Leslie K. Stromberg	2007	Norman McGillivray
1974	W.B. Camp		Jack Stone		William Pruitt
1975	Ichiro "Ike" Kawaguchi	1996	Henry Voss		J.D. Oster
1976	Malcom H. McVickar		Audy Bell	2008	V.T. Walhood
	Perry R. Stout	1997	Jolly Batcheller		Vern Marble
1977	Henry A. Jones		Hubert B. Cooper, Jr.		Catherine M. Grieve
1978	Warren E. Schoonover		Joseph Smith	2009	Dennis Westcot
1979	R. Earl Storie	1998	Bill Isom		Roland Meyer
1980	Bertil A. Krantz		George Johannessen		Nat Dellavalle
1981	R.L. "Lucky" Luckhardt	1999	Bill Fisher	2010	L. Peter Christensen
1982	R. Merton Love		Bob Ball		D. William Rains
1983	Paul F. Knowles		Owen Rice	2011	Blaine Hanson
	Iver Johnson	2000	Don Grimes		Gene Maas
1984	Hans Jenny		Claude Phene		Michael Singer
	George R. Hawkes		A.E. "Al" Ludwick	2012	Bob Matchett
1985	Albert Ulrich	2001	Cal Qualset		Don May
1986	Robert M. Hagan		James R. Rhoades		Terry Prichard
1987	Oscar A. Lorenz	2002	Emmanuel Epstein	2013	Harry Cline
1988	Duane S. Mikkelsen		Vince Petrucci		Clyde Irion
1989	Donald Smith		Ken Tanji		Charles Krauter
	F. Jack Hills	2003	VashekCervinka	2014	Gene Aksland
1990	Parker F. Pratt		Richard Rominger		Kerry Arroues
1991	Francis E. Broadbent		W.A. Williams		Stuart Pettygrove
	Robert D. Whiting	2004	Harry Agamalian		
	Eduardo Apodaca		Jim Brownell		
1992	Robert S. Ayers		Fred Starrh		
	Richard M. Thorup	2005	Wayne Biehler		
1993	Howard L. Carnahan		Mike Reisenauer		
	Tom W. Embelton		Charles Schaller		
	John Merriam	2006	John Letey, Jr.		
1994	George V. Ferry		Joseph B. Summers		
	John H. Turner				
	James T. Thorup				

**2014-15 Executive and Governing Board Members**  
**California Chapter – American Society of Agronomy**

**Executive Committee-President**

Steve Grattan  
Plant-Water Extension Specialist  
Dept LAWR/Veihmeyer  
One Shields Avenue  
Davis, CA 95616  
(530) 752-4618 - Office  
(530) 752-5262 - Fax  
(530) 304-1201 - Cell  
[srgrattan@ucdavis.edu](mailto:srgrattan@ucdavis.edu)

**First Vice President**

Richard Smith  
UCCE – Monterey County  
1432 Abbott Street  
Salinas, CA 93901  
(831) 759-7357 - Office  
(831) 758-3018 - Fax  
(831) 596-7086 - Cell  
[rifsmith@ucdavis.edu](mailto:rifsmith@ucdavis.edu)

**Second Vice President**

Bob Hutmacher  
Cooperative Extension Specialist  
and Center Director, West Side  
REC  
17353 West Oakland Avenue  
Five Points, CA 93624-0158  
(559) 884-2411  
(559) 260-8957  
[rjhutmacher@ucdavis.edu](mailto:rjhutmacher@ucdavis.edu)

**Executive Secretary-Treasurer**

Sharon Benes  
Professor, Dept of Plant Science  
Dept of Plant Science  
2415 E. San Ramon Ave, M/S AS72  
Fresno, CA 93740-8033  
(559) 278-2255  
[sbenes@csufresno.edu](mailto:sbenes@csufresno.edu)

**Past President**

Dave Goorahoo  
Associate Professor  
Dept of Plant Science  
2415 E. San Ramon Ave, M/S AS72  
Fresno, CA 93740-8033  
(559) 278-8448 / fax 278-7413  
[dgooraho@csufresno.edu](mailto:dgooraho@csufresno.edu)

**ONE YEAR TERM**

Anil Shrestha  
Associate Professor, Weed Science  
Dept. of Plant Science  
California State University  
2415 E. San Ramon Ave. MS A/S 72  
Fresno, CA 93740  
Phone: 559-278-5784  
Fax: 559-278-7413  
[ashrestha@csufresno.edu](mailto:ashrestha@csufresno.edu)

Richard Rosecrance  
Assoc. Professor  
College of Agriculture  
400 W 1st St  
CSUC  
Chico, CA 95929-0001  
(530) 898-5699 Office  
(530) 898-5845 Fax  
[rrosecrance@csuchico.edu](mailto:rrosecrance@csuchico.edu)

Warren Hutchings  
Agronomist  
Innovative Ag Services, LLC  
1201 Lacey Blvd, Suite 5  
Hanford, CA 93230  
(559)-587-2800 (office)  
(559)-587-2801 (fax)  
[whutchings@innovativeag.net](mailto:whutchings@innovativeag.net)

Dan Munk  
UCCE – Fresno County  
1720 S. Maple Avenue  
Fresno, CA 93702  
(559) 600-7285 Office  
(559) 600-7228 Fax  
[dsmunk@ucanr.edu](mailto:dsmunk@ucanr.edu)

**TWO YEAR TERM**

Mark Sisterson  
USDA Research Scientist  
9611 S. RIVERBEND AVE.  
PARLIER, CA, 93648  
(559) 596-2840  
(559) 596-2921 - Fax  
[mark.sisterson@ars.usda.gov](mailto:mark.sisterson@ars.usda.gov)

Karen Lowell  
NRCS Agronomist Central Coast  
744A La Guardia  
Salinas, CA 93905  
831-424-1036 x119  
[Karen.lowell@ca.usda.gov](mailto:Karen.lowell@ca.usda.gov)

**Scott Stoddard**

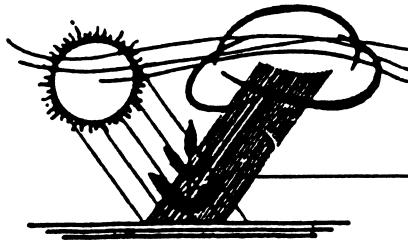
UCCE – Merced County  
2145 Wardrobe Avenue  
Merced, CA 95341-6445  
(209) 385-7403  
(209) 722-8856 Fax  
[cssstoddard@ucanr.edu](mailto:cssstoddard@ucanr.edu)

**THREE YEAR TERM**

Eric H. Ellison, Ph.D.  
Agronomist – Specialty  
Agriculture  
Agrium Advanced Technologies  
Mobile phone: 209-327-0707  
[ellison@agriumat.com](mailto:ellison@agriumat.com)

Anne Collins  
Soil Scientist  
Certified Crop Adviser  
Dellavalle Laboratory, Inc  
502 Mace Blvd, Suite 2B  
Davis, CA 95618  
Cell: 530.400.1346  
Fax: 530.756.5553  
[acollins@dellavallelab.com](mailto:acollins@dellavallelab.com)

Elizabeth "Betsy" A. Boyd, Ph.D.  
Assistant professor- Plant Science  
College of Agriculture  
California State University, Chico  
400 W 1st St  
Chico, CA 95929-0001  
Office: 225 Plumas Hall  
Campus Zip: 310  
Tel: (530) 898-6879  
Fax: (530) 898-5845  
[eaboyd@csuchico.edu](mailto:eaboyd@csuchico.edu)



**California Chapter  
AMERICAN SOCIETY OF AGRONOMY**

February 5, 2014

**Board Meeting Minutes  
California Chapter of the American Society of Agronomy (ASA)**

**February 8, 2014  
Radisson Hotel and Conference Center  
Fresno, CA  
12:45 PM – 2:10 PM**

**1. Call to Order: Dave Goorahoo, President, California Chapter ASA.**

- a. Welcomed attendees to the 43rd annual business meeting of the California Chapter ASA. He noted that the Chapter's annual meeting has been running since 1972. He mentioned that it is one of the longest running conferences in California and one of the few that still prints proceedings. President Goorahoo indicated that the Society still plans to print proceedings in the future and also make the proceedings available online on the Chapter website.
- b. The President acknowledged that like previous years the conference is again being conducted in cooperation with the California Certified Crop Advisors (CCA).
- c. Dr. Goorahoo provided comments on the importance of providing the committee with feedback on the conference and arrangements, and asked attendees to please fill out the evaluations.
- d. Student attendees were acknowledged and asked to stand and be recognized. Students were from CSU, Fresno & Chico, College of the Sequoia, and UC Davis. The assistance received from students in running certain aspects of the conference was acknowledged.
- e. The President acknowledged and thanked the sponsors for funds used for refreshments for the breaks and other conference events.
  - i. He mentioned that the many sponsors that are listed in the Proceedings.
  - ii. He acknowledged that the meeting attendees also help pay for conference costs with their registration fees, and the importance of this participation was noted.
  - iii. Acknowledgement was given to Western Plant Health Association and numerous other private donors to the Scholarship fund.
  - iv. Thanks were given for program support from the Department of Water Resources for irrigation and salinity related sessions this year.
- f. President Goorahoo introduced the Executive Committee and Governing Board and thanked members for their hard work for preparing this year's ASA Plant and Soil Conference. He emphasized that all Board member positions are volunteered. He recognized the members plus student help particularly from CSU Fresno, and the help of Mark Keeley of UCD for help with registration.

- i. Past President, Allan Fulton (Honorees)
- ii. 1<sup>st</sup> VP, Steve Grattan (Proceedings)
- iii. 2<sup>nd</sup> VP, Richard Smith (Conference site arrangements)
- iv. Secretary and Treasurer, Bob Hutmacher
- v. Governing Board (Florence Cassel-Sharma, Toby O'Geen, Rich Rosecrance, Anil Shrestha, Dan Munk, Karen Lowell, Warren Hutchings, Mark Sisterson, Scott Stoddard, Sharon Benes).
- g. Dave Goorahoo introduced and thanked Past Presidents

**2. Business meeting minutes from the 2013 ASA Plant and Soil Conference** (Goorahoo)

- a. Indicated that the minutes of the Feb. 8, 2013 conference was on page 4 of the proceedings
- b. Motion to approve the minutes was given (Munk) and seconded (Stoddard). Minutes for the 2013 business meeting passed as presented.

**3. Treasurer's Report** (Hutmacher)

- a. Presented Treasurer's report for the 2013 meeting and activities. \$25,413 was the current balance in the CA Chapter ASA account. Charges and credits for this year's conference are pending.
- b. A verbal report was provided to conference attendees and a written status report was prepared for the committee, providing an account of issues related to unrecovered funds from our prior contractor helping with online registration (Acteva Corporation).
- c. Approval of Treasurer's report was moved (Smith) and seconded (Grattan). Motion passed to approve Treasurer's report.
- d. Thanks were given to Kay Hutmacher, Mark Keeley of UC Davis and the following students from CSU Fresno for assistance in running registration both days at the meeting (Helen Mata, Mala To).

**4. Nomination and Election of persons to serve on the Governing Board** (Goorahoo / Grattan)

- a. Brief overview of the Governing Board structure was provided: 9 persons serving 3-year terms. According to by-laws, members on the Board represent diverse disciplines and represent academia, agencies and industry.
- b. The past President (Dave) and Board members completing their term of service were acknowledged and thanked for their dedication and hard work.
- c. Nominations opened for the election of persons to serve on the 2014-2015 Governing Board.
- d. Board nominations for the Executive Committee and Governing Board were presented (there were no nominations from the floor):
  - i. Steve Grattan as President
  - ii. Richard Smith as 1<sup>st</sup> VP
  - iii. Bob Hutmacher as 2<sup>nd</sup> VP
  - iv. Sharon Benes as incoming Secretary/Treasurer
  - v. Serving 3 year terms
    - 1. Eric Ellison, Agrium Advanced Technologies – 3 year term
    - 2. Anne Collins, Dellavalle Lab – 3 year term
    - 3. Elizabeth Betsy Boyd, CA State Univ. Chico – 3 year term
  - vi. Serving 2 year remaining terms

1. Mark Sisterson, USDA-ARS – 2 years
  2. Karen Lowell, NRCS – 2 years
  3. Scott Stoddard, Univ CA UCCE – 2 years
- vii. Serving 1 year remaining terms
1. Anil Shrestha – CA State Univ. Fresno = 1 year
  2. Richard Rosecrance – CA State Univ. Chico – 1 year
  3. Warren Hutchings – Innovative Ag Services – 1 year
  4. Dan Munk – Univ. CA UCCE – 1 year
- viii. Motion was made (Grattan), seconded (Goorahoo) and passed to approve new members

## **5. Presentation of awards to 2014 honorees. (Fulton)**

### i. Gene Aksland

Janice Cooper (CA Wheat Commission) provided and presented a summary of Gene's past accomplishments, particularly in regards to his contributions to California agriculture's industry

Mention was made that he was raised on a farm in the northern SJV, raising trees, vines, row crops and a dairy. His contributions mentioned were a wide range of forage crop cultivars, including extensive work in triticale and sorghum. He worked with Research Seeds, Goldsmith Seed Co. and collaborated with many UC researchers over the years, working in plant breeding, seed production, grower outreach regarding new developments.

The award was presented and Gene Aksland thanked and acknowledged those who helped him over the years.

### ii. Kerry Arroues

Bob Beede (UCCE) described Kerry's schooling and career, growing up in Susanville in northern CA and college at CA State University Chico, with a B.S. degree in 1973. He described many positions with SCS and NRCS over the years, leading many soil surveys and updates in the SJV and Delta areas, dealing with and leading these efforts on over 4 million acres, coming to Hanford in 1976. He won a Natl Achievement Award from the NRCS and retired from the USDA in 2012. He authored and co-authored many publications, and served as a member of the Natl Resources Advisory Council. He continues to coordinate multiple field trips per year. He thanked the committee and those attending for the honor.

### iii. Stuart Pettygrove

Rob Mikkelsen introduced Stuart Pettygrove, honoring his work as a UCCE Specialist / Soil Scientist since 1979. He grew up in Modesto, went to school at UC Berkeley, Cal Poly SLO and did graduate work at Oregon State University. He has worked on a wide variety of projects of statewide and even national importance related to nutrient management, potassium management issues, and has been very involved in recommendations for management and research related to dairy industry and feed production for dairies. He has been instrumental in development and expansion of the FREP program and in preparation

of training classes and information on topics such as nitrate management and potassium nutrition. Rob described Stuart Pettygrove as the “go to Guy” for nutrient management questions. Stuart thanked the committee and the attendees for the honor and commended the students for their interest and commitment to future work in agriculture.

## **6. Student Posters and Scholarships**

- a. Florence Cassel-Sharma (Chair of student scholarship committee).
  - i. Florence acknowledged other committee members (Dan Munk, Karen Lowell) as well as the support of sponsors.
  - ii. Florence briefly discussed the criteria used to judge the students, with applicants asked to provide 2 letters of recommendation plus a description of work aspirations.
- b. Winning essays were announced by Florence and the awards were presented. The scholarship funds were stated as being provided by the Western Plant Health Association (\$1500) and those individuals who donated to funds to the student scholarship funds. Their essays are reproduced in the proceedings, and can be found on pages 12 and 13. The two awards made were:
  - i. Aubrey Atwood, Cal-Poly, SLO (she was not able to attend); she wrote about Impacts of low flow irrigation and automation. She has a GPA of 3.9 and is involved in many activities, including FFA President for 2 years and work for Dow Agro as a Crop production intern. She was awarded \$750.
  - ii. Armando Guzman, CSU Fresno (he was able to attend); he wrote about Importance of Technology in Irrigation Innovation, the importance of soil characterization and knowledge. He has a GPA of 3.6 and is in the Fresno State University Plant Sciences Club. He was awarded \$750.
- c. Richard Smith announced awards for student posters. He thanked the students for putting up the poster boards. Awards were made to graduate and undergraduate students. He thanked committee members Toby O’Geen, Mark Sisterson who served with him on the evaluation committee.  
Undergraduate winners included:
  - i. Nadia Juarez (\$200)
  - ii. Vincent Servin (\$100)Graduate Student winners were:
  - iii. Matt Dumlaao (\$300)
  - iv. Wang Juan (\$200)
  - v. Navreet Mahal (\$100)

## **7. Old business and New business**

None was introduced.

8. President Goorahoo again requested attendees to fill out conference evaluation forms.
9. President Goorahoo passed the gavel (made special for the ASA California Chapter in 1978) over to Steve Grattan, the new incoming President.

- 10.** Newly elected President Grattan presented an award to President Goorahoo for his hard and excellent work over the years serving the Executive Board.
- 11.** Steve Grattan adjourned the business meeting at 2:10



## 2015 Honorees

**Bob Beede**

**Carol Frate**

**Allan Romander**

## **Robert H. Beede**

**University of California Cooperative Extension Pomology Farm Advisor  
Kings County      1980-2014**



It is with great pleasure that we honor Bob Beede at this 2015 Cal-ASA Plant-Soil Conference. His generosity, vitality of spirit and contributions to the improved production practices in almonds, pistachios and walnuts speak even more loudly than the pink shirt and purple tie he'd wear to some meetings! In his own words, "UC is blessed with hiring individuals who are outstanding academically and personally. I cannot imagine (any other institution) having the number of kind, wise, and encouraging individuals that we have within the ranks of Cooperative Extension. I wish to sincerely thank the University of California for providing me a career which allowed me to be

of service to such an important component of America as California agriculture, and to fulfill my life goal of contributing to the well-being of our society."

In the words of Allan Fulton (Irrigation and Soils advisor with Bob in Kings County 1984-1993, now in Tehama County), "Bob was and still is a tremendous mentor to me and to others. He is without question a skilled and talented horticulturalist. At the end of the day, his greatest achievement was to build up people and the communities around him."

Tim Spann (CA Avocado Commission) worked closely with Bob while finishing a Ph.D., working on pistachios and recalls that Bob's sagely wisdom was consistent with the nickname Bob has been given by his Central Coast surfing buddies – Buddha. The "All-Knowing One" encouraged Blake Sanden to take on the Kern County Irrigation/Soils Farm Advisor job and was a great mentor to his and Louise Ferguson's pistachio salinity tolerance work.

In the first part of his career, Bob was responsible for virtually every horticultural crop in Kings County: almonds, walnuts, pistachios, pecans, peaches, plums, nectarines, kiwis, wine and raisin grapes, olives, and even jojoba. In his earlier career he did extensive work on hedging and revised trellising for Columbard wine grapes and helped register dormant oil on Kiwis for control of Latania armored scale under both conventional and organic farming practices. But his work with walnuts and pistachios over three decades are among his most significant achievements.

He is considered to be the father of ReTain<sup>®</sup>, a plant growth regulator that reduces pistillate flower abortion (PFA) in walnuts – basically rescuing the Serr variety. He performed the first study of navel orangeworm (NOW) on pistachio to document the effect of nut development stage on NOW susceptibility – proving the potential damage of this worm to the nuts. His grower savvy and cooperation with Irrigation Specialist, David Goldhamer, made it possible to develop the first documented irrigation crop coefficients and seasonal water use data for pistachios and walnuts. Additional work over the next 20 years examined the limits of deficit irrigation in these two crops and identified crop development periods most susceptible to stress. Applied irrigation scheduling work with Allan Fulton in walnuts showed that increasing irrigation frequency had a big payback in yield. Bob and Louise Ferguson developed our current understanding and management practice for mechanical hedging in pistachios. Bob was the first to demonstrate the use of dormant oil to enhance fruiting in young pistachios, and along with Sevin<sup>®</sup> provide some control of *Phytocoris*. He has coordinated countless field meetings and

workshops over the years and continues in retirement to stay busy providing consulting to growers.

We are pleased to recognize Bob's long and productive career with UCCE and his valuable contributions to orchard crop production in California.

## **Carol A.Frate**

### **UC Cooperative Extension Farm Advisor, Emeritus**

Carol Frate lived on the East Coast, West Coast and in Japan by the time she graduated from high school in the San Francisco bay area. She enrolled as a Chemistry major at UC Davis but a love of the outdoors, botany, and applied science led her to a BS in Plant Science in 1975. Having worked as an undergraduate in the Plant Pathology Department, she pursued a Master's Degree in Plant Pathology evaluating fungicides for the control of sugarbeet powdery mildew, at the time a new disease in California. Dr. F. Jack Hills, Extension Specialist for sugarbeets, was on her graduate committee and his influence steered her toward a career as a Farm Advisor in Cooperative Extension.

During her graduate studies, Carol worked as a teaching assistant for the introductory plant pathology class at UCD and later as a post-graduate researcher with Dr. Joe Ogawa. She was in the second class of Farm Advisor Interns, spending half the year with Vegetable Crop Farm Advisor Don May in Fresno County and the other half with Jack Williams, Agronomy Farm Advisor in Sutter/Yuba counties. After a year working for Weed Science Extension Specialist Clyde Elmore, she had the practical experience with many crops, farming practices, field research techniques and extension methods to be competitive in seeking an extension position.

In 1980, Carol was appointed University of California Cooperative Extension Agronomy Farm Advisor in Tulare County. She remained in that position until her retirement in 2014. She conducted applied research programs over a variety of topics in alfalfa, blackeye cowpeas, field corn and, until the processing plant in Mendota closed, sugarbeets. Trials included variety evaluations, irrigation studies, pest management research, and assessment of new production practices. She collaborated with Extension Specialists, Farm Advisor colleagues, PCAs, consultants, growers, campus faculty, and NRCS engineers and agronomists. In the 1980's, she was part of a team that conducted trials in the San Joaquin Valley evaluating the short and long term impact of withholding summer irrigations on the yield and quality of alfalfa. She also evaluated the impact of winter grazing by sheep on alfalfa. Recent trials on *Sclerotinia* stem and crown rot of alfalfa contributed to the registration of a fungicide to help manage this disease. Carol worked closely with UC blackeye cowpea breeders to test promising lines on-farm, leading to the release of 3 blackeye varieties. Corn and cowpea insecticide trials for managing leafminers, aphids, lygus bugs and spider mites provided data to chemical companies for registration purposes and information to growers and PCAs for pesticide selection. Years before dairy nutrient management was regulated, Carol teamed with Farm Advisor colleague Marsha Campbell Mathews to conduct workshops for consultants and producers describing techniques to proactively manage pond water nutrients for crop production. More recently, she collaborated with Extension Specialists Dr. Stuart Pettygrove and Dr. Larry Schwankl on in-depth studies to manage dairy pond water for crop production.

In addition to organizing meetings and making presentations on the commodities with which she worked, Carol coordinated workshops on farm management, introductory computer classes specifically for farmers, an informational seminar on biosolids, and proper tractor tire inflation. She served on the Tulare County Ag Advisory Committee for a number of years. She was a Board member for the California Chapter of the American Society of Agronomy and was on the Executive Committee culminating in service as the Chapter President in 1990. More recently, she served out the remaining term for a retiring Board member and was on the scholarship and student poster judging committees for the Chapter.

Carol always felt it was a privilege to work in California's agricultural industry and values the many colleagues and friends with whom she worked during her career. As a Farm Advisor Emeritus, Carol continues to work on blackeye and alfalfa extension publications.

## **Allan Romander biography**

**Honoree Recipient 2015**

**California Chapter of the American Society of Agronomy**

A latecomer to irrigated agriculture in California, Allan Romander nonetheless made a career of working with growers of various crops as a PCA and CCA in western Stanislaus County. Allan was one of the first CCAs in the state and was instrumental to the success of the program, and continues to serve on the Executive Committee of the International Program. About his work with California agriculture, Allan comments, “We should all be proud of and happy to be a part of our state's ag industry. It is by far the most advanced and productive farming system in the world”.

Born in New Jersey, moved to CA at 4 near the end of WWII so pretty much considers himself to be a native. Lived in Redwood City but not involved in agriculture. From 16 - 18 worked on a cattle ranch in SE Oregon, which stimulated interest in agriculture. Went to Cal Poly Pomona for college, graduating with a Bachelor's degree in animal science in 1968. His first job was with HJ Heinz in Michigan. One of his first assignments was to develop an agronomy program for growing new cucumber varieties that could survive mechanized harvesting—a new process at the time.

“For a kid who had no formal training in agronomy, I had to learn from the ground up,” he recalls. “And I learned a lot—from talking to colleagues, talking to growers, talking to anybody who would listen. In 1979 went to Schmidt Soil Service (in California), which became Britz and eventually Simplot. In 1987 started working as PCA for Western Farm Service (now Crop Production Service) out of the Vernalis office (West Stanislaus County), and stayed there until retirement in 2007. Along the way, he handled an amazing assortment of crops, including canning tomatoes, apricots, almonds, walnuts, dry and freezer lima beans, cherries, apples, and even a little corn.

In 1994, Allan became one of the first Certified Crop Advisers (CCAs) in California, passing the state and international plan on the first try. He did this as a requirement by WFS. Continued to be a CCA member for the next decade, but overall numbers in California were small because there was not a lot of perceived benefits to be both a CCA and PCA — licensing fees, plus difficult to get CEU's. He often didn't tell people about his status as a CCA. “There wasn't a lot of need to do so,” he says.

That began to change in 2004. With retirement looming, Allan was looking for something to do next, and so he accepted an offer to join the California CCA Board and chair its marketing committee. The number of California CCAs was at an all-time low and the board hoped he could help turn things around. Based on the advice of marketing consultant Steve Beckley, Allan started making presentations about the program at every opportunity, such as at Extension meetings, CAPCA meetings, and agency meetings.

One of those agencies happened to be the California Water Quality Control Board, which was looking at nitrates in groundwater at the time. The meeting with the board turned out to be astoundingly productive. When it issued regulations in 2007 mandating that California dairies develop nutrient management plans for manure, the board also stipulated that either an engineer or a CCA had to write the plan.

This strategy worked well. The CCA program in California has been the fastest growing program in the world over the last eight years. The CCA program is being managed by CAPCA now, which has stabilized membership and made it a lot easier to achieve the required continuing education units. In 2007 there were about 350 CCAs in the state, and now there are more than 1000. California has the 3rd largest program in the U.S., behind Illinois and Iowa, which have been traditional CCA strongholds for many years.

As a representative of the California Program and its success, Allan was elected to be a member of the

Executive Committee of the International Program, becoming Chair in 2014. Internationally, there are about 15,000 CCAs. The program is well established in Canada, and Allan is working on growing the program in Mexico.

Allan's wife's name is Mary and they have four sons, ages 48 down to 37, and nine grandchildren aged 2 to 19. So they have one grandchild in College and one in diapers! Allan and Mary really love traveling!! If they are not traveling overseas, they are in their RV. They travel to visit friends and other family members scattered throughout the West, and have flown to Sweden six times to stay abreast of family and friends living there.



# American Society of Agronomy

## California Chapter

### 2015 Scholarship Recipients & Essays

#### **Essay Question:**

*Agricultural production occurs in an increasingly complex market and regulatory environment. What new technologies and/or skills will those supporting California agriculture need in the coming decades?*

#### **Scholarship Committee:**

Eric Ellison

Karen Lowell

Daniel Munk



## 2014/2015 Scholarship Award Winners

The California Chapter of the American Society of Agronomy awarded two scholarships of \$750 each to honor California residents currently enrolled a degree program in crop production, plant science, soil science or a related field at a 4-year California College or University.

**Applicants were evaluated based on the following criteria:**

- Essay narrative content and quality 50%
- Leadership, scholarship, and extracurricular activities 30%
- Letters of recommendation 10%

### 2014/2015 Essay Prompt

*Agricultural production occurs in an increasingly complex market and regulatory environment. What new technologies and/or skills will those supporting California agriculture need in the coming decades?*

- Work or business experience in agriculture 10%

Essays by the winning students follow.

**Financial support for the scholarships generously provided by  
Western Plant Health Association.**



**WPHA**  
Western Plant Health Association

**Charlie Garcia**

**California State University, Fresno**

### **What Can be Done to Feed a Population of 9 Billion?**

In the coming years the human population is expected to reach 9 billion. Meanwhile, fertile land is decreasing yearly and food production will need to double to accommodate the growing population. In order for food production to increase under increasingly restrictive regulations, growers will need innovative technologies and certain skill sets to produce more food in an environmentally friendly and sustainable manner. Intensive research must be conducted to minimize crop losses to diseases and pests and to improve genetic resources and the potential for genetic engineering to enhance crop tolerance to diseases and pests. Additionally the scientific community needs to improve the communication of information to the public in language that they will understand; because without their approval the use of many beneficial technologies will not be allowed.

I will focus my discussion of new technologies to improved food security on those related to pest control which is my area of focus within Plant Science. The development of pest resistance is one of the major issues that need to be addressed and studied to minimize its progression. Certain pests have begun to show resistance to one or more modes of actions (MOA) of our commonly used pesticides. Therefore, integrated pest management (IPM) and integrated weed management (IWM) need to become the foundation upon which growers control problematic pests and weeds. Through a combination of cultural, biological and mechanical practices, chemical applications can be used as a last resort. By rotating crops and MOA's, pesticides can retain their efficacy for a longer period of time.

Genetically modified crops are a developing tool that will be very useful to growers around the world. Genetic engineering can be very useful for the protection of many crops from native and invasive pests. For example, the citrus industry is currently contemplating the use of genetically modified organisms (GMO's) to control huanglongbing (HLB) or citrus greening disease. In an effort to control the spread of this deadly bacterium, citrus cultivars are being genetically engineered to be tolerant to the Asian citrus psyllid (ACP), the vector for this disease. This is one of many examples of how GMO's can and will be instrumental for food production in the future.

Another tool that will help growers in the future will be improved pathogen detection and pathogenic sequencing. By improving pathogen detection we will be better able to determine when a pest is actually present in the field. Today many growers rely on scouts to walk and survey the fields for the presence of pathogens, but recently some growers have begun to use aerial drones. In recent studies, drones have proven to be efficient in detecting the presence of pests. A bird's eye view can be useful for spot treatments because the location of the pest can be accurately pinpointed with GPS.

Pathogenic sequencing can help us better understand genotypic and phenotypic diversity within pests. This information is important because there can be a direct correlation between their sequencing and pathogenic capabilities. Understanding these correlations could help growers make better decisions regarding pest control.

Last and most importantly, the scientific community must improve their transmission of information to the public. Much of the public has the misconception that all pesticide use and GMO's are bad. Contrary to the argument that pesticides are destroying the environment, one

can emphasize the fact that they help to reduce weeds, insect pest and pathogenic diseases, thereby increasing food security, and when used properly, environmental impacts can be minimized. Also many people are ill informed as to what GMO's really are. GMO's are the result of decades of research and great discoveries in the study of molecular genetics. By inserting certain genes or by simply using plant breeding techniques that also range decades into the past, scientists can now provide growers with stronger more resilient crops that will outperform the pests that restrict them currently. This in turn, can have the benefit of reducing pesticide usage.

**Lindee Mae Jones**  
**California State University, Chico**

In the coming decades California agriculture will be faced with more challenges than ever before. California will need to increase the amount of food produced on the little amount of suitable agricultural land left to feed the increasing population. Keeping this in mind California's agricultural production will also be under strict laws and regulations in the future to ensure safe, high quality products.

With the current water situation in California, new technology will be in demand that will help the growers use the correct amount of water needed for their crops to be successful without using unnecessary water. Some water saving technologies are being used today on a regular basis by growers which may include a: tensionmeter, pressure bomb, gypsum block, capacitance probe, or other devices that measure the amount of water used by crops. Some growers have been implementing CIMIS (California Irrigation Management Information Systems), designed to aid growers with water budgeting and irrigation scheduling based on evapotranspiration of the soil and the crops. These devices are vital today and especially in the near future with more severe restrictions on water use.

For example, AB 1739 is a new ground water regulation that will put more pressure on growers in California to measure and manage water use. This regulation gives local land planners until 2017 to select or establish a groundwater sustainability agency. The agencies then have until 2020 or 2022 depending on the situation to draw up sustainability plans. The plans will put aquifers on a pathway to sustainability by 2040.

Water is one of the most sensitive topics for California agriculture, with California using eighty percent of its water for agriculture. It should be expected that new technology will begin to emerge to address water usage for agriculture in California. Water conservation technologies will be the leading technology in the future. Many growers have already converted most surface irrigation systems to low volume irrigation methods like drip line or micro-sprinklers over the past twenty years. Low volume irrigation methods are more complex and require more management than surface irrigation, thus this is why education will be significant in the future of California agriculture.

Education on water conservation will play a key role in California's agricultural production. Knowing how to use technology and being educated on water conservation will help individuals as well as agriculture as a whole. Education on water usage has already been seen at Chico State University through the irrigation course offered, the irrigation water training facility,

and at the farm where the University uses water measuring devices to be more accurate with watering the crops.

It seems apparent that the future of California's agricultural production technology will be directed toward water conservation. Individuals that are educated on water conservation methods and technology will play an essential role in the future of California's agriculture.



# American Society of Agronomy

## California Chapter

### General Session

**California Water: Balancing  
Quality and Quantity**

Steve Grattan

CA ASA President

### Keynote Speaker

Thomas Harter

UC Davis, Dept of Land, Air and  
Water Resources

**The Future of Groundwater Use  
and Protection in California's  
Agricultural Regions**

# **The Future of Groundwater Use and Protection in California's Agricultural Regions**

Thomas Harter, Robert M. Hagan Endowed Chair for Water Management and Policy

Department of Land, Air, and Water Resources,

University of California, Davis, CA 95616-8626

Phone (530) 400-1784, [tharter@ucdavis.edu](mailto:tharter@ucdavis.edu), <http://groundwater.ucdavis.edu>

## **Introduction**

Groundwater resources across California's agricultural regions have been more stressed during the most recent drought than at any other time in history (CDWR, 2014a). In most wells, depth to groundwater exceeded previous records, set by the same or nearby wells in the 2007-2009 drought or in the mid 20<sup>th</sup> century, prior to local, state, and federal water projects (reservoirs and canals) coming online. The drought, and the extreme stress on wells come at a time of increased crop intensification, large scale conversion of rangeland or field crops to permanent crops, and uncertainty about Delta deliveries, the heart of California's elaborate surface water conveyance system.

Lower groundwater levels have significantly increased pumping costs, and increased the need for constructing deeper wells, where wells were not sufficiently deep to keep up with falling water levels (Howitt et al., 2014). Greater reliance on groundwater resources during the drought has drastically increased the rate of land subsidence at a large scale in the Central Valley, coastal basins, and southern California, and has also exacerbated seawater intrusion where pumping occurs in aquifers near the coast (CDWR, 2014b). As wells pump deeper, water quality is sometimes compromised due to saline water or other naturally occurring contaminants.

Agricultural regions in California are not only challenged by dwindling groundwater supply – still a critical drought insurance in California - but are also impacted by significant groundwater quality degradation from nitrate and salt pollutions (Harter et al., 2012; SWRCB 2013; LWA 2014).

## **Groundwater Overdraft and Pollution: Policy Responses**

The problems of groundwater overdraft and water quality degradation have been recognized for some time. Increasing public concern raised the level of local, state, and federal government engagement of policy and decision makers. As a result, the agricultural community has experienced significant changes in its involvement with managing groundwater extraction and protection.

**Groundwater Quality.** Changes to California's water quality law, the Porter-Cologne Act, led to new regulatory requirements for point and nonpoint source discharges to groundwater in the early 2000s. While initially focused on surface water quality, these efforts now also address groundwater quality by requiring active source control and documentation of groundwater nitrate discharges and also by providing state and federal funds to improve the drinking water supply of affected communities.

Water quality regulations are implemented by Regional Water Boards (RWBs). The nine RWBs use different approaches to assess and control agricultural discharges. The Central Valley RWB and Central Coast RWB regions are home to California's most intensive agricultural operations and have perhaps the most extensive regulations, but all RWBs are obligated to consider discharges from nonpoint sources to groundwater and to develop basin plan amendments for nutrient and salt management.

In the Central Valley, three major programs have been or are being developed to control salt and nutrient discharges to groundwater and surface water: the Dairy Order, the Irrigated Lands Regulatory Program (ILRP), and the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) program. The Central Coast Region has developed its own version of the ILRP, referred to as the Agricultural Order. All programs have in common that they require:

- Assessment of sources, pathways (hydrogeology, water quality), and impacts,
- Source management plans,
- Reporting, and
- Direct or indirect (proxy) groundwater discharge monitoring

The 2007 Dairy Order was the first comprehensive California groundwater quality permitting program applicable specifically to farms. It provides the framework for permitting dairy discharges of nutrients and salts to surface water and groundwater. The dairy order requires dairies to prepare nutrient and waste management plans, annually report nutrient budgets for individual fields, tonnage of manure exports, and water quality of onsite wells. Targeted shallow groundwater monitoring and efforts to develop improved management practices that demonstrably improve groundwater quality are implemented through the Central Valley Dairy Representative Monitoring Program, an industry coalition that is working closely with the Regional Water Board and that offered an efficient alternative to individual groundwater monitoring plans.

Since 2010, the Central Valley is working on significantly expanding the Irrigated Lands Regulatory Program, which covers about 7 million irrigated acres with several tens of thousands of individual farms. Upon its inception in the early 2000s, the Central Valley ILRP (like a similar program in the Central Coast region) focused on surface water and watershed protection. But the

new program strives to add elements to also protect and improve groundwater quality, primarily nitrate, pesticide, and salt contamination, through source management on irrigated lands. In the Central Valley, permits (so-called waste discharge orders) are given either to individual farms or to several regional coalitions that farms can join as members. Coalitions include the Sacramento River Watershed, Rice Growers, Eastern San Joaquin Watershed, San Joaquin County and Delta, Western San Joaquin Watershed, Tulare Lake Basin Area, and Western Tulare Lake Basin Area Coalitions, each of which is subject to an individual order. Groundwater Assessment Reports are currently being developed or have been developed by the coalitions, which serve to identify historic and current groundwater quality conditions and to identify vulnerable groundwater regions. Monitoring and reporting requirements may differ within and between regions depending on groundwater vulnerability and risk to beneficial uses of groundwater. For 2015, nutrient management planning forms will need to be completed for the first time. In general, farmers will now be required to implement management practices, keep appropriate records (for random audits) and report some of the information collected to their respective coalition. The coalitions are responsible for performing groundwater monitoring, typically in a network of domestic wells, and – as in the dairy program – are responsible for developing management practices that demonstrably improve and protect groundwater quality. A significant focus will be on documenting nitrogen inputs and outputs and improving nitrogen use efficiency.

In 2012, the Central Coast RWB passed its update to the ILRP, the Agricultural Regulatory Program. The program, which covers about 4,000 farms on about 400,000 acres, was challenged but later upheld by the State Water Board. The program created 3 tiers of farms depending on the potential risk they pose to groundwater quality. The tiers are determined by pesticide use, farm size, nitrate occurrence in nearby public supply and farm wells, and by crop type. About 1 in 7 farms are in the highest tier, about half of the farms – mostly vineyards – fall in the lowest tier with the remainder being in tier 2. As in the Central Valley, farms in all tiers are required to perform proper nutrient, pesticide, and irrigation management, documented through farm plans and following best management practices. Backflow prevention and proper well abandonment are also required on all farms. All farms need to sample groundwater from existing wells twice during the first year. Subsequent groundwater sampling frequency varies from tier to tier. As in the Central Valley, farms can choose to implement the groundwater sampling program individually or by joining a larger coalition that has been created specifically to perform groundwater monitoring and support growers with the implementation of the Ag Order.

At an even larger scale and affecting stakeholders beyond agriculture, the Central Valley Salinity Alternatives for Long-Term Sustainability (CV-SALTS) program was created in 2009 to develop a comprehensive Salt and Nutrient Basin Plan Amendment for the Central Valley. Rather than being an agency developed plan, CV-SALTS allowed for a stakeholder-driven development of the basin plan amendment, a process that includes a wide range of assessments: source loading, surface water and groundwater quality, and potential management practice and infrastructure

solutions, in particular to avoid salinization of the Central Valley aquifer system. Stakeholders are organized within the Central Valley Salinity Coalition (CVSC), which is scheduled to provide its final Salt/Nitrate Management Plan (SNMP) to the Regional Water Board in 2016.

CVSC has already issued a number of critical reports, including:

- An assessment of the impact to agriculture and the California economy, if current conditions continue and no action is taken to prevent future salination of groundwater and surface water systems in the Central Valley. By 2030, these costs could exceed 6 – 10 billion dollars annually in lost production costs, job losses, and other impacts to the California economy
- A comprehensive Initial Conceptual Model (ICM) that provides a valley-wide estimate of salt and nutrient loading, separately for 22 groundwater sub-basins (referred to as “initial analysis zones”). The report details the historic and current distribution of salinity and nitrate concentration in groundwater throughout the Central Valley. It estimates salt and nitrate loading to streams, and it estimates salt and nitrate loading to groundwater, among other analyses.
- A Strategic Salt Accumulation and Transport Study (SSALTS) that uses historic water quality and current loading from the ICM to estimate the amount of desalination necessary to achieve water quality objectives for irrigation and drinking water, then evaluate potential infrastructure and costs to implement the necessary desalination on approximately 1.2 million acre-feet of Central Valley groundwater annually. Costs are estimated to be on the order off \$70 billion over the next 30 years, of which \$20 billion can be raised by selling approximately 1.1 million acre-feet of ultra-clean water annually to urban areas. These costs include some saline water being disposed of by deep injection, and some being stored in salt accumulation areas on the Tulare Lake Bed.

As a result of these efforts, the agricultural community is seeing new requirements for documentation, training, practice improvement, monitoring, and reporting. This is a significant and in some cases not inexpensive shift in farming practices that is historically unheard of. Similar to the development of the water quality programs in the late 20<sup>th</sup> century that targeted industrial and urban land uses, there will be a difficult transition period for this newly regulated community. This is not only a transition period for farmers, it is also a transition period for scientists and educators to provide innovative management practices and training, geared toward protecting groundwater quality and a better understanding of the groundwater-agriculture interface. It is also a transition period for regulatory agencies, which for the first time are regulating nonpoint sources of groundwater pollution that involve large tracts of land and numerous individual landowners, a situation that requires significant rethinking and innovation relative to strategies historically taken in existing programs focused on point sources or surface water quality.

One example of a challenge in science: Agronomic and crop scientists to date have rarely taken into account losses of contaminants to groundwater when developing best management practices and farm recommendations. Existing recommendations for fertilizer applications, for example, are in urgent need of revision to account for potential unwanted losses of nutrients to groundwater. Another example is groundwater monitoring networks: existing groundwater research has developed many approaches to monitoring distinct contaminant plumes, typically a few acres in size. However, recommendations for the design of nonpoint source monitoring networks are currently lacking.

An example of challenges to regulatory agencies is the focus on shallow groundwater monitoring wells as a tool to monitor discharges into groundwater. This approach has been developed and used for detecting inadvertent plumes, e.g., near potential underground gasoline storage tanks. These are discreet sources that can be detected, if leaking, with downgradient monitoring wells. Agricultural operations, in contrast, always “leak” – by design – and are therefore also a significant source of recharge Regulatory agencies have come to recognize that traditional site monitoring well networks are not the most effective tool. In the Dairy Order and in the ILRPs, the alternative approach has been to employ “proxy” monitoring: instead of groundwater monitoring wells to observe discharge of nitrate, nitrogen budgets at the farm scale are used to estimate potential groundwater nitrate losses, and research is implemented that shows the relationship between the nitrogen budget, management practices, and groundwater quality. Regional long-term trends in groundwater quality are monitored through trend monitoring programs, implemented through large farm coalitions.

***Groundwater Supply.*** In 2014, Governor Brown passed the Sustainable Groundwater Management Act (SGMA), California’s first comprehensive groundwater management legislation, focused on managing groundwater supplies as part of an integrated hydrologic system for the benefit of current and future generations of Californians.

The legislation and the governor’s water action plan explicitly recognize the importance of groundwater for California’s livelihood and its critical role in California water management. The legislation seeks to put a process in place that ends decades of unsustainable groundwater use and management in some California regions. The core principles that guided the development of the legislation include:

- A vision that groundwater is best managed and controlled at the local or regional level; the state would only step in if local efforts are not successful or are not moving forward in accordance with the law.
- A definition of groundwater sustainability and what undesired effects must be avoided. The latter include continuous water level drawdown, subsidence, seawater intrusions, water quality degradation, and continued (or new) impacts to groundwater dependent ecosystems and streams after the legislation takes effect.

- The state's role is focused on providing clear minimum guidelines, to be developed over the next two years by the Department of Water Resources, as well as providing technical and financial support.
- Existing water rights will continue to be protected.

Based on these principles the legislation lays out a framework for the entire state to manage its groundwater. In 127 medium and high priority groundwater basins (representing about 96% of groundwater extraction), groundwater sustainability agencies (GSAs) will have to be formed before June 2027. These GSAs will then be put in charge of developing and implementing a groundwater sustainability plan (GSP) that has specific objectives and meets specified sustainability targets. Groundwater basins have 2.5 years – until June 2017 – to form GSA(s), then another five years to develop and begin implementing the GSP (by 2022 or 2020 in critically overdrafted basins). GSAs must show significant progress in implementing their plan and achieve sustainability no later than 2040.

Over the next two years, the focus of the implementation of the SGMA will be multi-pronged:

- Forming GSAs that together cover all of the 127 medium and high priority groundwater basins, not just partially but entirely. This process will only be possible with significant local stakeholder involvement
- The Department of Water Resources will be the leader in developing minimum regulations for GSA formation, as well as having oversight regarding requirements of GSPs, basin boundary adjustments, identification of critically overdrafted basins, and the determination of medium and high priority basins that have significant groundwater dependent ecosystems or streamflow that are not already included in the current group of 127 medium and high priority basins
- Development of technical guidelines and financial support through the state.

While growers and landowners may not see any immediate impact from the legislation, their involvement in the formation of the GSAs and in the development of the GSPs provides opportunities to shape the political process in ways typically not possible in court proceedings, called adjudications, which have traditionally been the only tool to address significant conflict among groundwater pumpers in overdrafted basins. Adjudications will continue to be an alternative process to achieve sustainability, but are currently considered expensive and time-consuming. The legislature may develop an alternative, streamlined adjudication process in the near future.

In the intermediate and long run, the main impact from this legislation will be that pumpers may see restrictions in pumping or well drilling, and additional costs to secure the recharge needed to supply the groundwater used (see paper by S. Green on The New California Groundwater Law in these Cal ASA 2015 Proceedings). Future basin boundary adjustments may include fractured

rock aquifers currently not recognized as groundwater basins by the Department of Water Resources, but which are also subject to significant groundwater extraction in some areas. Litigation and state intervention will be inevitable in some cases, although it remains to be seen how frequently that route will be chosen over mediation or facilitated GSP development and implementation. The new groundwater legislation marks a turning point in California water management by no longer allowing for continued depletion of groundwater resources only temporary or seasonal drawdown to meet the needs of droughts and dry seasons and requiring an actively managed balance between human, economic, and environmental health.

## **Conclusion**

Groundwater is a critical resource for California water management, storing water from the rainy season for use during the dry and hot summers. Aquifers serve as a water bank that nature vested with a full account which we are able to use to carry us through longer-term droughts, and then have the account replenished in wetter years. Unfortunately, in many areas of California we have not been replenishing this account sufficiently during the wetter years. Managing groundwater quantity in the agricultural landscape is intricately linked to protecting groundwater quality and vice versa. New practices in the agricultural landscape to recharge clean water into aquifers while maintaining high irrigation efficiencies and controlling nutrient and pesticide leaching will address both groundwater overdraft and groundwater quality. Groundwater management also cannot be done without managing surface water resources. The future of groundwater use, protection, and management in California's agricultural landscape will be an increasingly integrated approach to manage water quality and quantity of surface water and groundwater. Landuse planners must also increasingly be involved in and informed by water planning and assessment activities. New regulations for groundwater sustainability and groundwater quality protection have emphasized the engagement of landowners and local stakeholders in the planning and implementation of new regulations, providing farmers with opportunities for engagement, dialogue, and education. New regulations also mean additional costs and efforts to farming and to local and state taxpayers, relative to historic practices. Disagreements, conflicts, and lawsuits over how to share costs and efforts will therefore continue to be part of the agricultural landscape as well.

## **Literature**

Additional information on the requirements and implementation of the Sustainable Groundwater Management Act can be found at <http://groundwater.ucdavis.edu/SGMA>

For water quality regulatory programs, the following websites are helpful:

Central Valley dairy regulatory program:

[http://www.waterboards.ca.gov/centralvalley/water\\_issues/dairies/dairy\\_program\\_regs\\_requirements/](http://www.waterboards.ca.gov/centralvalley/water_issues/dairies/dairy_program_regs_requirements/)

Central Valley Irrigated Lands Regulatory Program:

[http://www.waterboards.ca.gov/centralvalley/water\\_issues/irrigated\\_lands/](http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/)

Central Coast Irrigated Lands Regulatory Program:

[http://www.swrcb.ca.gov/centralcoast/water\\_issues/programs/ag\\_waivers/index.shtml](http://www.swrcb.ca.gov/centralcoast/water_issues/programs/ag_waivers/index.shtml)

Central Valley Salinity Alternatives for Long-Term Sustainability:<http://www.cvsalinity.org/>

***Cited Literature:***

California Department of Water Resources (CDWR), 2014a, Report to the Governor's Drought Task Force – Groundwater Basins with Potential Water Shortages and Gaps in Groundwater Monitoring, April 2014, 51 pages.

California Department of Water Resources (CDWR), 2014b, Public Update for Drought Response, November 2014, 52 pages.

Harter, T., J. R. Lund, J. Darby, G. E. Fogg, R. Howitt, K. K. Jessoe, G. S. Pettygrove, J. F. Quinn, J. H. Viers, D. B. Boyle, H. E. Canada, N. DeLaMora, K. N. Dzurella, A. Fryjoff-Hung, A. D. Hollander, K. L. Honeycutt, M. W. Jenkins, V. B. Jensen, A. M. King, G. Kourakos, D. Liptzin, E. M. Lopez, M. M. Mayzelle, A. McNally, J. Medellin-Azuara, and T. S. Rosenstock. 2012. Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis. 78 p. <http://groundwaternitrate.ucdavis.edu>.

Howitt R., J. Medellin-Azuara, J. Lund, and D. McEwan, 2014. Preliminary 2014 Drought Economic Impact Estimates in Central Valley Agriculture, Center for Watershed Sciences.

Larry Walker and Associates, Inc. (LWA), 2013, CV-SALTS Initial Conceptual Model (ICM) Technical Services – Tasks 7 and 8: Salt and Nitrate Analysis for the CCentral Valley Floor and a Focused Analysis of Modesto and Kings Subregions, Final Report, December 2013, 291 pages.

State Water Resources Control Board (SWRCB), 2013, Communities That Rely on a Contaminated Groudnwater Source for Drinking Water, Report to the Legislature, January 2013, 181 pages.



# American Society of Agronomy

## California Chapter

### Session I

### Professional Development

#### Session Chairs:

Scott Stoddard, UCCE

Anne Collins Burkholder

## Exploring Soil Survey Information With SoilWeb Apps

Toby O'Geen Soil Resource Specialist in Cooperative Extension  
Department of Land, Air & Water Resources, University of California, Davis  
One Shields Avenue, Davis, CA 95616  
Phone: (530) 752-2155, [atogeen@ucdavis.edu](mailto:atogeen@ucdavis.edu)

Dylan Beaudette USDA-NRCS Soil Scientist  
19777 Greenley Rd, Sonora, CA 95370  
(209) 532-3671 x374, [Dylan.Beaudette@ca.usda.gov](mailto:Dylan.Beaudette@ca.usda.gov)

Mike Walkinshaw  
Dept. of Land, Air and Water Resources, University of California, Davis  
One Shields Avenue, Davis, CA 95616  
[mikewalkinshaw@gmail.com](mailto:mikewalkinshaw@gmail.com)

### Introduction

Interactive, web-based mapping tools are used for a variety of land use applications. The California Soil Resource lab continues to evolve its online soil survey products into apps that distribute soils information rapidly in formats that are easy to use. The apps are customized to accommodate the diverse ways in which soil survey data is utilized.

In 2010, the Soil Resource Lab created the SoilWeb iphone app (Beaudette and O'Geen, 2010). This was a native app, meaning that the application needed to be downloaded on user's smartphones to operate. Recently our lab created several new apps that function similar to the iphone app, but are accessed via websites. The web interface allows for more flexibility in data presentation, map browsing and works across any device, all smartphones, tablets and desktops.

The CA Soil Resource lab has created four new apps (SoilWeb, SoilWeb Earth, CA Soil Properties, and Soil Series Extent Explorer that can be accessed at <http://casoilresource.lawr.ucdavis.edu/soilweb/>. The newly revised soil SoilWeb app blends the functionality of the iphone app with onscreen interactive maps depicting soil survey within Google Maps imagery. SoilWeb Earth app compliments SoilWeb's data visualization approach. It differs from SoilWeb in that it depicts STATSGO (1:250,000 scale) and SSSURGO (1:24,000 scale) and includes point data. The CA Soil Properties App depicts soil properties (e.g. clay content, soil organic matter, drainage class) in map form within Google Maps. Our most recent app, the Soil Series Extent Explorer (SEE) <http://casoilresource.lawr.ucdavis.edu/see/> allows users to map the extent of any soil series nationwide.

### Seeking Information for a location

#### *SoilWeb*

SoilWeb was updated recently into a website displayed in Google Maps. Users navigate to their area of interest in one of two ways within the "Zoom to Location" tab located in the Menu bar. Geolocating services allow web browsers to determine a user's current location through a variety of methods: IP address, wi-fi network, triangulating cell phone towers, or dedicated GPS hardware. Depending on the method a particular browser uses, the locational

accuracy may vary greatly. If it is 300 feet or less, the location will be marked on the map with an orange marker. Otherwise, the map will be centered in the general vicinity of the location query. Users with devices that have a built-in GPS (as found in many smartphones and tablets) are capable of obtaining the highest degree of accuracy when using the "Use My Current Location" function. The GPS device must be enabled, and it may require sufficient time to connect to satellites to triangulate a position. If at first the locational accuracy is unsatisfactory, try using the "Use My Current Location" feature repeatedly as needed, as it may take some time for the GPS to connect to enough satellites to obtain an accurate position. Buildings and dense tree cover will negatively affect locational accuracy using the GPS. One can also navigate to any location by entering a location as an address, city or town, zip code, landmark or coordinates.

The SoilWeb upgrade now depicts imagery and soil survey map unit delineations within an interactive display. Clicking on the area of interest on the map delivers a data display that organizes soil survey information into map unit information, component (soil type) information, horizon data including depth profiles, taxonomy, land-use interpretations and agricultural suitability classification systems. Data summaries closely resemble that described by Beaudette and O'Geen, 2009.

### ***SoilWeb Earth***

Soil-landscape relationships play an important part in the delineation of map units within a soil survey. Google's 3D geographic data viewer (Google Earth) is widely known and actively used. Simple controls and availability of high resolution imagery and terrain data make these platforms an ideal environment for exploring soil survey data. A streaming KML interface to SoilWeb (based on the SoilWeb API) is added to Google Earth as a network link, which is refreshed (updated) when the contents of the view are changed. Map unit polygons from STATSGO are presented at regional scales (i.e. 1:250K to 1:35K), and SSURGO map unit polygons are presented at finer cartographic scales. Map unit polygons are "draped" over the landscape surface, and labeled with map unit symbols. Clicking on a map unit label brings up the corresponding map unit summary page where soil survey data can be explored. SoilWeb Earth also identifies a record of point data including official series description sites and lab pedon data points. These points linked to soil pedon data.

## **Visualizing Spatial Trends**

### ***Soil Series Extent Explorer***

The Soil Series Extent Explorer (SEE) is our newest App <http://casoilresource.lawr.ucdavis.edu/see/>. SEE is a map interface that enables users to view the spatial extent of any soil series in the U.S. The acreage of up to three soil series can be mapped at a time. The mapped extent of soils is generalized by bounding boxes as a compromise between map complexity and geographic extent (Figure 1). Soil series with a large spatial extent are generalized (e.g. San Joaquin, Drummer, Rizno, Cecil, etc.) more aggressively using broader snap tolerances compared to series with lesser extent. However, reported acres for each series is a direct measure of the spatial extent of that series within each map unit scaled by its component percentage. Geographic extent and acreage estimates include soils similar to the queried series. For example, when querying "Marpa," data from "Marpa variant," "Marpa taxadjunct," and "Marpa family" are also included in the resulting map and acreage estimate.

Maps of series extent within SEE are linked to SoilWeb. This linkage of apps allows users explore all the soil survey data present in SoilWeb by clicking on the “open SoilWeb GMap” tab and then clicking on the area of interest in SEE. This process routes users to SoilWeb for the identified location. We are also working on creating data summaries for each series.

### ***California Soil Properties App***

The CA Soil Properties App was developed for California to enable clientele to visualize the spatial distribution of select soil properties across the state. A suite of soil properties are pre-aggregated and displayed in map form via 1-km grid. Thus information is aggregated from polygons to square grids based on their map unit composition and the amount of area of each map unit within a grid. There are many ways to aggregate soil survey data into maps. We chose some of the most common mechanisms, which include a soil profile aggregation in the form of depth sums, thickness weighted averages, maximum, and minimum values.

The evolution of soil survey apps in our program are a result of a strong collaboration with USDA-NRCS. Our goal is to continue to improve and evolve these apps. User feedback is always welcome.

## **References**

Beaudette and O’Geen, 2010. An iphone application for on demand access to digital soil survey information. *Soil Science Society of America Journal* 74: doi: 10.2136/sssaj2010.0144N

Beaudette, D., and A.T. O’Geen 2009. Soil-Web: An online soil survey for California, Arizona and Nevada. *Computers and Geosciences*. 35:2119-2128.

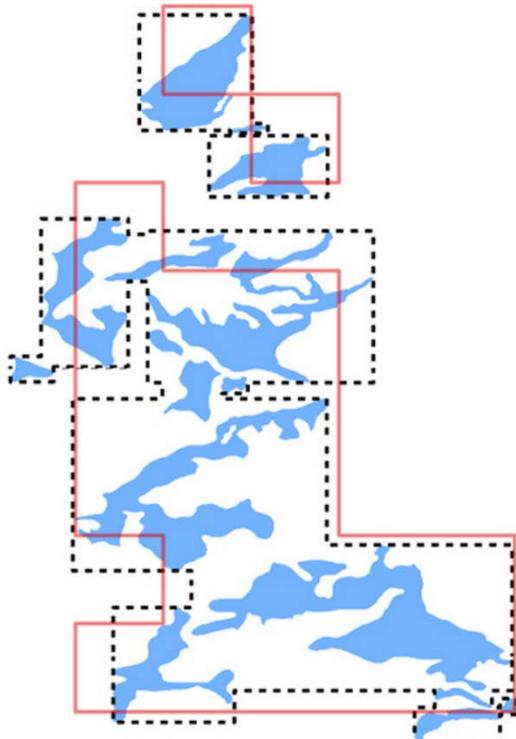


Figure 1. Select map units having the Marpa soil series as a major component are shown by the filled polygons, merged bounding boxes are shown by the dashed lines, and the generalized series extent is shown by the solid lines. A snapping tolerance of 0.01 decimal degrees was used for the generalized series extent polygons.

## **On-Farm Research and Testing: Suggestions for Making a Good Evaluation**

Scott Stoddard, Farm Advisor, UC Cooperative Extension  
2145 Wardrobe Ave, Merced, CA 95341  
Phone: 209-385-7403 Fax: 209-722-8856 [csstoddard@ucanr.edu](mailto:csstoddard@ucanr.edu)

Traditional small plot agronomic research is usually conducted on a research station, or within a small uniform area of a grower's field in order to minimize experimental error and improve the ability to detect true treatment effects. It can be used to evaluate a large number of treatments, but often requires specialized plot equipment and a lot of time spent measuring various factors. In contrast, on-farm research typically uses "real world" fields, which by their location and large size, are more variable. On-farm research evaluates treatments with replication but with field scale equipment, and therefore should be more focused than small-plot research, with a limited number of treatments. Generally, the number of treatments should be limited to 5 or less.

On-farm research can be used to gain confidence in current management practices or to help identify a need for a change. Done properly, it is a scientifically valid technique to develop answers to predict future responses. In order to provide good, meaningful data, trials need to be set up using a statistically valid design and thorough planning before going to the field.

One of the challenges with on-farm research is sorting out the true effects of applied treatments from the experimental error, or natural field variability common to any location. There is always some degree of uncertainty that measured yields, for example, in a trial are solely due to treatments being evaluated and not to some other factor like soil type, irrigation, pest damage, herbicide injury, weather, etc. Statistical tests have been developed to assign a probability that observed differences are real. In order to ensure that the results are unbiased requires replication and randomization.

Multi-year on-farm research sites in Oregon and the mid-West have shown that the randomized complete block (RCB) design is generally most appropriate for on-farm research sites with field scale equipment. The order of each treatment within a block is chosen randomly to ensure no bias in assigning treatments to plots (Figure 1). Blocks should be replicated at least four times (Figure 2), and positioned so that variations in the field (high and low areas, soil variations, borders, etc) will be encountered equally by each treatment plot within the block. When comparing two treatments, they must be repeated in side-by-side strips or plots, and need to be randomly ordered. Always having treatment A on the left and B on the right may favor one over the other.

Statistical analysis is necessary to show whether treatment differences are truly significant or can be explained by chance. When trial data are statistically analyzed, there are two main types of errors that can occur: declaring a difference when it does not exist (type I), which has a probability represented by alpha ( $\alpha$ ); declaring no difference when one actually occurs (type II), which is represented by beta ( $\beta$ ). Least significant difference (LSD) is often used to show the minimum difference needed between treatment means to be considered real and not due to chance or experimental error. For trials with more than two treatments, it is calculated after

doing the analysis of variance, sometimes abbreviated as AOV or ANOVA. For field experiments, the alpha level is frequently set to 0.05. This is synonymous with a probability value (p-value) of 95%, which means that 95% of the time this result can be expected to be correct.

Many computer programs, including Excel and AGSTATS02 (available online), are available to run simple statistics, and indeed an analysis can be done using a hand calculator, however, proper interpretation of the results can be challenging. Since most growers and CCAs have little time to conduct experiments, requesting help from University farm advisors or Extension specialists is advised. Nonetheless, even if on-farm research trials are not statistically analyzed, the results can still be useful if the trial layout was sound and properly implemented.

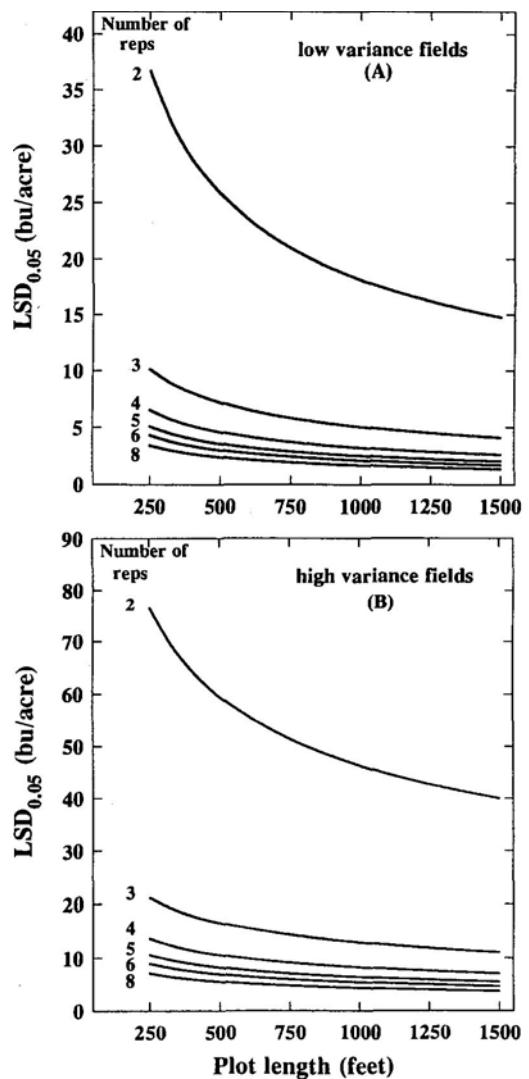
## References

- Anderson, D. 1996. On-farm research guidebook [online]. Available at [http://web.aces.uiuc.edu/vista/pdf\\_pubs/GUIDEBK.PDF](http://web.aces.uiuc.edu/vista/pdf_pubs/GUIDEBK.PDF) (verified 6 Jan. 2015).
- Mullen, R., E. Lentz, G. Lagarge, and K. Diedrick. 2008. Statistics and agriculture research. Ohio State Univ. Fact Sheet [on-line]. Available at [http://ohioline.osu.edu/anr-fact/pdf/statistics\\_ag\\_research.pdf](http://ohioline.osu.edu/anr-fact/pdf/statistics_ag_research.pdf).
- Murrell, T.S. 2013. On-farm trials and statistics. In Proceedings Western Nutrient Management Conference, Vol. 10. Reno, NV.
- Nielsen, RL (Bob). 2010. A practical guide to on-farm research. Purdue Univ Extension [online]. <http://www.kingcorn.org/news/timeless/OnFarmResearch.pdf>.
- Wuest, S.B., B.C. Miller, J.R. Alldredge, S.O. Guy, R.S. Karow, R.J. Veseth, and D.J. Wysocki. 1994. Plot length influences on experimental error on on-farm tests. Jour. Production Agric. Vol. 7. No. 2.

block 1			block 2		block 3			block 4			block 5			block 6	
A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
		SKIP					SKIP			SKIP			SKIP		

----→-----→-----→----- GRADIENT -----→-----→-----→

**Figure 1. Example plot layout for an on-farm test with two treatments and 6 replications. To achieve randomization, a few strips should be skipped during data collection and harvesting. The gradient could be any environmental or biological factor that may influence the results (e.g., soil moisture).**



**Figure 2.** Effect of replication number and plot length on wheat LSD values at  $\alpha = 0.05$  based on field uniformity trials in Idaho, Oregon, and Washington (Wuerst et al, 1994). LSD values decrease (precision increases) as the number of replications increases, but the gain in statistical power with more than 4 replications is minimal and may not be worth the extra effort.

## **Fostering Effective Teams**

Linda Marie Manton, Executive Director for UC Agriculture and Natural Resources Human  
Resources Staff Personnel  
2801 Second Street, Davis, CA 95618-7774  
Office: 530-750-1318; [lmmanton@ucanr.edu](mailto:lmmanton@ucanr.edu)

The seminar participant will gain knowledge in workplace interactive team building. The skills and activities learned are transferable to team leaders of a company, organization or local office.

The seminar will be interactive and participants will gain skills on innovative ways to enable individuals and groups to achieve personal and team goals.

Areas covered in the seminar include: Context of team building, commitment to the team, collaborative and coordinated teams, the consequences of positive team participation, and team dynamics and cultural change.



# American Society of Agronomy

## California Chapter

### Session II

## **Water Re-use: Use of nonconventional Waters for Irrigation**

**Session Chairs:**

Sharon Benes, CSU Fresno

Steve Grattan, UCCE

# Strategies for Irrigating with Saline Water

Blake Sanden, Irrigation & Agronomy Advisor, UC Cooperative Extension, Kern County  
1031 S. Mt. Vernon Ave., Bakersfield, CA 93307  
Phone (661) 868-6218, Fax (661) 868-6208, [blsanden@ucdavis.edu](mailto:blsanden@ucdavis.edu)

***“But I only have 24 inches of good canal water for 2009? Do I put on 28 inches more of this crumby well water to keep my almonds adequately irrigated?***

**Table 1. Guidelines for water quality for irrigation<sup>1</sup>**  
(Adapted from FAO Irrigation and Drainage Paper 29)

Potential Irrigation Problem	Units	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
<b>Salinity</b> ( <i>affects crop water availability</i> )				
EC <sub>w</sub>	dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS	mg/l	< 450	450 – 2000	> 2000
<b>Infiltration</b> ( <i>affects infiltration rate of water into the soil. Evaluate using EC<sub>w</sub> and SAR (sodium adsorption ratio) together</i> )				
<b>Ratio of SAR/EC<sub>w</sub></b>		< 5	5 – 10	> 10
<b>Specific Ion Toxicity</b> ( <i>sensitive trees/vines, surface irrigation limits</i> )				
Sodium (Na) <sup>2</sup>	meq/l	< 3	3 – 9	> 9
Chloride (Cl) <sup>2</sup>	meq/l	< 4	4 – 10	> 10
Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0

<sup>1</sup> Adapted from University of California Committee of Consultants 1974.

<sup>2</sup> For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride; use the values shown. Most annual crops are not sensitive; use the salinity tolerance only. With overhead sprinkler irrigation and low humidity (< 30 percent), sodium and chloride may be absorbed through the leaves of sensitive crops.

and usually cause a decline in yield. Most row crops, except for some sensitive veg crops, pistachios and pomegranates have no problem tolerating irrigation water at the “Severe” restriction limit in Table 1 where only the soil is wetted – no sprinkling on the green tissue.

## Strategy 2: Know how to calculate potential impacts on yield

Table 2 summarizes soil EC thresholds and the slope of the yield decline along with specific ion toxicities for various tree and vine crops in California:

$$\text{Relative yield (\%)} = 100 - \text{Decline Slope (Soil ECe - Threshold EC)}$$

Many crops, and especially different varieties and rootstocks do not have documented thresholds. Remember, Table 2 numbers are guidelines only. Figure 1 illustrates this relative yield calcula-

## Strategy 1: Understand normal salinity standards & toxicity

Table 1 provides general water quality guidelines for the average commercial crop. Water can only move into plant roots by osmosis, which means that the xylem sap in the plant root must have a much higher concentration of solutes than the soil water. As salinity in the rootzone increases the plant must work harder to generate the sugars and other solutes in the root tips in order to keep water moving into the plant to satisfy the transpiration demand. Plants have differing abilities to generate these root solutes to maintain crop growth and yield. In general, the plant is good to a certain threshold. As salinity increases above this threshold, crop water use begins to decrease. Often this is combined with toxic levels of specific ions like boron, sodium and chloride that accumulate in leaf tissue – even causing severe burn (necrosis)

**Table 2.** Summary of published tolerance limits for various permanent crops. S = sensitive, <5-10 meq/l. MT = moderately tolerant, <20-30 meq/l (Ayers and Westcott 1989, \*Sanden, unpublished)

Crop	EC <sub>thresh</sub> (dS/m)	Slope (%)	Sodium (meq/l)	Chloride (meq/l)	Boron (ppm)
Almond	1.5	19	S	S	0.5-1.0
Apricot	1.6	24	S	S	0.5-0.75
Avocado			S	5.0	0.5-0.75
Date palm	4.0	3.6	MT	MT	
Grape	1.5	9.6		10-30	0.5-1.0
Orange	1.7	16	S	10-15	0.5-0.75
Peach	1.7	21	S	10-25	0.5-0.75
Pistachio*	5.5	4.5	20-50	20-40	3-6
Plum	1.5	18	S	10-25	0.5-0.75
Walnut			S		0.5-1.0

on Panoche soils are irrigated with high calcium well water that is over the EC (total salt) threshold for almonds. In Westside Kern County some growers have pushed the limits, irrigating with wells that have the same EC as some of these Fresno orchards, but the sodium concentration is 10-15 times the calcium and the orchard performs poorly. Of course water penetration problems can result in increased rootzone salinity and tree stress due to lack of leaching even when the water salinity appears to be acceptable.

Figure 1 shows various permanent crop relative yield as a function of soil salinity (EC<sub>extract</sub>) in comparison to cotton. (The pistachio tolerance shown in this figure was calculated from a 1994-2002 trial by Sanden, et.al, 2004 and is different from the 5.5 dS/m threshold and 4.5% decline listed in Table 2 to illustrate the problem with these salt tolerance estimates. The reduced tolerance shown in Table 2 is more recent data resulting from a more extensive 10 year trial and similar to the 2014 yield decline measured in saline areas of 9 other Kern County fields. Symbols on lines are for legend identification and do not represent specific data points.) Almond examples are provided at the end of this paper.

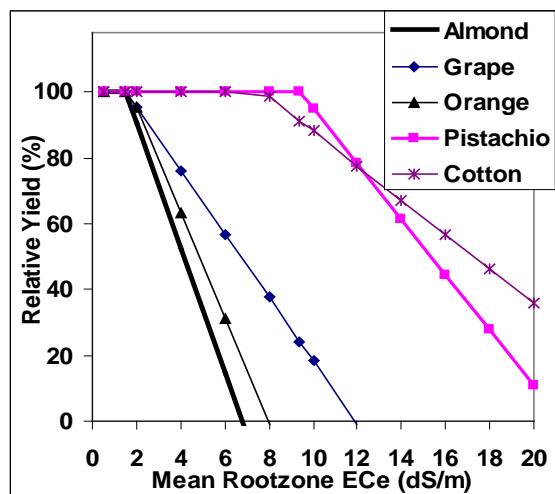


Fig. 1. Relative yield (RY) of various crops as a function of soil EC<sub>e</sub>. (Sanden, et.al., 2004)

probes that enable you to hand sample to a minimum depth of 3 foot and preferably to 6 feet is not an “option” – it’s a necessity! It is essential to sample different depths to insure that salts are moving down and out of the more sensitive upper part of the rootzone. If the salt burn on the crop appears severe, I will do a mid-season composite sample in a representative area for each different soil type in the field over three depths: 0-20, 20-40 and 40-60 inches. This gets you down to 5 feet with only 3 discreet samples (instead of 5 samples for every foot) but still gives enough resolution to establish the required leaching trend needed to avoid excessive salt accumu-

tion. The soil texture /mineralogy, drainage/aeration, irrigation system/scheduling and the ratio of certain salts to others along with different rootstock/scion combinations (especially with grapes and almonds) will shift these numbers up or down. Compare your soil and water numbers to your neighbor. A good number of highly productive Westside Fresno County almond orchards

### Strategy 3: Monitor in-season soil water content, collect & analyze soil and water samples

Bucket augers and various soil sampling

lation in the upper 40 inches. Alternatively, if I have been farming this field over several years and regularly collecting soil samples I will do the sampling at the end of the season as a means of quantifying rootzone salinity at the beginning of winter – which is the optimal time for reclamation and leaching in permanent crops especially. If you or your neighbors are losing flow on your wells then the water table is dropping and your water quality will likely change. At the minimum take a well water sample in July at peak demand time – better still is 3 times/year in April, July and October.

#### **Strategy 4: Understand distribution uniformity, irrigation efficiency and leaching fraction**

This is the biggie and most difficult. Some of the most trouble-free and uniform irrigation systems in California are designed with pressure-compensating (PC) drip emitters. A good quality PC emitter will maintain about the same flowrate whether the pressure is 15 to 50 psi inside the hose. These systems can achieve a distribution uniformity (DU) of 95%. This same level of DU can be achieved with a non-PC microsprinkler, but quality system design, field slope and precise pressure regulation are critical. To measure field DU you want to catch the flow from 60 to 100 emitters across the field that represents the potential low pressure to high pressure areas and the sort the equivalent inches/day or whatever units you prefer from low to high then divide the numbers into 4 ranked groups.

$$\text{DU} = 100\% * \frac{\text{Average Low Application Quarter}}{\text{Average for the Whole Field}}$$

Figure 2 illustrates the difference in applied water for a DU of 90% compared to a DU of 70% for a micro irrigation system designed to apply 1 inch/day. When I took my first irrigation classes 40 years ago a 70% DU was considered a “good” uniformity number for most of ag. But the reality of this number means that the “wet quarter” of the field gets twice as much water as the “dry” quarter. So if your irrigation schedule is trying to just match crop ET, say 0.25”/day and you irrigate every 4 days, the balance sheet says you are at **100% irrigation efficiency**. In reality, you end up with a **42% leaching fraction** ( $\text{LF} = 1 - \text{water applied/water consumed}$ ) in the “wet quarter”, a 16% LF in the medium wet quarter and 0% LF over the drier half of the field. So this half of the field is not only deficit irrigated but leaves virtually all the salt in the top couple feet of rootzone. Table 3 below gives the expected long-term rootzone ECe for different irri-

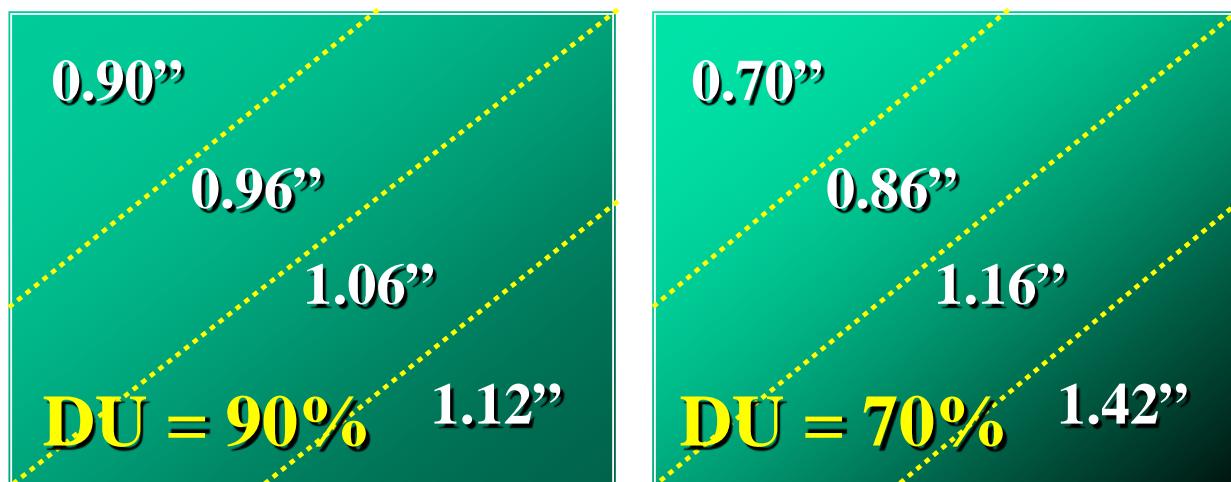


Fig. 2. Conceptual illustration of total applied water for the “wet (high) quarter” compared to the “dry (low) quarter” for a 1 inch/day microsystem design operating at a 90% and 70% DU.

gation water EC (ECirr) applied with different leaching fractions. As you can see from the table the rough rule of thumb for **rootzone salt accumulation (ECrz)** is:

**5% LF: ECrz ~ 3x ECirr**

**10% LF: ECrz ~ 2x ECirr**

**30% LF: ECrz ~ ECirr**

**Table 3. Average rootzone saturation extract EC (dS/m) after long-term irrigation with a given salinity of water with a Leaching Fraction of 5-30% (ignoring precipitation/dissolution reactions in the soil).**

Irrigation Water EC (dS/m)	Leaching Fraction (LF) above crop ET requirement				
	0.05	0.1	0.15	0.2	0.3
0.2	0.62	0.41	0.32	0.27	0.21
0.6	1.87	1.24	0.97	0.81	0.64
1.0	3.12	2.06	1.61	1.36	1.06
1.5	4.69	3.09	2.42	2.04	1.60
2.0	6.25	4.12	3.23	2.72	2.13
2.5	7.81	5.15	4.03	3.39	2.66
3.0	9.37	6.18	4.84	4.07	3.19
3.5	10.94	7.21	5.65	4.75	3.72
4.0	12.50	8.24	6.46	5.43	4.26
4.5	14.06	9.27	7.26	6.11	4.79
5.0	15.62	10.30	8.07	6.79	5.32
5.5	17.19	11.33	8.88	7.47	5.85

#### SOLVING FOR DESIRED LEACHING FRACTION DIRECTLY:

$$\text{LF} = 0.3086(\text{Desired ECe}/\text{ECirr})^{-1.66}$$

**How do I calculate how much salt is going into the profile to know if I'm headed for a problem?** Table 3 is to predict long-term conditions and it can be difficult to maintain a dedicated leaching fraction in the summer with most micro systems in the San Joaquin Valley. In practice, most fields are irrigated to "normal year" ET during the season and leaching is done during the winter with effective rainfall and grower applied water. "So I've adjusted all the pressures in my system and now have a DU of 95%, but I only have 4 feet of well water for my almonds and I'm starting with a rootzone EC of 1.4 dS/m at bloom. Am I headed for trouble?" There is about 4 million lbs of soil/ac-ft – 20 million lbs in a 5 ac-ft rootzone. Water with an EC of 1 dS/m (same value as mmho/cm) has a mass of total dissolved solutes (tds) of about 640 mg/L or part per million (ppm).

Water weighs 2.713 million lbs/ac-ft so  $2.713 \times 640 = 1,736$  lbs salt/ac-ft

4 ac-ft for the season = 6,944 lbs salt

6,944 lbs/20 million lbs/50% wetted volume of irrigation system

= 694 ppm salinity increase added to rooting / wetted area.

Now it gets tricky – the final actual concentration of salts that the roots see in the pore water will be dependent on the soil texture. But our salinity standards are listed by ECextract which is made by saturating the pores of the dried, sieved soil sample with distilled water then extracting the water from. This amount of water is divided by the mass of the soil sample to get a "saturation percentage" (SP). This value is low for sandy soils and high for fine textured soils. Divide the added ppm salt by SP and by 640 ppm/EC unit to estimate the increase in rootzone salinity.

**Loamy sand, SP 14%: Possible EC increase =  $694 / 0.16 / 640 = 6.8$  dS/m**

**Sandy clay loam, SP 34%: Possible EC increase =  $694 / 0.34 / 640 = 3.2$  dS/m**

Ouch! The same total salt load in the water can more than double the salt concentration seen by the roots in a coarse sandy soil compared to a fine-textured clay loam **if there is no leaching**. Of course the salt load is slowly accumulating over the season and in the loamy sand field you

have leaching fractions exceeding 20-30% in the top 3-4 feet of profile while this may be true for only the top 2 feet of the sandy clay loam with more than twice the water holding capacity. The reality, however, is that thousands of acres of Eastside San Joaquin Valley almonds had to use much more groundwater of marginal quality than in previous years during the 2013 drought year and experienced worse salt burn and defoliation than many Westside growers.

#### **Strategy 5: Calculating the required depth of leaching for reclamation (Kern almonds)**

The following soil analyses are from a block of mature almonds on Nemaguard rootstock. Yields have been low, the trees have exhibited poor shoot growth in the previous year and no district water is available. Calculating the relative yield, assuming that this analysis represents the average condition for the orchard during 2006:

$$\text{Relative yield (\%)} = 100 - 19*((3.9+4.2+3.9+4.2)/4 - 1.5) = 51.5\%$$

**Table 4. SW Kern: Bakersfield sandy loam, flood**

Depth	SP	pH	EC	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	SAR	Cl (meq/l)	B (ppm)	HCO3 (meq/l)	SO4 (meq/l)	Sum Cations	Sum Anions
0-1'	43	7.0	3.9	27.8	3.0	7.4	0.3	1.9	0.8	0.6	1.3	33.3	38.5	37.5
1-2'	45	7.5	4.2	24.3	4.0	13.9	0.2	3.7	2.4	0.5	1.1	32.1	42.4	38.9
2-3'	43	7.6	3.9	18.1	3.3	17.0	0.2	5.2	4.3	0.5	1.6	18.1	38.6	21.4
3-4'	43	7.5	4.2	23.6	4.4	14.1	0.1	3.8	5.7	0.4	1.2	30.0	42.2	30.4
Well		7.9	0.59	2.6	0.2	3.1	0.0	2.6	0.8	0.2	3.7	1.2	5.8	1.4

This example has some problems. The well water salinity is not that different from the California Aqueduct, but the rootzone salinity of this orchard is excessive for almonds. You will also notice that the Cl is much lower than the Na with the calcium (Ca) and sulfate (SO4) being very high. The two right hand columns show that the sum of the *Cations* (Ca, Mg, Na, K) and *Anions* (Cl, HCO3, SO4) for the 3 and 4 foot depth are out of balance. Actual Cl may be higher at these depths. Yields in this orchard are not off by 50% (maybe 30% compared to an adjacent hybrid rootstock block) because the high Ca/Na ratio reduces the impact of the salinity damage to the crop. This grower uses a lot of gypsum but has also irrigated with 8 hour sets every 7 to 10 days that may not allow enough infiltration time. Water penetration in his last irrigation only made it to 2.5 feet. He is going to longer set times and higher irrigation frequency.

**Reclamation:** Using an average rootzone EC of 4.05 dS/m over 4 feet, the depth of leaching required to reclaim this rootzone to an EC of 1.5 can be calculated with the following equation (Hoffman, 1996):

$$\text{Required Leaching Ratio (depth water/depth soil)} = K / (\text{Desired EC}/\text{Original EC})$$

(Use K factor of 0.15 for sprinkling, drip or repeated flooding. Use 0.3 for continuous ponding.)

$$\text{Required Leaching Ratio (depth water/depth soil)} = 0.15/(1.5/4.05) = 0.405$$

$$\text{Actual depth of leaching water needed} = 0.4055 * 4 \text{ feet} = 1.62 \text{ feet}$$

This means that sufficient water needs to applied to completely refill the lower profile and then an additional 1.62 feet of water needs to be pushed out below the 4 foot depth of the rootzone. This is virtually impossible to do in the middle of the season without causing problems with waterlogging and phytophthora and should be done during the winter.

Maintain long-term leaching fraction of 7 to 10%. Irrigate occasional 48 hour sets.

### **Strategy 6: Search out information on soil amendments and infiltration**

[http://cekern.ucanr.edu/Irrigation\\_Management/ANALYTICAL\\_CONVERSIONS\\_AND\\_LEACHING\\_CALCULATIONS/](http://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/)

[http://cekern.ucanr.edu/Irrigation\\_Management/MANAGING\\_SALINITY\\_SOIL\\_AND\\_WATER\\_AMENDMENTS/](http://cekern.ucanr.edu/Irrigation_Management/MANAGING_SALINITY_SOIL_AND_WATER_AMENDMENTS/)

[http://cekern.ucanr.edu/Irrigation\\_Management/SITE\\_EVALUATION\\_AND\\_SOIL\\_PHYSICAL\\_MODIFICATIONS/](http://cekern.ucanr.edu/Irrigation_Management/SITE_EVALUATION_AND_SOIL_PHYSICAL_MODIFICATIONS/)

[http://cekern.ucanr.edu/Irrigation\\_Management/IMPROVING\\_WATER\\_PENETRATION/](http://cekern.ucanr.edu/Irrigation_Management/IMPROVING_WATER_PENETRATION/)

### **References**

Ayers, R.S., D.W. Westcot. Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev. 1, Reprinted 1989, 1994 . <http://www.fao.org/DOCREP/003/T0234E/T0234E00.htm>

DWR. 1993. Crop Water Use – A Guide for Scheduling Irrigations in the Southern San Joaquin Valley. 1977-1991. Dept of Water Resources.

Hoffman, G.J. 1996. “Leaching fraction and root zone salinity control.” Agricultural Salinity Assessment and Management. ASCE. New York, N.Y. Manual No. 7:237-247

Jones, D.W., R.L. Snyder, S. Eching and H. Gomez-McPherson. 1999. *California Irrigation Management Information System (CIMIS) Reference Evapotranspiration*. Climate zone map, Dept. of Water Resources, Sacramento, CA.

Sanden, B.L., L. Ferguson, H.C. Reyes, and S.C. Grattan. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Proceedings of the IVth International Symposium on Irrigation of Horticultural Crops, Acta Horticulturae 664:583-589

## **Overview of Recycled Water Quality and Landscape Plants**

Nelda Matheny, Horticultural Consultant, HortScience, Inc.  
325 Ray St., Pleasanton, CA 94566  
Phone (925) 484 0211, [Nelda@hortscience.com](mailto:Nelda@hortscience.com)

Laurence R. Costello, Oracle Oak LLC  
146 Jordan Ave., San Francisco, CA. 94118  
Phone (415) 668-0105, larrycostello@me.com

David Kelley, Kelley and Associates Environmental Sciences, Inc.  
20 E. Baker Street, Winters, California 95694  
Phone (503) 795-6006, dbkelley@jps.net

Irrigating landscapes with recycled water (also called reclaimed water) is an important component of California's efforts to conserve water resources. By using recycled water to irrigate landscapes, potable water is conserved for human consumption.

The production, delivery and management of recycled water is not without its complexities; assuring users of its timely supply and quality are important economic and acceptance issues. Wu and others (2009) stated that a necessary safeguard during the design of an urban reclaimed water distribution system is that, "The recycled water agency must assure that the reclaimed water delivered to the customer meets the water quality standards for the intended uses."

Recycled water can contain salts and specific ions in concentrations that damage sensitive plants and degrade soil quality (Costello and others 2003, Harivandi 2000, Matheny and Clark 1998, Miyamoto 2008, Qian and Mecham 2005, Tanji and others 2009, Wu and others 2009). An important goal in landscape management is to ensure that recycled water is of sufficient quality to maintain healthy plants. To achieve healthy landscapes using recycled water, we address key factors to consider: responses of plants and soils, site evaluation, interpretive guidelines to assess water quality, and water quality categories based on species sensitivity, soil texture, and soil drainage.

### **Evaluating Response of Landscapes to Recycled Water**

The response of an existing landscape to irrigation with recycled water depends on the degree to which soil will become affected and on the tolerance of plant materials to salts and specific ions in the water. Evaluation of sites for irrigation with recycled water must consider water, plant, and site factors as well as irrigation management. There are several factors to investigate and consider when evaluating site suitability for irrigation with a specific recycled water.

**Water quality** –The salt concentration of recycled waters varies depending on the amount of salt in the original water source, what components are added during municipal, industrial and/or agricultural use, and what treatments are applied to reclaiming the water for reuse. The primary constituents of concern are salinity, sodium, chloride, boron, and bicarbonate.

**Soil characteristics** – As a rooting environment, soil holds water and nutrient elements for root uptake. Some constituents in recycled water, such as sodium, can have negative effects on soil and plants as they concentrate over time. There are four soil characteristics of key importance.

**Soil salinity and pH** – Well-buffered soils with low concentrations of salts can accommodate more salts from the water as salt accumulates in the root zone and causes plant damage. The threshold for salt damage will be reached sooner if starting with saline soil than if starting with a soil low in salts.

**Soil texture** – In general, clay (fine-textured) soils are slower to drain and more vulnerable to degradation by excess sodium than sandy (coarse-textured) soils.

**Soil profile** – Vertical gradation, stratification, compaction, and layering with soil depth affects water percolation, salt accumulation, and plant root distribution and rooting patterns.

**Soil drainage** - Soils with poor drainage characteristics accumulate salts and cannot be easily leached. The poorer the drainage, the better quality water required for irrigation to avoid plant damage.

**Salt-sensitivity of plants in the landscape.** Plants vary widely in their tolerance or sensitivity to salts. Although some species have been evaluated for salt sensitivity, many have not. For those that have been evaluated, assessments are largely based on field observations across a limited range of landscapes.. Current assessment of species tolerance are based on field observations across a limited range of landscapes.

**Irrigation method and scheduling.** Because of absorption of salt by leaves, many plants can be injured at lower concentrations of sodium and chloride when water is applied to the foliage as opposed to the soil. Sensitive plantings irrigated by sprinklers require water lower in sodium and chloride to avoid injury. Drip irrigation, where plants are watered frequently, can be less damaging to plants. However, drip emitters can become clogged by calcium carbonate precipitates and suspended solids that may be present in recycled water.

When using recycled water, irrigation frequency should be adjusted to maintain moist soil and water applications must be increased to leach accumulated salts below the root zone.

A thorough site evaluation that assesses soil, plant, and water conditions should be performed prior to introducing recycled water to a landscape. The results of these assessments are key to evaluating the impacts a given recycled water supply will have on the landscape, and will inform future landscape management activities.

### **Do Urban Landscapes and Agricultural Crops Respond Similarly to Recycled Water?**

The physiological responses of landscape and agricultural species to excess salt are similar: When salt concentration becomes too high, ions can accumulate in plant tissues, slowing growth and eventually killing tissues. The complexity and variation within and among landscape sites and plant species present, however, can make the actual response of the plant landscape system difficult to predict. Although agricultural cropping systems and landscape systems have some characteristics in common, there are significant dissimilarities too. Urban landscapes are:

- Composed of many species from different environments around the world and with wide ranges of salt tolerance;
- Grown for appearance and environmental and ecological functions rather than a product (yield);
- Primarily made up of long-lived plants that are expected to stay in place for decades;
- Often planted in disturbed, degraded, remediated, and/or artificial soils that are highly layered, compacted, and poorly drained;
- Often surrounded by pavements and buildings that cover the soil with materials that are impermeable to water.

### **Water Quality Guidelines for Urban Landscapes**

FAO water quality guidelines (Ayers and Westcot 1985) were developed for agricultural uses, but they are commonly applied to landscapes as well. The authors have observed a wide range in landscape plant and soil response to irrigation with recycled water. Because of the wide range in site and soil conditions, plant species, microclimates, irrigation and other maintenance practices, it can be difficult to compare different sites and draw conclusions about landscape response. Limited research has been done to identify salinity thresholds for landscape plants.

One factor that can be studied among landscapes is recycled water quality. In the San Francisco Bay Area (SFBA) there are currently 17 agencies providing recycled water for landscape irrigation to 31 communities (Matheny and others 2015). The range in concentrations of salts and ions in the SFBA recycled waters varies substantially (Table 2).

**Table 1: Range in recycled water quality data reported by nine agencies in the San Francisco Bay Area.** Data primarily from 2011. (Matheny and others 2015)

Parameter	Range in concentration	
	Annual average	Annual maximum
pH	6.8-7.8	7.1-8.8
EC <sub>w</sub> (dS/m)	0.44-0.95	0.68-1.00
Sodium (mg/l)	75-211	117-220
Chloride (mg/l)	64-315	182-328
Bicarbonate (mg/l)	132-292	172-390
SAR	3.6-5.6	4.0-6.0
Boron (mg/l)	0.3-1.0	0.4-1.8

We recommend evaluating water quality of irrigation water to be applied to landscapes based on 1) the tolerance of the plant materials to salts and specific ions in the specific water source, and 2) the degree to which soil is expected to become degraded due to salt accumulation. We define four categories of water quality as (see Table 2):

- Category 1: Good water quality with no restrictions regarding site use.
- Category 2: Moderate water quality that is appropriate for all landscapes except those with salt and/or boron sensitive plants and poorly drained soils that cannot be leached.
- Category 3: Fair water quality that can be used where plants have at least moderate salt

and/or boron tolerance and soils are at least moderately well drained; landscapes on poorly drained sites must be comprised of plants with good salt and/or boron tolerance.

Category 4: Poor water quality that is appropriate only for sites having salt and/or boron tolerant plants and moderate to good drainage.

**Table 2: Interpretive guidelines for recycled water quality for landscape irrigation in the San Francisco Bay Area.**

Parameter	Category 1	Category 2	Category 3	Category 4
TDS, mg/l	<640	640-830	830-1,600	>1,600
EC <sub>w</sub> , dS/m	<1.0	1.0-1.3	1.3-2.5	>2.5
Specific ion toxicity				
Boron (mg/l)	<0.5	0.5-1.0	1.0-2.0	>2.0
Chloride (mg/l)	<120	120-200	200-350	>350
Sodium (mg/l)	<70	70-150	150-200	>200
Sodium adsorption ratio (SAR)				
If SAR is:	and EC <sub>w</sub> is:			
0-3	>0.7	0.7-0.5	0.4-0.2	<0.2
3-6	>1.2	1.2-0.8	0.7-0.3	<0.3
6-12	>1.9	1.9-1.2	1.1-0.5	<0.5
12-20	>2.9	2.9-2.1	2.0-1.3	<1.3
Bicarbonate (mg/l)	<90	90-200	200-500	>500
Residual chlorine (mg/l)	<1.0	1-2.5	2.5-5.0	>5.0

Sources: Ayers and Westcott 1985, Barnes, Oki and Evans 2007, Cayanan and others 2008, Devitt and others 2005, Morris and Devitt 2002; Myamoto and others 2001, 2004; Oster 2009, Tanji and others 2007.

According to Grieve and others (2007), “It is not adequate only to identify maximum TDS [total dissolved solids] or EC<sub>w</sub> [electrical conductivity of the water] for use in landscapes containing salt-sensitive species; limits for sodium, chloride, boron, and RSC [residual sodium carbonate] must also be established.” Therefore, ranges for each of these components in each of the four water quality categories are identified in Table 2. These ranges were derived from a review of the scientific literature, as well as our experience over the last 20 years evaluating and analyzing soil, water, and tissue samples from landscape irrigated with recycled water.

The poorer the water quality, the less suitable it is for use at sites with heavy soils and salt-sensitive plants (Table 3). For example, prolonged irrigation with Category 2, 3, or 4 water will damage salt sensitive species such as coast redwood (Oster 2009). Soils with complex structures (including compacted layers) and stratified horizons will respond differently to water application and throughflow, so permeability of the root zone is another factor affecting use and efficacy of recycled water for landscape irrigation.

**Table 3: Water quality categories appropriate to sustain healthy landscapes as affected by soil texture, drainage, and plant sensitivity to salts.** (Matheny and others 2015)

Soil Texture/ Drainage	Plant Tolerance to Salts		
	Low (Sensitive)	Moderate	High (Tolerant)
Sandy / well drained	Category 1 or 2	Category 1, 2, 3	Category 1, 2, 3, 4
Loam / moderately well drained	Category 1 or 2	Category 1, 2, 3	Category 1, 2, 3, 4
Clay / somewhat poorly or poor drained	Category 1	Category 1 or 2	Category 1, 2, 3

When assessing water quality it may be found that more than one category is represented. For instance, the salinity concentration may place the water in Category 2; the SAR, in Category 1. In this case, the highest (Category 2) would be used. Some parameters are more important than others, however. The parameters in Table 2 are listed in approximate order of importance: salinity and specific ions are most important, followed by SAR, and then by bicarbonate. Unlike salinity and specific ions (sodium, chloride, boron), SAR can be improved by addition of calcium. If the water salinity were in Category 2 and the bicarbonate in Category 3, we suggest classifying the water in Category 2.

For new landscapes, species can be selected that will perform well when irrigated with the specific category of recycled water (Table 4). Site modifications may also be implemented to improve soil drainage and aid leaching treatments.

For established landscapes, a wide variety of plants with a large variation in salt sensitivity may be present. In many cases, these plants occur in soils that are characterized by poor porosity and permeability and, therefore, are difficult to leach.

In landscapes comprised of a variety of species, Wu and Guo (2006) indicated that, "...salt concentrations in recycled water must be acceptable for the most sensitive landscape plant species." For example, coast redwood (*Sequoia sempervirens*) is a key landscape tree, and one that is sensitive to salt (Wu and Guo, 2006; Barnes and others, 2007). For landscapes to remain healthy and functioning, salt concentrations in recycled water quality must not exceed the low salt threshold of redwoods, which is approximately 1 dS/m (Oster 2009). In contrast, Italian stone pine (*Pinus pinea*) is highly salt tolerant (Miyamoto and others 2004). When both coast redwood and Italian stone pine are present in the landscape, recycled water quality must meet the low salt tolerance of coast redwood. Although Italian stone pine will tolerate Category 4 water, when growing with coast redwood, Category 1 water would be required to maintain landscape health and function.

**Table 4. Examples of plants suitable for each of the four categories of water quality with favorable soil conditions.** Note: The site soil in each case is assumed to be favorable: deep sandy loam with low potential for salt or specific ion accumulation when managed properly. For sites with restrictive soils, refer to Table 3 for adjustments to salt tolerance plant selections. This list does not consider boron tolerance (boron concentration in water is assumed to be less than 0.5 ppm). (Matheny and others 2015)

Plant type	Category 1	Category 2	Category 3	Category 4
trees	coast redwood ( <i>Sequoia sempervirens</i> )	London plane ( <i>Platanus × hispanica</i> )	ornamental pear ( <i>Pyrus calleryana</i> cvs.)	goldenrain tree ( <i>Koelreutaria paniculata</i> )
	Japanese maple ( <i>Acer palmatum</i> )	sawleaf zelkova ( <i>Zelkova serrata</i> )	autumn purple ash ( <i>Fraxinus americana</i> 'Autumn Purple')	Nichol's willow-leaved peppermint ( <i>Eucalyptus nicholii</i> )
	Michelia ( <i>Michelia doltsopa</i> )	southern magnolia ( <i>Magnolia grandiflora</i> )	Brisbane box ( <i>Lophostemon confertus</i> )	Canary Island pine ( <i>Pinus canariensis</i> )
shrubs	heavenly bamboo ( <i>Nandina domestica</i> )	Japanese barberry ( <i>Berberis thunbergii</i> )	blue mist ( <i>Caryopteris × clandonensis</i> )	<i>Ceanothus</i> spp.
	Japanese aucuba ( <i>Aucuba japonica</i> )	abelia ( <i>Abelia grandiflora</i> )	pink breath of Heaven ( <i>Coleonema pulchrum</i> )	purple rockrose ( <i>Cistus × purpureus</i> )
	princess flower ( <i>Tibouchina urvilleana</i> )	gardenia ( <i>Gardenia augusta</i> )	Oregon grape ( <i>Mahonia aquifolium</i> )	evergreen euonymus ( <i>Euonymus japonica</i> )
groundcovers	creeping mahonia ( <i>Mahonia repens</i> )	<i>Cotoneaster microphyllus</i>	gazania ( <i>Gazania</i> hybrids)	<i>Acacia redolens</i>
	<i>Pachysandra terminalis</i>	dwarf periwinkle ( <i>Vinca minor</i> )	<i>Juniperus horizontalis</i>	<i>Ceanothus gloriosus</i>
	baby tears ( <i>Soleirolia solerolii</i> )	creeping St. Johnswort ( <i>Hypericum calycinum</i> )	star jasmine ( <i>Trachelospermum jasminoides</i> )	<i>Rosmarinus officinalis</i> 'Prostratus'

## Summary

The response of landscape plants and soils to irrigation with recycled water depends on the degree to which soil will become affected over time and the tolerance of plant species to salts and specific ions. Evaluation of sites for irrigation with recycled water should include an assessment of soil conditions, plant species salt tolerance, water quality, and irrigation management. To address the water quality component, we defined four categories of water quality that encompass the range of salt and specific ion concentrations present in 17 San Francisco Bay Area (SFBA) recycled waters that are available for landscape irrigation. These water quality categories can be used both to select plant species suitable for a particular landscape, and to predict how an existing landscape is likely to respond to irrigation with a specific recycled water.

## Literature Cited

- Ayers, R. S., and D. W. Westcot. 1985. *Water quality for agriculture*. FAO Irrigation and Drainage. Rome: FAO. <http://www.fao.org/docrep/003/T0234E/T0234E00.htm>.
- Barnes, C. S., L. R. Oki, and R. Y., Evans. 2007. Determining the tolerance of coast redwood, *Sequoia sempervirens* 'Aptos Blue' to sodium and chloride. University of California Davis, August.
- Cayanan, D. F., Y. Zheng, P. Zheng, T. Graham and M. Dixon. 2008. Sensitivity of fine container-grown nursery species to chlorine in overhead irrigation water. *HortScience* 43(6): 1882-1887.
- Costello, L. R., E. Perry, N. Matheny, J.M. Henry and P. Geisel. 2003. *Abiotic disorders of landscape plants: A diagnostic guide*. Pub. 3420. Univ. of CA Ag and Natural Resources, Oakland CA.
- Devitt, D. A., R. L. Morris, and L. K. Fenstermaker. 2005. Foliar damage, spectral reflectance, and tissue ion concentrations of trees sprinkle irrigated with waters of similar salinity but different chemical composition. *HortScience* 40, no. 3: 819-826.
- Grieve, C.M., S. Wu, S. Grattan, and A. Harvandi. 2007. Tolerance of plants to salinity and to specific ions. In: Salt Management Guide for Landscape Irrigation with Recycled Water in Coastal Southern California. Chapter 5:1-60.
- Harivandi, M. A. 2000. Irrigating turfgrass and landscape plants with municipal recycled water. In *ISHS Acta Horticulturae* 537, 537:697-703. ISHS.
- Matheny, N. and J. Clark. 1998. Managing landscapes using recycled water. In: *The Landscape Below Ground II*. D. Neely and G. Watson, ed. International Society of Arboriculture. Champaign IL.
- Matheny, N, L. R. Costello, C. Randisi. 2015. *Designing and managing landscapes irrigated with recycled water in the San Francisco Bay Area*. WaterReuse. Washington DC. *In press*.
- Miyamoto, S., S. Khurram, I. Martinez, D. Ornelas, and D. Tierre. 2008. *Establishing the guidelines for landscape uses of reclaimed or saline water*. El Paso, TX: Texas AgriLife Research Center at El Paso, Texas Ag Exp Station, Texas A&M University. <http://elpaso.tamu.edu/research/factsheet/Miyamoto%20Establishing%20Guidelines%209-9-08.pdf>.
- Miyamoto, S., I. Martinez, M. Padilla, A. Portillo, and D. Ornelas. 2004. *Photo guide: landscape plant response to salinity*. El Paso, TX: Texas A&M Univ. Ag. Res. Ctr. <http://elpaso.tamu.edu/research/Docs/Photo%20Guide%20Landscape%20Plant%202004.pdf>.
- Miyamoto, S., John White, Raymond Bader, and D. Ornelas. 2001. *El Paso guidelines for landscape uses of reclaimed water with elevated salinity*. El Paso, TX: Texas A&M Univ. Ag. Res. Ctr.
- Morris, R. L., and D. A. Devitt. 2002. *Sampling and interpretation of landscape irrigation water*. Fact Sheet. University of Nevada, Reno, Cooperative Extension.

- Oster, J. D. 2009. Irrigation with recycled water in Santa Clara County: Limitations and potentials. In: Solutions Project Report, Santa Clara Valley Water District. Pp. 1-31.
- Qian, Y. L., and M. A. Harivandi. 2007. Salinity issues associated with recycled wastewater irrigation of turfgrass landscapes. In *Handbook of Turfgrass Management and Physiology*, ed. Mohammed Pessarakli. Boca Raton, FL: CRC Press.
- Qian, Y. L., and B. Mecham. 2005. Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways. *Agronomy Journal* 97: 717-721.  
doi:10.2134/agronj2004.0140.
- Tanji, K., S. Grattan, C. Grieve, M. A. Harivandi, L. Rollins, D. A. Shaw, B. Sheikh, and L. Wu. 2009. *Salt management guide for landscape irrigation with recycled water in coastal Southern California: A comprehensive literature review*. WaterReuse Foundation. [www.salinitymanagement.org](http://www.salinitymanagement.org).
- Wu, L., W. Chen, C. French, and A. Chang. 2009. *Safe application of reclaimed water reuse in the Southwestern United States*. Publication. Univ. of Calif., DANR. <http://anrcatalog.ucdavis.edu/pdf/8357.pdf>.
- Wu, L. and X. Guo. 2006. Response of two coast redwood (*Sequoia sempervirens* Endl.) varieties to moderate levels of salt and boron spray measured by stress symptoms: Implications for landscape irrigation using recycled water. *Env. and Exp. Botany* 58: 130-139.

## **Use of reclaimed municipal water for irrigation of vegetables: A grower's perspective**

Dale Huss, Ocean Mist Farms  
10855 Ocean Mist Pkwy, Castroville, CA 95012  
(831) 633-2144



# American Society of Agronomy

## California Chapter

### Session III

## Pest Management

### Session Chairs:

Anil Shrestha, CSU Fresno  
Mark Sisterson, USDA-ARS

## **Effects of drought conditions on weed control performance and herbicide fate**

Brad Hanson, Cooperative Extension Weed Specialist,  
Plant Sciences Dept. One Shields Ave, Davis, CA 95616  
Phone (530) 752-8115, [bhanson@ucdavis.edu](mailto:bhanson@ucdavis.edu)

Environmental conditions before, after, and during herbicide applications can have a dramatic impact on the performance of the herbicide and on the environmental fate of the product. The environmental condition that is most on people's minds the past couple seasons, of course, is drought. While specific weed management situations will be affected differently, or not at all, by drought, it's useful to think about how dry conditions can impact weeds and herbicides in and on the plant as well as in the soil.

**Weed pressure:** First, the good news about drought and weeds. Under drought conditions, we typically have fewer weeds. Weeds often have inherent or enforced dormancy mechanisms that protect seed from germinating into inhospitable environments; so overall weed germination typically is reduced under dry conditions. This is especially true for small-seeded weeds because they usually germinate on or near the soil surface; however, deep-rooted perennial weeds or larger-seeded weeds that can emerge from deeper in the soil are less affected. Second, under dry conditions or periodically dry conditions, fewer of the seeds that do germinate are able to successfully establish which further reduces weed pressure under dry conditions. Now the bad news: those weeds that do establish because of timely germination relative to rain or irrigation or those that are in low spots that hold water longer may actually be more competitive because they have less competition with other weeds for resources (weeds compete with each other too).

Dry conditions can also affect the proportion of the various weed species present in a field – some weeds do better than others under dry conditions. For example, we often see more drought weeds like field bindweed (deeply rooted perennial), prostrate knotweed, and puncturevine under drought conditions because the water-loving plants like common purslane, nutsedges, and spurge don't do as well under moisture stressed conditions. This effect is much more noticeable with the winter-germinating weeds because our irrigation practices in cropped fields overcome this stress for summer-germinating weeds.

**Preemergence herbicides:** The performance of preemergence (aka PRE or residual) herbicides can be affected in several ways by drought conditions. First, to be effective, these herbicides must be incorporated into the soil, in many permanent crops and non-crop situations, we count on winter rains to incorporate or "activate" the herbicide. Lack of incorporation or delayed incorporation can lead to poor performance with many PRE herbicides because most of them have activity on the germinating seed or the very small seedling. In these instances, weeds that germinate below the herbicide layer at the soil surface may be able to grow roots and push shoots through the herbicide zone before it can be washed into the layer of soil where germination occurs. In the past few years with little winter rain, we've seen erratic performance with some PRE herbicides in orchards and vineyards – growers who happened to time PRE applications ahead of a rain often had very good performance while others who missed the rain did not get adequate incorporation for several weeks and had less than stellar performance. A second way that lack of incorporation can affect PRE herbicide performance is through "photodegradation". This refers to the chemical degradation of some herbicides after long exposure to sunlight on the soil surface. Fortunately, most of the modern PRE herbicide chemistries and formulations are

not very prone to this; however, long periods on the soil surface will never increase PRE herbicide performance either.

On the other hand, in some cases dry conditions can extend herbicide life in the soil. The primary mechanism for the degradation of most herbicides in the soil environment is microbial activity. Conditions like drought and excess heat or cold that are not good for microbial life often lead to slower herbicide degradation while conditions such as warm, moist soils can increase microbial activity and lead to faster degradation. As an illustration of this, think about where PRE herbicide performance first breaks in crop and non-crop situations. Usually herbicides fail first under the drippers in a vineyard, nearly leaky valves in a field or lawn, and in low areas where water stands longer because the herbicide degrades more quickly in these areas relative to the dryer areas – drought presents the same issue on a larger scale. Conversely, dry areas such as those between drip emitters in a vineyard, the tops of berms in furrow-irrigated orchards, or non-irrigated industrial sites may have much longer herbicide persistence.

If possible, timing applications ahead of even a small rain event will help reduce these problems. Second, if solidset sprinkler or microspray irrigations can be used, even a very short irrigation set will greatly improve herbicide efficacy. Finally, in drip-irrigated orchards or vineyards, some growers delay PRE applications until late winter trying to time the next rain event, some apply the PRE materials normally and plan on a followup POST application to pick up any weeds that emerge before the PRE herbicides are incorporated, and some forgo using PRE programs altogether in really dry years.

Slowed degradation of PRE herbicides caused by drought conditions can have both positive and negative results for weed management. In 2013, for example, we saw situations where weed control duration was actually much better than expected from herbicides generally considered to be “short residual” materials. If incorporated by an early rain or irrigation event but then surface soils remained relatively dry for much of the winter, materials like Goal and Matrix had much longer effective weed control in orchards than typically expected in a wetter winter season and long-lasting material lasted even longer. While that scenario presents a bit of a cloud-with-a-silver-lining for perennial crops, excess persistence due to drought can be a big problem in annual crops with complex rotations. Abnormally long carryover of PRE herbicides can sometimes lead to crop injury in a rotational crop because rate recommendations and rotational crop restrictions based on “normal” degradation rates may not provide a high enough margin of safety in really dry conditions. The worst case for this in our systems probably are those fields that were prepared, sprayed, and planted in spring but had the crop terminated due to irrigation cutbacks – full rate herbicides, followed by a non-irrigated, dry summer conditions could lead to carryover problems in some areas and should be considered in the coming season. For these growers, selection of appropriate rotational crops can minimize carryover issues and deeper tillage can be used to dilute the herbicides; if in doubt, consider conducting a soil bioassay with the planned rotational crop seed to verify an acceptable level of crop safety.

**Postemergence herbicides:** The efficacy of postemergence (POST) herbicides also can be greatly impacted by drought conditions. First, although it seems a little counterintuitive, stressed weeds are harder to kill than unstressed plants. It’s always easier to kill weeds with POST herbicides when they are healthy, happy, and growing quickly because all biosynthetic processes (photosynthesis, synthesis of amino acids, proteins, and other cellular components, and meristematic growth) are all proceeding at full speed. When we disrupt one or more of those processes with a POST herbicide, the negative impacts on plant growth are usually faster and

more complete. Conversely, a plant that is growing very slowly, or not at all, due to drought, cold, heat, etc will have all those same physiological processes occurring at a very slow rate and symptom development may be very slow and possibly incomplete if there is sufficient time for the herbicide to be metabolized or if it does not move to other parts of the plant.

Drought stress can reduce efficacy of POST herbicides due to physical changes to the plant architecture, leaf surfaces, and spray droplet behavior. When plants are subjected to sufficient moisture stress, leaves can droop which can change the angle at which spray droplets are intercepted. This can lead to a greater proportion droplets bouncing off the leaf or running off after they are deposited on the surface. This can be mitigated to some degree by timing POST herbicide applications within a few days after an irrigation event so that plants are fully hydrated and by selecting appropriate adjuvants to reduce droplet surface tension.

Second, plants grown under hot, dry conditions typically produce a much thicker cuticle with a higher proportion of waxy constituents. The plant cuticle functions to keep water inside the plant from being lost to evaporation; however, it also functions as a barrier to the spray droplets applied to the leaf surfaces. This is usually mitigated with spray adjuvant selection; often times more non-polar (wax-loving) adjuvants such as COC or MSO can be used to solubilize the surface waxes and increase absorption. Additionally, higher application rates are often used to compensate for the reduced absorption efficiency. Morning applications rather than afternoon or evening applications may also help overcome this problem to some degree as the plant is usually as hydrated as it can be at that time and will have a slightly more open cuticle due to cracks and channels that may close as the plant dries later in the day.

Finally, dry conditions can greatly impact the spray droplet performance itself. Droplets are subject to evaporation between the time they leave the spray nozzle and being absorbed by the leaf surface – this is much more dramatic under hot, low humidity conditions. Drying of the spray droplet in the air can increase the chances for drift as larger droplets become smaller. More importantly, the droplets may dry very quickly once they are on the leaf surface leaving insufficient moisture to facilitate transfer of the herbicide (which is usually a crystalline form) from the droplet into the plant. Ways to overcome this problem include spraying in the morning when humidity is higher and temperature is lower; add higher rates or use a high oil surfactant to slow droplet evaporation, and avoiding silicone surfactants because they reduce droplet surface tension to increase spreading which can increase evaporative losses on the leaf surface.

Like most aspects of crop production, weed management operations are affected by moisture conditions. Weed emergence and growth, herbicide performance and longevity, and weed/herbicide interactions all can be affected by California's seasonal moisture availability as well as the dramatic drought conditions currently impacting the state. Understanding how drought can affect weed management can lead to informed decisions on technology and practices to minimize herbicide performance problems.

# Drought-mediated effects on vector movement and pathogen spread: Insights to epidemiology of *Xylellafastidiosa*-elicited diseases

Rodrigo Krugner

United States Department of Agriculture, Agricultural Research Service, San Joaquin Valley Agricultural Sciences Center, 9611 S Riverbend Ave, Parlier, California, 93648. E-mail: [Rodrigo.Krugner@ars.usda.gov](mailto:Rodrigo.Krugner@ars.usda.gov), Phone: 559.596.2887.

Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

## SUMMARY

The glassy-winged sharpshooter (GWSS), *Homalodiscaviridis*, is a xylem fluid-ingesting leafhopper that transmits *Xylellafastidiosa*, a plant-infecting bacterium that causes several plant diseases in the Americas, including Pierce's disease of grapevines. Two studies were conducted to evaluate the effects of plant water stress on GWSS population density, movement, and feeding behaviors. The first study investigated the effects of deficit irrigated citrus trees on the spatiotemporal distribution and net dispersal rates of GWSS within a citrus orchard, whereas the second study determined the influence of plant water stress on GWSS stylet probing behaviors associated with acquisition and inoculation of *X. fastidiosa*. Sex-specific net dispersal rates showed that GWSS males and females moved consistently and contributed equally to the level of population change within the experimental orchard. Trees under severe water stress were the least preferred by GWSS and yet, about 80% of the population in severely water-stressed plots were inflow individuals. In laboratory conditions, long and frequent feeding events associated with host plant selection and acquisition and inoculation of *X. fastidiosa* were observed only in fully irrigated plants (i.e., > -10 Bars), which suggests that even low levels of plant water stress may reduce the spread of *X. fastidiosa*. Movement towards less suitable plants indicates that there is a random component to GWSS movement, which may result from the inability of GWSS to use plant visual and/or olfactory cues to make well-informed long-range decisions. Therefore, GWSS host selection behavior appears to be controlled by mechanosensory and/or chemosensory cues received after probing a host plant. Results provided insights to disease epidemiology and support that application of regulated deficit irrigation has the potential to reduce the incidence of diseases caused by *X. fastidiosa* by reducing the number of vectors and by decreasing pathogen transmission efficiency.

## INTRODUCTION

Irrigation is the most significant input in agrosystems in arid and semi-arid regions worldwide. In California, future climate projection models predict water shortages due to reduced water reservoir carryover storage, reduced water availability to farmland in the Western San Joaquin Valley, and increased groundwater pumping (DWR, 2009). Water stress mediates plant interaction with both herbivorous arthropods (Koricheva et al. 1998) and plant pathogens (Colhoun 1973). For instance, water stress enhances symptom severity and disease progression

in grapevines (*Vitis vinifera* L.) infected by the xylem-limited pathogenic bacterium *Xylella fastidiosa* Wells et al. (Thorne et al. 2006). The glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae), is a xylem fluid-ingesting leafhopper that transmits *X. fastidiosa* to grapevines (Purcell and Saunders 1999), wherein it causes Pierce's disease (Davis et al. 1978). In California, GWSS populations are strongly associated with commercial citrus plantings and ornamental plants in urban landscapes. Infested citrus orchards can act as a source of vectors to adjacent vineyards as a result of the movement of GWSS between these two crops, which affects Pierce's disease incidence (Perring et al. 2001).

In this manuscript, results from two studies conducted separately are presented to illustrate the effects of plant water stress on GWSS feeding behaviors, population density, and movement. In the first study (Krugner et al. 2009, 2012), the objective was to evaluate the effects of regulated deficit irrigation in a citrus orchard on GWSS population density and movement. In the second study (Krugner and Backus, 2014), the objective was to investigate the effects of deficit irrigation on GWSS feeding behaviors associated with acquisition and inoculation of *X. fastidiosa*.

## MATERIALS AND METHODS

**GWSS population density and movement in a water-stressed citrus orchard.** A two year study was conducted on a citrus orchard [*Citrus sinensis* cv. 'Valencia']. Irrigation treatments included: 1) trees irrigated at 100% of the crop evapotranspiration rate ( $ET_c$ ), 2) a continuous deficit-irrigated treatment maintained at 80%  $ET_c$ , and 3) a continuous deficit-irrigated treatment maintained at 60% of  $ET_c$  throughout the two years of the experiment. Plant water stress was characterized by measurements of stem water potential using a pressure chamber. All oranges were harvested and taken to a local commercial packing house where oranges were mechanically counted, sized, and color graded to assess fruit quality and yield. Populations of GWSS within experimental plots were monitored by visual inspection and beat net sampling. Sticky traps were used to monitor insect activity. Three different proteins were used to mark GWSS in the 60, 80, and 100%  $ET_c$  treatments. Marking materials were diluted in water and applied to trees using a tractor PTO-driven, airblast sprayer. ELISA was performed on field-captured GWSS to determine the area of origin of individuals. Sex-specific net dispersal rate (NDR) of GWSS for each irrigation treatment was calculated as the ratio of the difference between the number of inflow and outflow individuals to the number of residents, as follows:

$$NDR = \frac{i-o}{r}[1]$$

where the number of residents ( $r$ ) was the number of insects caught in the reference irrigation treatment that were ELISA-positive only for the protein marker applied to the reference irrigation treatment. The number of inflow individuals ( $i$ ) was the number of insects caught in the reference irrigation treatment that were ELISA-positive for one or both of the protein markers applied to the other irrigation treatments. Finally, the number of outflow individuals ( $o$ ) was the number of insects caught outside the reference irrigation treatment that were ELISA-positive for the protein marker applied to the reference irrigation treatment. Positive values for NDR indicate that more GWSS entered an irrigation treatment than left, whereas negative values for NDR indicate that more GWSS left an irrigation treatment than entered. The impact of such movement on population composition was measured relative to the size of the resident population.

**GWSS feeding behaviors on water-stressed citrus and almond plants.** Xylem tension ranges in the two plant species were established by controlling irrigation of test plants. Insect feeding behaviors were monitored using Electrical penetration graph (EPG) technique while measurements of xylem fluid tension were taken from plants using a pressure chamber. One group of EPG waveforms is presented here. This group of waveforms represents behaviors that are likely associated with acquisition and/or inoculation of *X. fastidiosa*. Briefly, GWSS performs behaviors to test the acceptability of the cell, including salivating, tasting, and egesting. Behaviors represented by XN waveforms are thought to control inoculation of *X. fastidiosa*. The second portion of the X wave, XC, represents brief ingestion events that primarily serve to test the mechanical seal of the stylets into a xylem cell. Sustained ingestion of xylem fluid is represented by waveform C2.

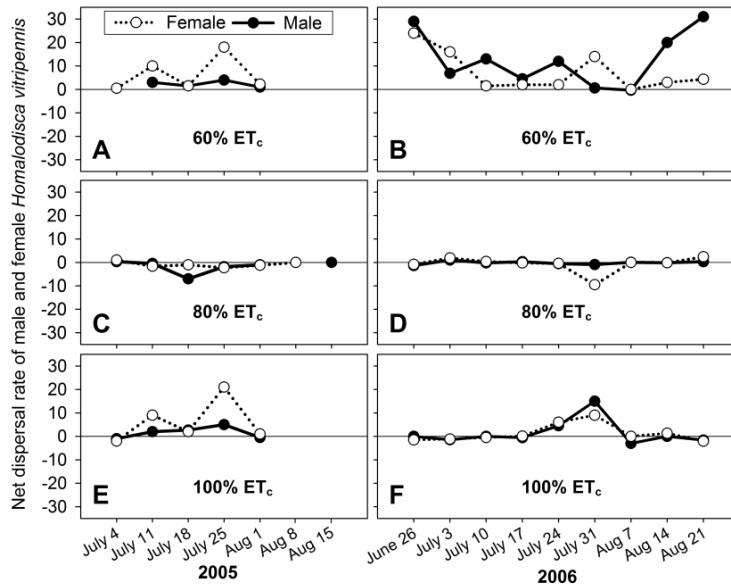
## RESULTS

**GWSS population density and movement in a water-stressed citrus orchard.** Stemwater potential was consistently lower in the 60% ET<sub>c</sub> treatment than in the 80 or 100% ET<sub>c</sub> treatments. There were no differences in stem water potential between the 80 and 100% ET<sub>c</sub> treatments. In 2006, the percentage of first grade fruit was highest in the 80% ET<sub>c</sub> treatment. Moreover, the percentage of first grade fruit was lower in the 60% than in the 100% ET<sub>c</sub> treatment. In 2007, the numbers of fruit across all fruit grade categories were lowest in the 60% ET<sub>c</sub> treatment. There were no differences in number of fruit per grade category between the 80 and 100% ET<sub>c</sub> irrigation treatments.

In 2005, adult GWSS levels increased from late June to a peak in mid July. During this period, about 50% fewer adults were counted on trees irrigated with 60% of the ET<sub>c</sub> than with 80 and 100% ET<sub>c</sub>. There was no difference in the number of GWSS adults per tree between the 80 and 100% ET<sub>c</sub> treatments. In 2006, there was an increase in the number of adult GWSS per tree in early July to the population peak in late July. Up to the peak of GWSS numbers in late July, fewer adults were found on trees irrigated at 60% ET<sub>c</sub> than at 80 and 100% ET<sub>c</sub>. There was no difference in the number of GWSS adults per tree between 80 and 100% ET<sub>c</sub> treatments.

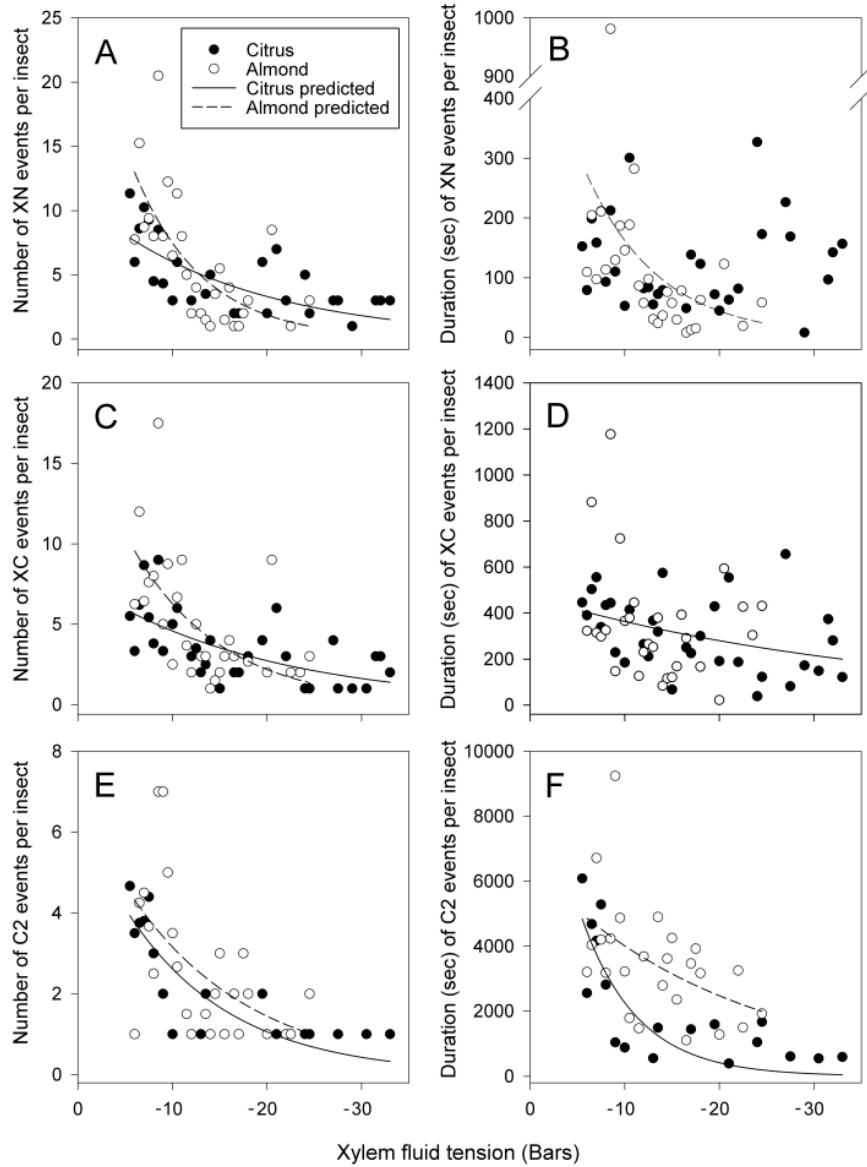
Male and female GWSS net dispersal rates (NDRs) were similar and followed the same trend during the 2005 and 2006 seasons (Fig. 1). Weekly NDRs calculated for each irrigation treatment showed that inflow movement (i.e., individuals moving into a block) was consistently higher than outflow movement (i.e., individuals moving out of a block) in the 60% ET<sub>c</sub> (2005 and 2006) and 100% ET<sub>c</sub> treatments (2005 only). NDRs were generally neutral in the 80% ET<sub>c</sub> treatment in both years (Figs. 1C and 1D) and neutral in the 100% ET<sub>c</sub> treatments in 2006 only (Fig. 1F). In the 80% ET<sub>c</sub> treatment, NDRs of male and female GWSS deviated from zero only on 18 July 2005 and 31 July 2006, respectively. Ignoring gender, more individuals moved into the 60% ET<sub>c</sub> treatment than moved out of the 60% ET<sub>c</sub> treatment in 2006. Conversely, more individuals moved out of the 80% ET<sub>c</sub> and 100% ET<sub>c</sub> treatment areas than moved into the 80% ET<sub>c</sub> and 100% ET<sub>c</sub> treatments.

The composition of GWSS populations within irrigation treatments was similar during the 2005 and 2006 seasons. In 2005, inflow individuals that originated from the 80% ET<sub>c</sub> irrigation treatment were more abundant in the 60% ET<sub>c</sub> and 100% ET<sub>c</sub> treatments than residents and other inflow individuals. In 2006, individuals that originated from the 80% ET<sub>c</sub> treatment were also more abundant than the resident populations in the 60% ET<sub>c</sub> and 100% ET<sub>c</sub> treatments. Resident populations in the 80% ET<sub>c</sub> treatment were higher than the inflow populations. Resident populations in the 60 and 100% ET<sub>c</sub> treatments were in the minority in both 2005 and 2006.



**Fig. 1.** Net dispersal rates (NDRs) of male and female GWSS in irrigation treatments during the 2005 and 2006 sampling seasons obtained from data on number of dispersing individuals captured on traps. NDRs were calculated using equation 1. Positive and negative NDRs in the 60% (Fig. A and B) and 80% ET<sub>c</sub> irrigation treatments (Fig. C and D) show higher inflow and outflow movement, respectively.

**Relationship between feeding behaviors and stem water potential.** Adult GWSS successfully located xylem vessels, then performed salivation/egestion and trial ingestion behaviors, and finally ingested xylem fluid from citrus and almond plants under the tested xylem-fluid tensions ranging from -5.5 to -33.0 Bars and -6.0 to -24.5 Bars, respectively. In general, recordings revealed a significant curvilinear relationship between GWSS waveforms (XN, XC and C2) and measurements of xylem-fluid tension (Fig. 2). Durations and numbers of events both decreased with increasing irrigation stress levels (i.e., more negative xylem fluid tension; Fig. 2). The numbers of salivation and egestion (XN) events per insect decreased in citrus and almond plants as the xylem-fluid tension became more negative (Fig. 2A). There also was a relationship between the durations of salivation and egestion per insect and decreasing xylem-fluid tension in almond plants; the durations decreased as xylem-fluid tension decreased (Fig. 2B). However, in citrus plants, there was no relationship between the duration of salivation/egestion events per insect and decreasing xylem-fluid tension (Fig. 2B). Similar to the XN regressions described above, the numbers of trial ingestion (XC) events in citrus and almond plants (Fig. 2C), and duration of XC per insect in citrus plants (Fig. 2D), decreased non-linearly as xylem fluid tension became more negative. However, on almond, there was no relationship between the durations per insect of trial ingestion and decreasing xylem-fluid tension (Fig. 2D). On almond, the mean ( $\pm$ SEM) duration per insect of XC across all xylem tension ranges was  $60.39 \pm 3.20$  sec (range = 2.4 to 288.8 sec, by insect), whereas on citrus, the XC duration per insect was  $79.23 \pm 4.11$  (range = 2.4 to 297.6 sec). There was a significant relationship for both numbers of events of C2 (sustained ingestion) per insect in citrus and almond, as well as durations per insect in citrus and almond, when regressed to plant xylem-fluid tension. Both variables decreased with decreasing (more negative) xylem-fluid tension (Fig. 2E and F).



**Fig. 2.** Relationship between stylet probing behaviors of GWSS and xylem-fluid tension. (A) Number and (B) duration of xylem cell contacts (waveform XN), (C) Number and (D) duration of trial ingestion events (waveform XC), (E) Number and (F) duration of sustained fluid ingestion events (waveform C2).

## DISCUSSION

Knowledge of the effects of plant water stress caused by natural drought periods or controlled deficit irrigation on the spread of *X. fastidiosa* are key to understanding disease, as well as for developing disease management strategies. Two deficit irrigation regimes tested in the field experiment, 60 and 80% ET<sub>c</sub>, differentially affected the population dynamics of GWSS

in the citrus plots. Trees irrigated at 60% ET<sub>c</sub> were host to fewer GWSS eggs, nymphs, and adults than trees irrigated at 80% ET<sub>c</sub>. Moderate water stress in trees (e.g., 80% ET<sub>c</sub>) may increase solute concentrations (i.e., carbohydrates, amino acids) that may serve as feeding stimulants. However, reduced water potential in severely water-stressed plants might impede GWSS feeding because more energy would be needed to extract xylem fluid. Conversely, well-watered plants may facilitate extraction of xylem fluid. However, more fluid would have to be ingested to compensate for a more dilute xylem food source. Thus, trees irrigated at 80% ET<sub>c</sub> may combine two important plant characteristics for GWSS: 1) a nutrient-concentrated food source and 2) a water potential at acceptable thresholds for GWSS fluid extraction.

Sex-specific net dispersal rates showed that males and females moved consistently within the habitat and contributed equally to the overall level of population change within and among irrigation treatments. Among all marked individuals trapped in the 60% ET<sub>c</sub> irrigation treatment, about 75 and 88% of them in 2005 and 2006, respectively, were inflow individuals. Movement towards less suitable host plants indicates that GWSS were unable to make well-informed decisions based on visual or olfactory cues in selecting host plants and habitats during movement. Collectively, data demonstrate that there is a random component to GWSS movement and dispersal in agricultural landscapes dominated by perennial monocultures.

Although the adult GWSS population was reduced, on average, by 50 to 65% in citrus plots maintained under severe water stress, there was a lower yield and fruit quality (50% overall reduction), which impedes the adoption of this specific irrigation regimen to reduce GWSS populations. Successful implementation of the technique requires knowledge of the drought-sensitive growth stages of a plant to avoid yield reduction. In California, regulated deficit irrigation can be applied to crops such as grapevines (Williams 2000), almonds (Stewart et al. 2011), and citrus (Goldhamer and Salinas 2000) to reduce water use without affecting yield, but irrigation schedules are often not directly transferrable among areas and cultivars due to regional differences in soil profiles and evaporative demands. Information on GWSS population dynamics and schedules for regulated deficit irrigation are available to design management techniques to suppress GWSS populations in some regions and perennial woody crops.

Several feeding behaviors involved in *X. fastidiosa* transmission and host acceptance by GWSS were evaluated. Irrigation status likely affected *X. fastidiosa* transmission behaviors in several important ways. First, GWSS performed fewer salivation/egestion events when feeding on a water-stressed plant compared to a fully irrigated plant. Because *X. fastidiosa* may be inoculated into plants during salivation/egestion events, there may be a lower probability of inoculation of *X. fastidiosa* to plants under water stress than to fully irrigated plants. Second, xylem fluid ingestion events were also shorter and less frequent in insects feeding on water-stressed than fully irrigated plants. Events of sustained xylem fluid ingestion (which likely controls most acquisition of *X. fastidiosa*) were much shorter and less frequent on water-stressed citrus than all other treatments, and together, led to much lower duration of fluid ingestion. Thus, there is diminished likelihood of *X. fastidiosa* acquisition on water-stressed plants.

In summary, data indicated that GWSS performs behaviors that control *X. fastidiosa* acquisition and inoculation more often and longer on fully irrigated citrus and almond plants than those that are water-stressed. Results provided insights to the vector component of the complex *X. fastidiosa* disease epidemiology, and support that application of regulated deficit irrigation has the potential to reduce incidence of diseases caused by *X. fastidiosa* by reducing vector population density and pathogen acquisition and inoculation efficiency during vector feeding.

## LITERATURE CITED

- Colhoun, J. 1973. Effects of environmental factors on plant disease. Annu. Rev. Phytopathol. 11: 343-364.
- Davis, M. J., Purcell, A. H., and Thompson, S. V. 1978. Pierce's disease of grapevines: isolation of the causal bacterium. Science 199: 75-77.
- DWR. 2009. Using future climate projections to support water resources decision making in California. California climate change center, Report to the Legislature, California Department of Water Resources. Available at <http://www.water.ca.gov/climatechange/articles.cfm>. Accessed January 17, 2013.
- Goldhamer, D.A., and Salinas, M. 2000. Evaluation of regulated deficit irrigation on mature orange trees grown under high evaporative demand. Proc. Intl. Soc. Citricult. IX Congr. Pp. 227-231.
- Koricheva, J., S. Larsson, and E. Haukioja. 1998. Insect performance on experimentally stressed woody plants: A meta-analysis. Annu. Rev. Entomol. 43: 195-216.
- Krugner, R., Groves, R.L., Johnson, M.W., Flores, A.P., Hagler, J.R., Morse, J.G., 2009. Seasonal population dynamics of *Homalodiscaviripennis* (Hemiptera: Cicadellidae) in sweet orange trees maintained under continuous deficit irrigation. J. Econ. Entomol. 102, 960-973.
- Krugner, R., Hagler, J. R., Groves, R. L., Sisterson, M. S., Morse, J. G., and Johnson, M. W. 2012. Plant water stress effects on the net dispersal rate of the insect vector *Homalodiscaviripennis* (Germar) (Hemiptera: Cicadellidae) and movement of its egg parasitoid, *Gonatocerusashmeadi* Girault (Hymenoptera: Mymaridae). Environ. Entomol. 41: 1279-1289.
- Krugner, R. and Backus, E.A. 2014. Plant water stress effects on stylet probing behaviors of *Homalodiscaviripennis* (Hemiptera: Cicadellidae) associated with acquisition and inoculation of the bacterium *Xylellafastidiosa*. J. Econ. Entomol. 107:66-74.
- Perring, T. M., Farrar, C. A., and Blua, M. J. 2001. Proximity to citrus influences Pierce's disease in Temecula Valley vineyards. Calif. Agric. 55: 13-18.
- Purcell, A. H., and Saunders, S. R. 1999. Fate of Pierce's disease strains of *Xylellafastidiosa* in common riparian plants in California. Plant Dis. 83: 825-830.
- Stewart, W. L., Fulton, A. E., Krueger, W. H., Lampinen, B. D., and Shackel, K. A. 2011. Regulated deficit irrigation reduces water use of almonds without affecting yield. Calif. Agric. 65: 90-95.
- Thorne, E. T., J. F. Stevenson, T. L. Rost, J. M. Labavitch, and M. A. Matthews. 2006. Pierce's disease symptoms: comparison with symptoms of water deficit and the impact of water deficits. Am. J. Enol. Vitic. 57: 1-11.
- Williams, L. E. 2000. Grapevine water relations. Pages 121-126 In L.P. Christensen [ed.], Raisin Production Manual, University of California, Division of Agriculture and Natural Resources, Publication 3393, Oakland, CA.

# Botryosphaeria Canker and Blight of Walnut and Approaches for Its Management

Themis J. Michailides, Plant Pathologist, UC Kearney Agricultural Research and ExtensionCenter,  
9240 South Riverbend Avenue, Parlier, CA 93648  
Phone (559)-646-6546, FAX (559) 646-6593, [tjmichailides@ucanr.edu](mailto:tjmichailides@ucanr.edu)

David P. Morgan, Daniel G. Felts, UC Kearney Agricultural Research and ExtensionCenter,  
9240 South Riverbend Avenue, Parlier, CA 93648

Phone (559)-646-6562, FAX (559) 646-6593, [dpmoran@ucanre.edu](mailto:dpmoran@ucanre.edu); [dgfelts@ucanr.edu](mailto:dgfelts@ucanr.edu)

Janine K. Hasey, UC Cooperative Extension, Yuba, Sutter, and Colusa Counties, Yuba City, CA  
95991; Phone (530)-822-7515, FAX (530) 673-5368, [jkhasey@ucdavis.edu](mailto:jkhasey@ucdavis.edu)

and Katherine Pope, UC Cooperative Extension, Sacramento, Solano, & Yolo Counties,  
Woodland, CA95695

Phone (530)-666-8733, FAX (530)-666-8736, [kspope@ucanr.edu](mailto:kspope@ucanr.edu)

## Introduction

Over the past few years we have been studying Botryosphaeria canker and blight disease of walnuts. Although there was a 1915 report on a Botryosphaeria canker disease (Howard, 1915) in the old walnut cultivars killing major tree scaffolds, the disease was not of any concern for decades until about five years ago when growers started noticing a general reduction in yields and an unusually large number of dead spurs that accumulated year after year on the trees. In the 1960's another disease, branch wilt, was shown to be caused by *Hendersonula toruloidea* (*Nattrassia mangiferae*; synonym: *Neoscytalidium dimitiatum*). Control of this disease was achieved by just pruning the affected branches and destroying the prunings. In the last several years, however, we collected several blighted branches that appeared symptomatic of branch wilt. From these samples, we isolated the branch wilt pathogen, or HendersonulaBotryosphaeria, and Phomopsis pathogens, or Botryosphaeria only. A systematic survey of walnut orchards located in all major walnut producing counties from dead walnut wood (branches, shoots, and spurs) and black nuts revealed that there are 10 different species of Botryosphaeriaceae infecting walnuts (Chen et al., 2014). We continue diagnosing walnut diseases for growers and PCAs and have isolated both *Botryosphaeria* and /or *Phomopsis* from 'Chandler', 'Hartley', 'Tulare', 'Vina', 'Payne', 'Howard', and 'Serr' walnut cultivars. Samples were collected from Tehama, Glenn, Colusa, Butte, Yuba and Sutter, San Joaquin, Stanislaus, Merced, Madera, Fresno, Tulare, Kings, San Benito, and Kern counties, which indicates that these fungi are widespread in CA walnut orchards.

## Symptoms

The symptoms of Botryosphaeria canker and blight can be classified in six different categories:

### (1) Blighted branches.

Blighted branches look very similar to branch wilt symptoms except *Botryosphaeria* and/or *Phomopsis* can occur on all exposures , not just the southwest exposure. Blighted branches may or may not be associated with sunburn or other wounds. In some cases, both the branch wilt pathogen (*H. toruloidea*) and *Botryosphaeria/Phomopsis* are recovered from the same blighted branch.

#### **(2) Botryosphaeria shoot and fruit blight.**

Infected fruit turns brown and the canker moves from the fruit to the peduncle and down into the shoot causing it to blight ( the leaves dry up and are firmly attached). This blight phase is similar to the panicle blight and shoot blight disease of pistachio where infections from clusters move into the sustaining shoot and create cankers.

#### **(3) Blighted spurs.**

These symptoms can be seen all year around because the killed spurs can accumulate on the trees. In the fall after harvest and leaf drop, infected spurs become obvious. Cankers in spurs vary in size but the majority of them will bear pycnidia of *Botryosphaeria* and/or *Phomopsis*. Blighted spurs result also in killing the vegetative and flower buds, and as a result there is a reduction in yield. Growers have been reporting reduced yields in orchards where higher yields were expected.

#### **(4) Walnut blight and Botryosphaeria blight.**

In some instances where there is plenty of *Botryosphaeria* inoculum, fruit infected by walnut blight (*Xanthomonas juglandis*) can also be infected by fungi including *Botryosphaeria* and/or *Phomopsis*. In this case, the black lesion that develops at the stylar end of the fruit may have a brown hue, an indication of the presence of other fungal infections. In addition to *Botryosphaeria* and *Phomopsis*, other fungal pathogens isolated from lesions of walnut blight include, *Fusarium*, *Alternaria*, *Gleosporium*, *Colletotrichum*, *Aspergillus niger*, and *Epicoccum*. Among these. *Botryosphaeria*, *Phomopsis*, *Fusarium*, and *Alternaria* spp. are the most commonly isolated from walnut fruit showing walnut blight symptoms. By splitting infected nuts, one can observe mycelia of these fungi internally on top of the kernels.

#### **(5) Cankers initiated from pruning cuts.**

Infections of pruning wounds can lead to canker formation that can vary in length as affected by the age of the shoot. The importance of these cankers is that they also supply spore inoculum of the *Botryosphaeria* and/or *Phomopsis* fungi when pycnidia form.

#### **(6) Branch canker and dieback.**

This symptom involves the killing of major branches up to 10 to 15 cm in diameter. Although the killing of these branches was not shown experimentally, it seems that there must be three major factors that probably interact and contribute to the killing: i) shade; ii) walnut scale; iii) large pruning cuts, and iv) *Botryosphaeria/Phomopsis* infections. It is necessary that these branches are pruned out since we have observed repeatedly that they are covered with *Botryosphaeria*.

pycnidia. Removing and destroying these branches will result in significant reduction of spore inoculum in an orchard.

### Causal Agents

Ten species in the Botryosphaeriaceae family (“Botryosphaeria” species) were recovered from diseased samples and two from the Diaporthaceae family (“Phomopsis” species) (Chen et al., 2014; Fig. 1). Among the 10 “Botryosphaeria” species, the most virulent were *Lasiodiplodia citricola*, *Neofusicoccum parvum*, and *N. mediterraneum*. *N. mediterraneum* is the most frequently isolated species and the most wide spread. It was isolated from walnuts in almost every county surveyed (Fig. 1). Among the “Botryosphaeria”, six species can infect walnut shoots and cause cankers while the remaining four cannot cause any canker on shoots. However, all ten species can infect the walnut fruit and move through the peduncle to cause cankers and become established in the fruit-bearing spurs. The two “Phomopsis” species, identified as *Diaporthe neotheicola* and *D. rushicola*, cannot infect shoots directly but can infect fruit which subsequently invades the spurs. A general way of infection could be the direct infection of fruit (via latent infection which will develop symptoms as the fruit matures during summer and fall), invasion of peduncle, and eventually the tip of the spurs, usually killing 3 to 4 nearby buds.

In the fall, as fruit is harvested and leaflets and leaves start dropping, one can find infections that start from peduncles, leaflets, and leaf scars. These are black and grow more towards the base than the top of the trees. After examining infected samples of walnuts, we determined that, in addition to pycnidia formation - which is very common - both the “Botryosphaeria” and “Phomopsis” fungi develop perithecia. Perithecia (which produce air-borne spores) of *Botryosphaeria* were found in samples of prunings collected from the ground and dead branches on trees in Stanislaus, Colusa, and Butte counties.

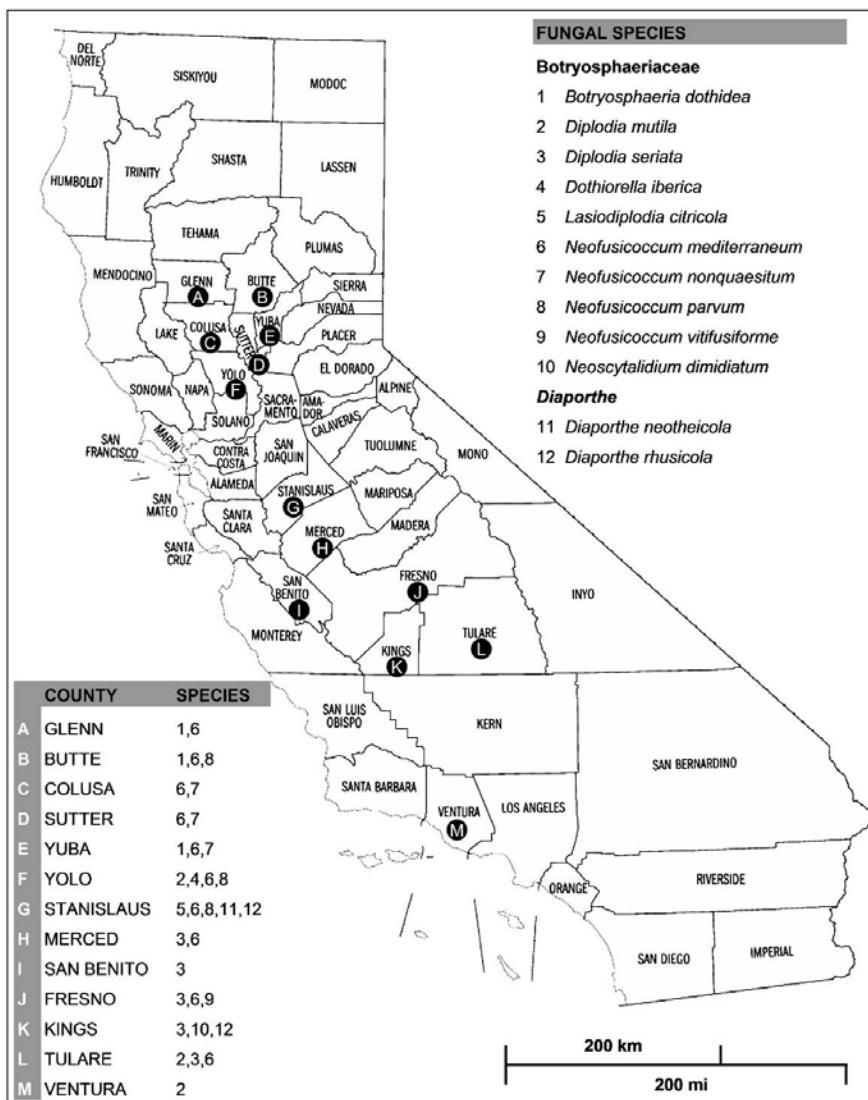
### Predisposing factors

There are several factors that affect the infection of walnut by “Botryosphaeria.” Environmental stress, such as drought or freeze damage, predisposes woody plants to diseases including those caused by *Botryosphaeria* species as has been demonstrated for sweetgum (Schoeneweiss, 1981) and pistachio (Ma et al., 2001). In walnuts, we showed that shoots infested by scales favored infection and resulted in larger cankers caused by three species of “Botryosphaeria” than shoots not infested by scales (Fig. 2). For example, 60-75% more shoots were infected when scales were present than when scales were not present, after inoculating walnut shoots with “Botryosphaeria” species (Fig. 2).

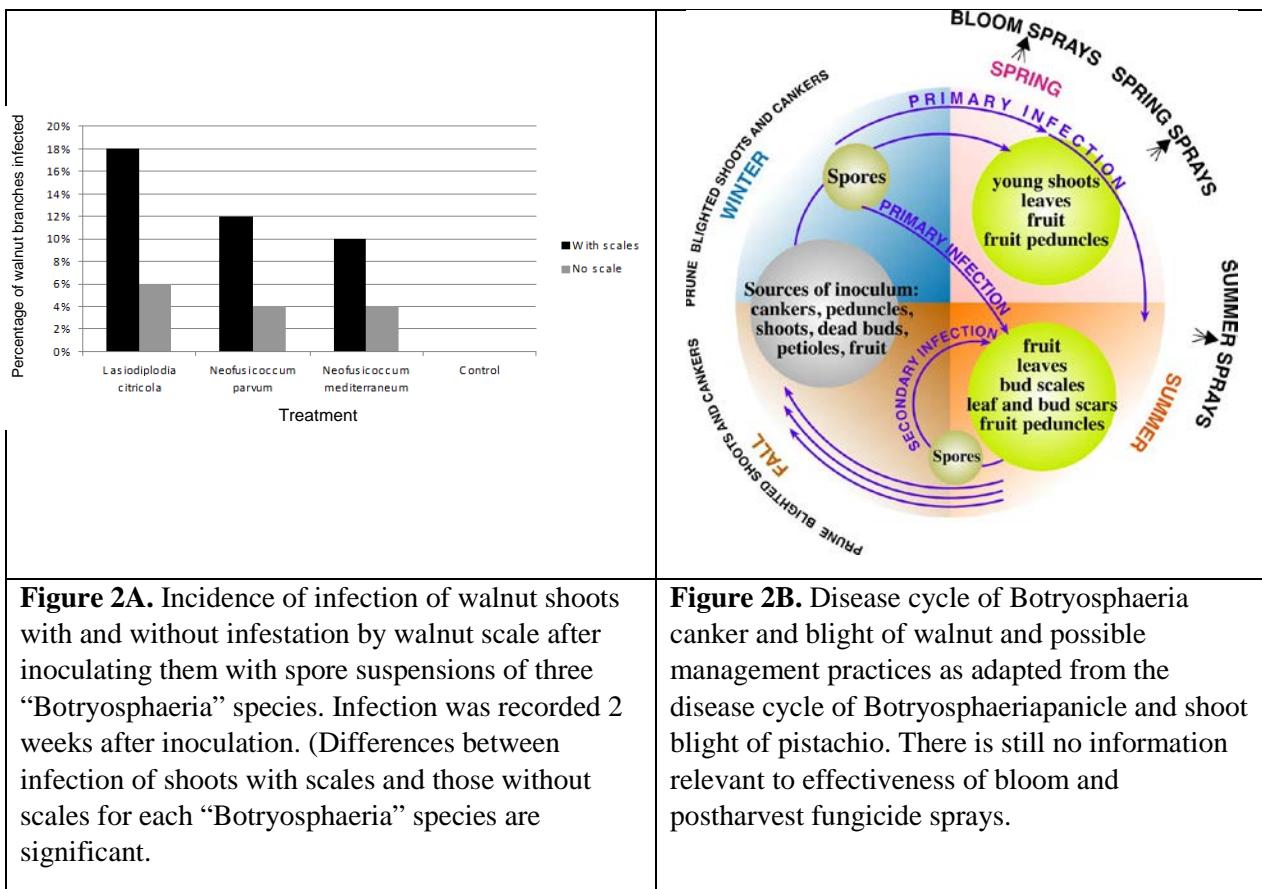
### Epidemiology

“Botryosphaeria” and “Phomopsis” fungi spread in nature primarily by water splashing due to the fact that they produce abundant pycnidia. In some instances, they also can spread by air currents due to the fact that they also develop perithecia in walnut orchards. In general, “Botryosphaeria” fungi are favored by warm temperatures. For instance, *B. dothidea* has an optimum temperature ranging from 81 to 86°F, and usually most of the disease symptoms from new infections during the growing season show during the summer when the temperatures become high and the crop physiologically mature. Pycnidia release spores after a rain event (at

least 4 mm rain), and the released conidia will require at least 1.5 hours of wetness to germinate and infect plant tissues. For pistachios, an infection can occur when there is a 4 mm rain event (less than a ¼ of an inch) and an average temperature of at least 10°C (50°F).



**Figure 1.** Map of California indicating counties where English walnut trees were sampled and the species of *Botryosphaeriaceae* and *Diaporthe* obtained from each county. The 10 species of *Botryosphaeriaceae* and 2 species of *Diaporthe* are indicated as numbers 1 to 12.



## Control

Growers need to use an integrated approach for management of Botryosphaeria canker and blight disease of walnut. It is necessary to supplement cultural control methods with fungicide sprays in order to reduce infection of young susceptible tissues and over time reduce inoculum. Prune all dead branches (killed by branch wilt) and /or shade, walnut scales, and "Botryosphaeria" and "Phomopsis" because all these tissues can be covered with a dense layer of pycnidia and sometimes perithecia. (See also details in "Management of Botryosphaeria canker and blight in different age orchards" below.)

- 1) If sprinkler irrigation is used in an orchard, use only those with a low trajectory angle in order to prevent the water from wetting the canopy.
- 2) Improve infiltration in orchards with poor infiltration to avoid excess moisture in the orchard due to standing water.
- 3) Use effective fungicides registered for walnut to combat the Botryosphaeria disease. Although no specific information exists at the time this report was written regarding bloom and postharvest applications, initial results suggest that sprays during May, June, and July reduce shoot blight and fruit infection.

## Management of Botryosphaeria canker and blight in different age orchards:

*Orchards with heavy infection*(saturated with “*Botryosphaeria*” and “*Phomopsis*” inoculum): Prunings can be shredded and left in the orchard; apply fungicide sprays yearly to reduce infection and sources of inoculum over time.

*Orchards with light to medium infection:* Prune or hedge these orchards first and then move into heavily infected orchards; remove prunings from the orchard; apply fungicide spray programs yearly to reduce infection and inoculum over time.

*Orchards with no Botryosphaeria infection(young orchards):* if pruning is done, prunings can be shred and left on the orchard floor. Monitor orchard yearly for appearance of blighted spurs and prune them as soon as possible; this approach will delay the invasion of the orchard by the “*Botryosphaeria*” and “*Phomopsis*” fungi.

## Literature cited

- Chen, S.-F., D. P. Morgan, J. K. Hasey, K. Anderson, and T. J. Michailides. 2014. Phylogeny, morphology, distribution, and pathogenicity of *Botryosphaeriaceae* and *Diaporthaceae* from English walnut in California. *Plant Disease* 98:636-652.
- Fawcett, H. S. 1915. Melaxuma of the walnut “*Juglans regia*” (A preliminary Report). College of Agriculture, Agricultural Experiment Station, University of California, Berkeley. Bulletin 261. Berkeley, CA.
- Ma, Z., D. P. Morgan, and T. J. Michailides. 2001. Effects of water stress on *Botryosphaeria* blight of pistachio caused by *Botryosphaeria dothidea*. *Plant Disease* 85:745-749.
- Schoeneweiss, D. F. 1981. The role of environmental stress in diseases of woody plants. *Plant Disease* 65:308-314.



# American Society of Agronomy

## California Chapter

### Session IV

## Water Management in the Face of Changing Supplies

**Session Chairs:**

Warren Hutching, Innovative  
AgServices

Sharon Benes, CSU, Fresno

## **Weather Prediction**

Steve Johnson, Meteorologist  
Steve Johnson Meteorology  
[sjassoc@yahoo.com](mailto:sjassoc@yahoo.com)

# **GROUNDWATER OVERDRAFT AND MANAGEMENT IN THE SAN JOAQUIN VALLEY**

Kenneth D. Schmidt, Principal, Kenneth D. Schmidt & Associates,  
600 W. Shaw Ave., Suite 250, Fresno, CA 93704  
Phone 559-224-4412, classotovitch@gmail.com

## **Introduction**

Groundwater overdraft has been occurring in parts of the San Joaquin Valley for more than 80 years and I am very familiar with the last 50 years. Recently inacted legislation calls for managing the groundwater and controlling the overdraft. In this paper, methods of determining the overdraft are first discussed. This is followed by a discussion of historical estimates of overdraft in the valley. Data gaps are identified and thus is followed by a brief discussion of groundwater management.

## **Methods of Estimating Overdraft**

There are two basic approaches to determining groundwater overdraft. This first is by the water budget approach, whereby amounts of groundwater recharge are compared to amounts of groundwater discharge. The calculated change in groundwater storage can then be compared to the imbalance (if any) between recharge and discharge. The problem with applying this approach in most of the valley is that values for most of the items in the water budget are not measured. The water budget in most agricultural areas is dominated by pumpage, canal seepage, and deep percolation from irrigated areas. Pumpage for irrigation in large parts of the valleyis not directly measured. However, pumpage can be estimated from power consumption records, or from crop consumptive use of applied water and the irrigation efficiency. Canal seepage is a major source of recharge of good quality water, but is often not measured. Deep percolation of excess applied irrigation water is indicated to be the major source of recharge beneath irrigated lands in the valley. This is not directly measured, but is calculated from the difference between water applied for irrigation and crop consumptive use of this water. Crop consumptive use is probably one of the most accurate items in the water budget. Other large influenceson the groundwater budget are groundwater inflows and outflows. These are not directly measured, but can be estimated from Darcy's Law. In order to do this, hydraulic gradients (water-level slopes) and aquifer transmissivities must be known. Aquifer transmissivity is ideally determined from aquifer tests. At least several thousand aquifer tests have been conducted in the valley, primarily by consultants to cities, districts, counties, industries, and agricultural concerns. An inferior and often inaccurate method of determining transmissivity is by estimating the hydraulic conductivity from grain size descriptions and multiplying this by the thickness. Besides lateral groundwater flows, vertical groundwater flows are important in most of the valley. This is because of the layering of the alluvial deposits, and the presence of at least two aquifers beneath most of the valley. The second method of estimating groundwater overdraft is simpler and focuses on using water level changes along with specific yield values. Both the water budget and change in groundwater storage approaches are done for specific time periods, commonly for a hydrologic base period (a period of normal precipitation). Representative values of specific yields have

been developed for most of the valley based on textural descriptions. In evaluating changes in storage, one should separate the upper confined groundwater from the deeper confined groundwater. Using specific yields only applies to unconfined aquifers. In contrast, for confined aquifers, storage changes are generally very small, because the aquifer essentially remains full of water. Water-level declines cause some water in confined aquifers to be expelled from clay layers that compact, resulting in land subsidence.

A problem with the historical semi-annual water-level measurement program has developed in the last decade or so, because of changes in cropping patterns. The semi-annual measurements have normally been in late January and early October. This was intended to represent the seasonally shallowest and deepest static water levels. Decades ago when cotton and other field crops were predominant, these measurements provided useful information. It was common to compare seasonal highs from one year to another, and if these values fell during a hydrologic base period, then groundwater overdraft was indicated. With the development of more tree crops with longer irrigation periods, it is becoming more difficult to select times for the semi-annual measurements. That is, pumping is occurring during much of the year. However, continuously recording water-level devices, which have been used for many decades, are becoming more common. Modern technology makes use of water-level sensors or transducers to show the full range of seasonal water-level variations. Values other than the seasonal shallowest levels should also be considered. The continuous records are expected to provide important information for future groundwater management.

### **Historical Estimates of Groundwater Overdraft**

Considering that the San Joaquin Valley groundwater basin has been among the most heavily pumped groundwater basins in the country, it is somewhat surprising to observe the paucity of estimates of overdraft that have been made. For example, the classic U.S. Geological Survey Water Supply Paper 1469 “Groundwater Conditions and Storage Capacity in the San Joaquin Valley” (1959) contains no estimate of groundwater overdraft. As part of developing the Tulare Basin 5D plan in the early 1970’s, the groundwater overdraft in the part of the San Joaquin Valley south of the San Joaquin River was estimated to have averaged about 2.0 million acre-feet per year prior to the importation of water in the California Aqueduct in the mid 1960’s. By 2000, it was projected that the overdraft in Basin 5D would be reduced to about 1.3 million acre-feet per year (Schmidt, 1975). U.S. Geological Survey Professional Paper 1766 “Groundwater Availability of the Central Valley Aquifer” (2009) contained an estimate of an average of 1.4 million acre-feet per year of overdraft for 1962-2003. This includes both the San Joaquin Valley and Sacramento Valley, and most of this estimated overdraft is indicated to have been in the San Joaquin Valley.

A substantial amount of the overdraft in the San Joaquin Valley is in Basin 5D and in Madera County. Updated amounts of overdraft in parts of the valley have been made in recent years, such as an average of about 160,000 acre-feet per year in Madera County alone. The present overdraft in the San Joaquin Valley, once newly planted trees become mature, will likely be between 1.5 and 2.0 million acre-feet per year.

It is clear that updated, specific determinations of the amount of groundwater overdraft in much of the valley are not available. One of the reasons for this can be gleaned from California Department of Water Resources (DWR) Bulletin 118, “California Groundwater” (2003 update). In 1978, the legislature directed the DWR to develop a definition of critical overdraft and to identify basins in the state that were in conditions of critical overdraft. Eleven basins in the state

were identified as being in critical overdraft, and eight of these were in the San Joaquin Valley. It should be noted that the basin in western Fresno and Kings Counties comprising the Westlands W.D. wasn't one of these basins, because of the importation of surface water at that time. However, with the loss of surface water from the Delta in recent years and the San Joaquin River restoration project, most of Basin 5D and Madera County are in a state of critical condition overdraft. On page 88 of the updated Bulletin 118 it was stated:

“This update to Bulletin 188 did not include similar direction from the legislature, nor funding to undertake evaluation of the state’s groundwater basins to determine whether they are in state of overdraft”.

Indeed, the reason for the continuing condition of critical groundwater overdraft in part of the valley is economics. Namely, it has appeared to be cheaper to continue overdrafting than to solve the problem.

### **Groundwater Management**

There are several approaches to groundwater management. From my standpoint, the preferred approach is the technical one, where qualified hydrogeologists are at the forefront. Groundwater modeling, because of the historical shortcomings of such efforts in the San Joaquin Valley, is deemed to be of little use in such management. Rather, the emphasis should be on development of a sound hydrogeologic conceptual model of each basin being considered. Data gaps should be identified and addressed. Development of updated subsurface geologic cross sections, updated water-level maps for both the shallow and deep groundwater, and interpretation of water-level hydrographs are essential. As for data collection, measurement of pumpage from all large-capacity wells (preferably by totalizing flowmeters) is needed. Enhanced measurements of canal seepage should be done in specific reaches of major canals. Also, an improved water-level measurement program is essential.

The bottom line in determining groundwater overdraft is to compare the amount of surface water diverted into an area to the consumptive use of applied water. If groundwater flows area not considered, a stable water level will result when these two items are in balance. If the consumptive use of applied water is greater than the amount of the surface water, then groundwater levels will fall. If the consumptive use of applied water is less than the amount of surface water, then groundwater levels will rise. Thus groundwater management to reduce and hopefully eliminate groundwater overdraft entails 1) obtaining or developing more surface water, and 2) reducing the consumptive use. There is such a large imbalance in the San Joaquin Valley at present, that it has been estimated that about a million acres of cropland would have to be removed, if no more surface water could be developed, to eliminate the groundwater overdraft. This stresses the importance of useful projects such as clearing the watersheds in the Sierra Nevada of excessive plant growth to increase runoff, and the development of additional water storage projects.

### **Literature Cited**

Bertoldi, G. L., Johnson, R. H., and Everson, K. D. 1991. Groundwater in the Central Valley, California- a summary report. U. S. Geological Survey Professional Paper 1401-A.

California Department of Water Resources, 2003. California groundwater update, 212 p.

Davis, G. H., Green, J.H., Olmsted, F.H., and Brown, D.M. 1959. Ground-water conditions and storage capacity in the San Joaquin Valley, California. U.S. Geological Survey Water Supply, Paper 1469: 287 p.

Faunt, C.C., Belitz, K., and Hanson, R. T. 2009. Groundwater availability in California's Central Valley". U.S. Geological Survey Professional Paper 1766. Chapter B-59-116.

Schmidt, K.D., 1975. Salt balance in groundwater of the Tulare Lake Basin, California. Hydrology and Water Resources in Arizona and the Southwest. Volume 5: 177-184.

# **The New California Groundwater Law**

## **Clarity or Uncertainty for Agricultural Water Users?**

Sargeant J. Green, Project Director, California Water Institute

6014 N. Cedar Avenue, Fresno, CA, 93710

Phone (559) 278-8653, [sgreen@csufresno.edu](mailto:sgreen@csufresno.edu)

### **Introduction**

California has a new groundwater law and the impact of the law on agricultural water users is not well understood at this time. The law will likely add both clarity and uncertainty for many groundwater users, especially agricultural users that are not within the scope of existing surface water supply organizations or groundwater management agencies. The clarity is that all groundwater users will soon be part of a structured organization that will need to meet the goals of the law and assist in managing groundwater. The uncertainty is that no one yet knows whether the goal of the law, sustainable groundwater, will allow for continued use of the groundwater at rates and amounts that have been used in the past and that many groundwater users who have had to only pay for the well and power to supply their water will have new costs. The best advice for the groundwater users outside of existing groundwater management agencies would be to join a new structure as soon as possible and to participate in the strategies that can assist with groundwater sustainability, especially conservation and groundwater recharge, specific efforts that can positively influence the groundwater system. The following summarizes some of these impacts and opportunities for groundwater users.

### **The New Law**

The new law, the “*Sustainable Groundwater Management Act of 2014*”, requires new plans, expanded coverage to all groundwater users and new goals for groundwater management. It includes dates for organization, new plan adoption and plan implementation. It also provides for State agency roles including such as development of required plan elements, adequacy of locally proposed institutions and overall competency review of the plan and agency by the California Department of Water Resources. In the circumstance of failure to comply with the law locally, the California State Water Resources Control Board can adopt and enforce a plan. The goal of all plans will be “sustainability”. That term is sufficiently broad to allow for some local flexibility, but still will likely result in allocation strategies in locations where long-term extraction has substantially exceeded replenishment. There are already models of such allocation control strategies in California in adjudicated basins, largely in Southern California.

### **Impacts**

In the short term there will be two kinds of agricultural groundwater users; those within the scope of an existing agency that has contemporary authority and existing plans for managing groundwater and those who are outside of any such authority. Those within existing agencies will likely be notified by their planning agency about the new law and the proposed changes the agency proposes to make to maintain their authority, or if they are not going to continue to provide coverage, what that will mean to the well owner. The areas without a current agency have no such communications and currently the individual will have to find out what may be

required of them, both in the short term or long term, on their own. In some cases, the backstop agency in a groundwater area may be county government (as provided for in the new law) in which case the well operator may be contacted by the appropriate county department. The vacuum of information in areas without a planning agency or the county stepping forward could be met by other business and consulting professionals that serve the water well and agricultural community; in fact, it would make sense to do so as another service for customers. The major impact of all of this agency-available vs. no agency, lack of information, is that the organizational structure for new groundwater agencies has to be in place by June 30, 2017. For those well operators who are not in an organized area that could be a fairly short time schedule to understand and make a decision about what to do. The critical issue is to determine the best organization to join— a local organization or the county— because the decision for those who do not choose either will be to default to control by the California State Water Resources Control Board. Clearly the best choice for most well operators will be an existing agency with experience in groundwater matters. The decision, however, will involve understanding the responsibilities and costs of enrollment. Under the new law, local agencies that meet the terms of the law will ask all well owners to register their well with the agency and the agency “may” ask for measurement of the well and “may” seek fees based on the rate of extraction. If the well is under the scope of a county or the State, they will seek measurement and water extraction based fees.

Since local agencies must meet their costs of service it is fairly certain all well owners will likely have some costs to pay to meet the needs of their chosen or default agency. In the case of existing agencies, many may already have facilities or projects to assist with groundwater improvements and the new enrollees will likely be charged operations and maintenance fees as well as sinking funds for replacement of existing facilities. They may also be required to pay for any new activities needed to reach the goal of the ongoing groundwater management plans, “sustainable groundwater”. Determining which organization to join, if they are available, would involve finding out these current and future costs so they can be calculated into an individual’s cost of doing business and finding the best fit. If the individual ends up with a default organization they will have to try and develop their own estimates of those costs and also try to influence the scope and nature of the program potentially imposed on them by the relevant agency. In that case the county would likely be a more attractive alternative because the individual would likely have the opportunity to work with their neighboring groundwater users in a like position and perhaps develop a more effective network locally that can collectively deal with the county rather than staff in Sacramento.

While the whole process of bringing many previously unregulated water using areas under the scope of management agencies sounds onerous and daunting, a majority of the water community believes the organizational process is necessary at this time. The groundwater conditions in many areas of the State have reached critical conditions and substantial damage is occurring in the forms of lost wells, diminished quality and permanent damage to the landscape by subsidence. Such events have occurred during the past one hundred years (since widespread adoption of the deep well turbine pump) and the previous response was to develop more surface storage and import water into over-drafted areas. No such opportunities exist any further; additional storage can only assist with timing of distribution, very little new water can be squeezed out of our watersheds. The new investments will be to improve conveyance, recharge, efficiency and reuse and the scope of the new institutional arrangements will be designed to capture the costs of those

investments by groundwater users who heretofore had not participated in such costs. The concept of fairness and equity will pervade not only the future costs to manage surface and groundwater but the use of the groundwater itself. This may be a rude awakening for those who have been using more than the natural water recharge of our groundwater systems. The existing management system operators that have been conjunctively using surface and groundwater have become frustrated by the loss of groundwater outside of their boundaries by areas who have not contributed to the costs and benefits of their efforts. This dynamic will be part of the discussion when individual well owners in un-districted areas join in the management scheme demanded by the new law.

## **The Opportunities**

The new groundwater law will undoubtedly join together a much larger water community and while the initial organizational process may be difficult and frustrating for some, the opportunities should also be illuminated. Many groundwater areas that are within the scope of surface water systems will be able to influence the activities that can enhance groundwater reliability. Too often wet year water has been lost from many watersheds and collective coordination and investment can improve capture and distribution of such flows. Better distribution systems, new recharge activities and facilities in the best locations and efficient groundwater extraction and water use activities, can all be included in new planning efforts spread out over larger areas with the costs more evenly distributed to the beneficiaries. All well owners will benefit if the average depth to water can be improved. The potential reduced costs of pumping could be part of the money available to repay the investments. The location, timing and costs of these investments will need to be carefully thought out and the newly added areas of well owners would be well served to join the best-fit management agency to influence and enjoy these efforts.

## **Conclusion**

California has a new law that brings all groundwater users into a process that has both impacts and potential benefits. All well owners would be better served to understand the impacts and opportunities created by the new process.

## **Literature Cited**

“Sustainable Groundwater Management Act”, California Legislature, September 2014, California Water Code Amendments to Sections 10750 et. seq.



# American Society of Agronomy

## California Chapter

### Session V

## Water Related Management Issues

### Session Chairs:

Scott Stoddard, UCCE Merced

Dan Munk, UCCE Fresno

## **Deficit Irrigation of Cotton: Furrow, Drip Irrigation Approaches**

Robert B. Hutmacher, Cooperative Extension Specialist / Agronomist  
Univ. CA Davis Plant Sci.Dept., Univ. CA West Side Res.& Ext. Ctr; P.O. Box 158, Five Points,  
CA 93624; Phone: (559) 884-2411, Ext. 206; e-mail: rbhutmacher@ucdavis.edu

### **Introduction**

Competition for limited supplies of irrigation water will continue to be a part of western U.S. agriculture for many years to come. Crops that require moderate to high amounts of water for production will be under pressure to tighten up irrigation management practices to adjust to restricted water supplies. Cotton has a relatively long growing season for an annual crop in the Central Valley of California, and as such can be considered moderate when compared with the water use for crops ranging from the low water use of cool-season vegetables all the way to the much higher water use of long-season perennial crops such as alfalfa or most tree crops.

Cotton management under full irrigation in California has typically involved irrigation scheduling that imposes mild to moderate plant water deficits that help manage vegetative growth rates and limit rank growth. When water stress is imposed at less-damaging timing, cotton vegetative growth is typically reduced much more than lint yield, thereby increasing the harvest index. In part the perceived need for vegetative growth management in California cotton production was influenced by the vigor, growth habit and relative indeterminacy of the cotton cultivars being grown. Flower bud and fruit losses that may occur with some types of insect damage or with unfavorable weather conditions can further complicate irrigation management plans. More severe water stress imposed during bloom and early fruit development can result in fruit/yield losses, which in turn can trigger excess vegetative growth and vigor that may require either delayed irrigation or plant growth regulator applications to manage. Cotton growth stages considered least sensitive to soil and plant water deficits are early vegetative development, through about 7 to 9 main stem node stage, and after peak flowering and into the early boll-opening phase of development. Growth stages found most sensitive to moderate to severe plant water deficits in a wide range of studies include early flower bud (square) development through the early flowering stage, with later flowering and boll development periods intermediate in sensitivity (Hake et al, 1996; Hutmacher et al, 1995).

### **Furrow Irrigation Approaches - Management**

Under furrow irrigation, deficit irrigation approaches in the western U.S. have included: (1) delays in applying the first within-season irrigation, with irrigation timing determined based on mid-day leaf water potential thresholds (Steger et al, 1998); or(2) extended irrigation frequencies that allow more soil water depletion and higher stress levels imposed prior to irrigations (Grimes and Yamada, 1982), or (3) elimination of some late-season irrigations after vegetative cutout (Munk et al, 1994). Under conditions with moderate to deep rooting depth, yields were maintained or reduced significantly less than ET<sub>c</sub>, and water applications were reduced with these furrow management schemes.

The development of growth stage-specific, threshold levels of mid-afternoon leaf water potentials for growers to use in irrigation scheduling (Grimes and Yamada, 1982) represented a significant tool for California cotton growers. Since their research related threshold leaf water potentials to specific yield responses identified in their research, growers could use leaf water potential measurements to improve scheduling of irrigations to avoid both unnecessary, earlier

than required irrigations as well as delays in irrigation that could result in more severe water stress and damage to yield potential. Similarly, Howell et al (1984) and Hutmacher et al (1995) demonstrated the utility of leaf water potential measurements and the Crop Water Stress Index approach, based on canopy temperature measurements, to assess levels of water stress associated with soil water depletion. Howell et al (1984) furthermore demonstrated the utility of these approaches to assess plant stress associated with soil rootzone salinity.

### **Drip Irrigation Approaches - Management**

Drip irrigation has been shown in multiple studies to be one approach that can be used that can allow reductions in total applied water, and that allows some flexibility in determining specific periods or growth stages if reduced / deficit irrigation strategies are required due to limited water availability. Hutmacher et al (1995, 1998) reported that under subsurface drip irrigation in a deep clay loam soil, lint yields of both Acala and Pima types of cotton at irrigation levels that supplied 80% of estimated daily crop ET<sub>c</sub> during the period from late squaring through two weeks past peak bloom were not significantly different from yields at 100% ET<sub>c</sub> applications. This resulted in higher water use efficiencies than plants in treatments receiving irrigation water at 100% ET<sub>c</sub> during this same period. Similarly, Bhattacharai et al (2006) reported that cotton lint yields in Queensland, Australia were similar to those in drip irrigation treatments that supplied 75%, 90%, or 105% of estimated daily crop ET<sub>c</sub> during the period from squaring through late bloom, resulting in higher water use efficiency at lower water application rates. More recent drip irrigation studies by the author have focused on deficit subsurface drip irrigation in a clay loam soil site at the West Side REC and in a sandy loam soil at Shafter. In recent projects by the author involving deficit drip irrigation using widely-grown cultivars of pima and acala cotton, several general findings included:

- Under drip irrigation, cotton growth and yields respond to higher pre-plant irrigation amounts (better replenishment of stored soil moisture) when moderate to even severe deficit irrigation is practiced, particularly during flower bud formation and flowering;
- The best responses to the higher initial stored soil moisture amounts at West Side REC location were with moderate deficit irrigation treatments with 60% and 80% replacement of estimated evapotranspiration during the period from early flowering into vegetative cutout;
- With more severe deficit irrigation treatments which involved longer periods of 40% and 60% ET replacement during the growing / irrigation season, access to more stored soil moisture helped increase yields some, but could not overcome the more severe impacts of these deficit irrigation treatments
- Impacts on hvi fiber quality were generally not seriously damaging with moderate deficit irrigation treatments with periods of 60% and 80% ET replacement. The more severe deficit irrigation treatments which received only 40% and 60% ET replacement during reproductive growth can be more damaging to fiber strength and micronaire, potentially resulting in discounts in some years, particularly if soil water reserves are low.

- The general responses of Pima and Acalato deficit irrigation have been relatively similar in terms of what levels of deficit irrigation start to impact yields or that impact some components of fiber quality.

Deficit irrigation strategies may sound relatively straight forward in terms of potential for direct impacts of reduced water applications on yields and quality. However, there can be additional factors to consider that may be less direct. Some factors with potential to influence crop choices and suitability of deficit irrigation plans include: (a) Salinity and trace element composition of available water supplies; (b) resulting salt and toxic trace element accumulations in the root zone, and deficit irrigation impacts on reductions in leaching fractions (amounts of applied water in excess of ET<sub>c</sub>) that can promote downward transport of these constituents; (c) potential for crops to make use of shallow groundwater, including groundwater supplies with degraded quality (salinity, trace elements, nitrates); (d) price of the crop and profit potential; (e) impacts of deficit irrigation on crop quality (improved with modest deficit irrigation in some crops; quality damaged in others particularly under more severe stress); (f) desirability of rotating crops for disease or pest control; (g) recent or significant investments in production, harvesting equipment or processing facilities for single crops or types of crops; and (h) fulfillment of long-standing contract requirements to produce specific crops. In comparing crops for suitability for salinized soils or for use of degraded irrigation water supplies, salt tolerance can influence water supply and water management options. While varietal differences in salt-tolerance are known to exist in cotton (Fowler, 1986), there have not been many efforts the past two decades to identify specific cultivar differences in salt tolerance or yields under specific salinity levels either in Upland or Pima cotton.

### **Crop Maturity Classes, Growing Season Length**

When irrigation water is relatively inexpensive and fairly available, California producers of many annual crops can take advantage of a relatively long growing season, with a lot of available heat units to produce crops, and high yield potentials due to the generally favorable climate for longer-season crops. Cultivars of some annual crops such as cotton developed for the California market reflect this in terms of being indeterminate in growth habit, with long duration fruiting periods to aim for high yields. In addition, many of the crop and insect pest management schemes developed for cotton in the San Joaquin Valley and for Arizona were based on the approach that some early season fruit losses were allowable since early losses could be compensated for with a lengthened fruiting period and continued growth and fruit maturation time added at the closing end of the growing season. This approach, in some respects assumes that irrigation water supplies are adequate and affordable to extend the growing season, and that the value of the incremental yield added with that later fruit has a value significantly greater than the irrigation water cost. When water supplies are limited and/or more expensive, these assumptions may no longer be valid. Attempts to reduce total seasonal water requirements by switching to earlier maturing varieties is one approach under consideration. However, identification of appropriate cultivars or cultivar characteristics may not be straightforward. There is some evidence for crops such as cotton that early maturing varieties can produce higher yields under a range of drought conditions (Namken, 1973), while other research suggests that higher yielding cultivars under water-limiting conditions are not related to earliness and shorter season production (Bourland, 1989; Cook and El Zik, 1993). It should be noted that most of these types of studies have been done under conditions of climatic drought, where the timing and

relative intensity of the drought periods can be quite variable. In these instances, a high degree of reproductive flexibility or a very short period for harvestable product production can be beneficial. The situation in semi-arid areas with little rainfall during the growing season and nearly full dependence on irrigation may be different. Additional investigations into shorter-season production approaches and cultivars are likely to be of value for water limiting conditions, since the timing of our limited water periods may be at least partially be under our control. In the marketplace, of course, cultivars and production methods developed involving shorter season production will only be workable if profitable yields and acceptable quality are produced.

## References

- Bhattarai, S.P., A.D. McHugh, G. Lotz, D.J. Midmore. 2006. The response of cotton to subsurface drip and furrow irrigation in a Vertisol. *Experimental Agric.* 42:26-49
- Bourland, F.M. 1989. Trends in available cotton cultivars. *Agric. Expt. Station Report, Div. Agric., Univ. Arkansas.* No. 138, pp. 69-75.
- Cook, C.G., K.M. El Zik. 1993. Fruiting and lint yield of cotton cultivars under irrigated and nonirrigated conditions. *Field Crops Res.* 33: 411-421.
- Fowler, J.L. 1986. Salinity and fruiting. In: J.R. Mauney, J. McD. Stewart (eds.) *Cotton Physiology*. The Cotton Foundation, Memphis, TN. Pp. 107-111.
- Grimes, D.W., Y.H. Yamada. 1982. Relation of cotton growth and yield to minimum leaf water potential. *Crop Sci.* 22: 134-139.
- Hake, S.J., T.A. Kerby, K. D. Hake. 1996. *Cotton Production Manual*. Public.# 3352.University of CA, Agric. Natural Res. 422 pp.
- Howell, T.A., J.L. Hatfield, J.D. Rhoades, M. Meron. 1984. Response of cotton water stress indicators to soil salinity. *Irrig. Sci.* 5 (1): 25-36.
- Hutmacher, R. B., C. J. Phene, K. R. Davis, S. S. Vail, T. A. Kerby, M. Peters, C. A. Hawk, M. Keeley, D. A. Clark, D. Ballard, N. Hudson. 1995. Evapotranspiration, fertility management for subsurface drip Acala and Pima cotton. In *Proc. 5 Int'l. Microirrigation Congress*, ed. F. R. Lamm, 147–154. St. Joseph, Mich.: ASAE.
- Hutmacher, R. B., K. R. Davis, S. Vail, M. S. Peters, A. Nevarez, and J. Covarrubias. 1998. Root distribution of cotton: Effects of water application amounts under subsurface drip irrigation. In *Proc. Beltwide Cotton Conf.*, 1491–1495. Memphis, Tenn.: Nat. Cotton Council.
- Munk, D.S., D.W. Grimes, T.A. Kerby. 1994. Plant responses to late season water deficits in Acala cotton cultivars. Pp. 103-108. In: Challenging the Future. Proc. World Cotton Conf. I. G.A. Constable, N.W. Forrester )
- Namken, L.N., M.D. Heilman. 1973. Determinate cotton cultivars for more efficient cotton production in the lower Rio Grande Valley. *Agron.J.* 65: 953-956.
- Steger, A., J.C. Silvertooth, and P.W. Brown. 1998. Upland cotton growth and yield response timing the initial post-plant irrigation. *Agron. J.* 90: 455-461.

# Subsurface Irrigation of Alfalfa – Promises and Pitfalls

Dan Putnam, Extension Forage Specialist, Plant Sciences,  
MS#1, One Shields Ave., University of California, Davis 95616.  
Phone 530-752-8982, [dhputnam@ucdavis.edu](mailto:dhputnam@ucdavis.edu)

Ali Montazar, Project Scientist, Plant Sciences,  
University of California, Davis 95616  
Email: [amontazar@ucdavis.edu](mailto:amontazar@ucdavis.edu)

Khaled Bali, UCCE Farm Advisor, Imperial County,  
1050 East Holton Road, Holtville, CA 92259  
Email: [kmbali@ucanr.edu](mailto:kmbali@ucanr.edu)

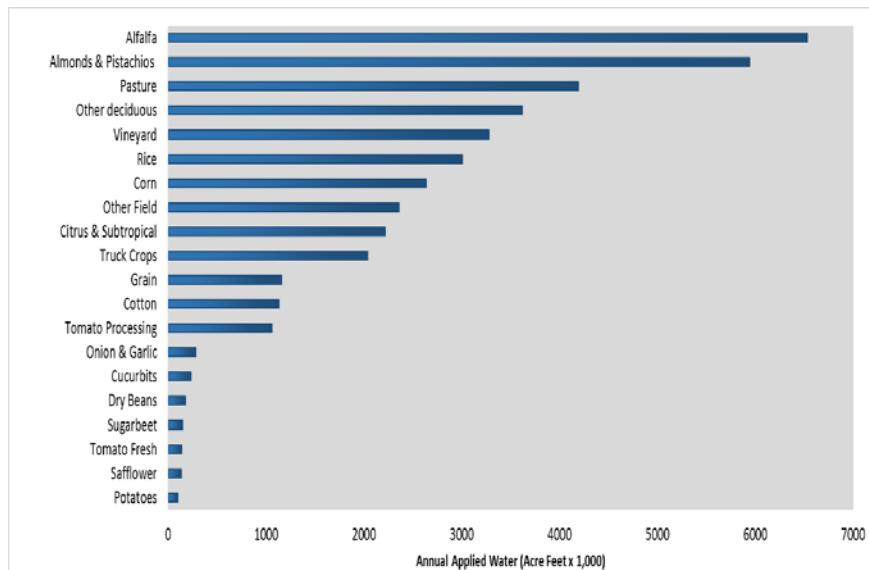
Daniele Zaccaria, Agricultural Management Specialist, Land Air and Water Resources,  
University of California, Davis 95616  
Email [dzaccaria@ucdavis.edu](mailto:dzaccaria@ucdavis.edu)

## Introduction

Long-term strategies for improvement of water-efficient alfalfa production systems are necessary to meet the needs of a growing population, to mitigate drought events, and to lessen demands on water resources (Putnam, 2012). Of these strategies, one of the most important is to improve the technology of water application and control. Management strategies which improve the ability of growers to apply water at rates closely matching true crop demand are important, regardless of crop and the irrigation technology utilized.

Alfalfa (*Medicago sativa L.*), is California's highest acreage crop and is a major irrigated crop in virtually all western states. In California, alfalfa is grown on nearly 1 million acres per year. It consumes the highest amount of water of any single crop (Figure 1), about 16% of California's agricultural water. It is also a critical component of dairy and livestock production, accounting for over 20% of CA's agricultural revenue.

In spite of this high seasonal water use, alfalfa has some very positive biological features with regards to water: it is one of the most water-use efficient crops due to its perennial nature, deep roots, high yields, and the fact that the entire above-ground portion is harvested as an economic product. Alfalfa can also be deficit irrigated during droughts – a strategy not always available



**Figure 1.** Water utilization by crops in California, 4-year average 2006-2009 (DWR).

to other perennial crops (Orloff et al., 2013)

Surface irrigation methods (specifically check-flood) dominate in the Central Valley and deserts of California, and center pivot or other sprinkler systems dominate in the high elevation regions. Although drip irrigation has swept through other crops such as tomato, it is currently a very minor component of the western alfalfa irrigation techniques, currently estimated at about 20,000 acres in California or less than 2% of acreage whereas surface techniques are likely >80% and the remainder utilize sprinklers of various types. During the past 7 years, UC scientists have been working with growers and in controlled studies examining the potential of subsurface drip irrigation (SDI) for alfalfa. In this presentation we summarize general observations about SDI in alfalfa and examine the potential advantages and disadvantages of SDI as applied to alfalfa.

### **What's the Best Irrigation System for alfalfa?**

While the principles for irrigation management are universal across crops, the application of those principles differs significantly across crops. Orchard and vineyard crops, for example are planted on widely spaced geometries, and thus targeted drip or micro-sprinkler technology makes sense, especially during early stand establishment. Row crops similarly have defined geometries—whereas it may not be necessary to wet the entire soil profile throughout the growing season. Shallow-rooted annual vegetables must be frequently irrigated, and cannot significantly tap into deep residual soil moisture. Alfalfa, as a deep-rooted broadcast closely-spaced herbaceous perennial typically requires most or all of the soil profile to be wetted. Additionally alfalfa is harvested from 3-10 times per year, a major difference with annual or other perennial crops that affects irrigation practices, since water must be withheld before, during, and after harvest to allow for timely machinery operations.

*The ideal irrigation system for alfalfa is one that:*

- Maximizes Distribution Uniformity (DU), approaching 85-95%
- Allows operators to very closely match applied water with real-time crop demand and use
- Can quickly irrigate an entire field within a day or two
- Allows for small increments of water when needed
- Can completely fill the root zone to field capacity
- Minimizes water losses below the root zone, off-site surface runoff, and evaporation.
- Minimizes energy requirements
- Requires little labor
- Maintains sufficient oxygen in root zone (not excessive saturation)
- Prevents salinity accumulation
- Is flexible and able to adjust for the requirements of frequent harvests (drying periods)
- Does not worsen pest problems (particularly rodents, weeds, nematodes and diseases)
- Minimizes cost

It should be immediately obvious that no system (surface, sprinkler or drip) will fully meet all of these conditions, but each has advantages and disadvantages and strengths for each criterion.

Choice of the best irrigation system for a farm must be carefully analyzed considering the available water supply, soil features, and economic criteria. Here we review SDI as applied to alfalfa, as per its major advantages and disadvantages, and suggest methods to improve success with SDI for alfalfa.

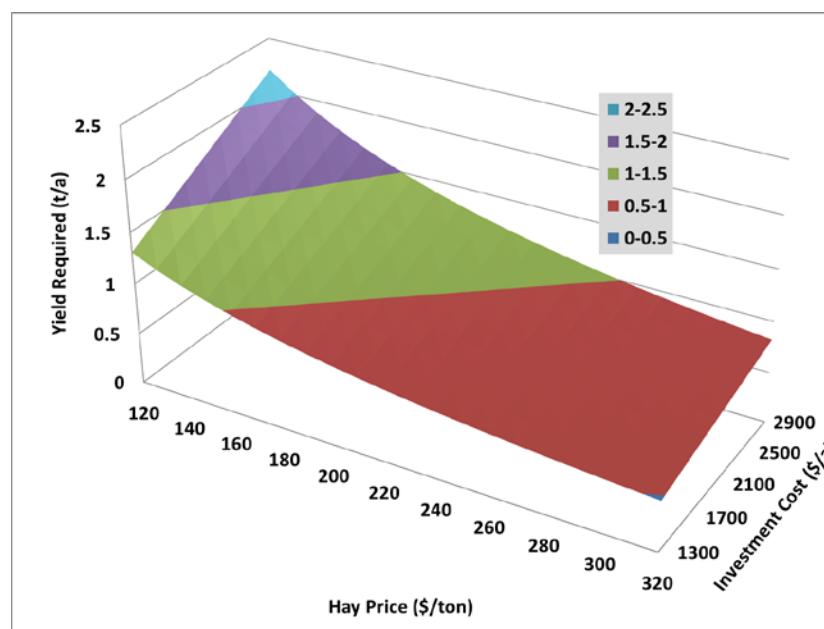
## Description of Subsurface Drip Irrigation (SDI) Systems in California.

We have been observing installation of drip systems on 12-14 farms in California during 2013-2015. Subsurfacedripirrigationis defined as theapplication ofwaterbelowthesoilsurface through emitters with discharge rates generally in the same range as surface dripirrigation (ASAE Standards 2005). Although SDI has been a part of irrigated agriculture in the USA for over 50 years, its nationwide use of SDI in the USA has increased of 59% between 2003 and 2008, which reached 260,000hectare acres in 2008 (USDA-NASS 2009). Surface drip irrigation (DI) has increased with a more modest rate of 23% during the same period.

In alfalfa, drip lines with a lifetime of 6 to 12 years are typically buried8 to 18" below the soil surface on 30'-80" centers between lateral drip lines, depending upon soil type. The most common spacing on farms has been 40" spacing, with 10-12" depth, with regular spacing between emitters at 12-16" (note that ideal spacing parameters are dictated by soil type and other factors). A pressurized system (pumps) as well as a filtering and filter maintenance system are necessary for SDI in all crops – as are water treatment capabilities and the ability to apply fertilizers through the system. Most of the systems we have observed source water from wells, whereas some have surface water sources, and in those cases settling ponds or small reservoirs may be necessary to improve reliability of water supply and enable settling of suspended particles.

## Key Potential and Observed Advantages and Disadvantages of SDI in alfalfa

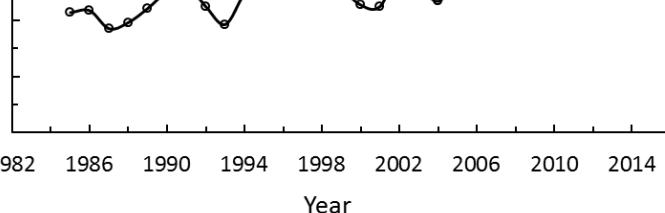
**Yield.** Both from a theoretical basis, and from observations, water management in alfalfa under SDI has the potential to significantly improve yields in alfalfa. Yield advantages have been widely seen with tomato (Hartz and Hanson, 2009) and in experimental and observational evidence with alfalfa (Hutmacher, 2001) and with growers (Michael, 2009), across many types of soils. Why is this? There are several key mechanisms which may lead to improved yield in alfalfa, as compared especially with surface irrigation systems (the dominant system in California), but also with some sprinkler systems. These will be detailed below with regards to irrigation management. We should be careful in our analysis here, since all three systems (flood, sprinkler, and drip) in alfalfa have the capability to be improved so as to improve yields (e.g. re-designing and automating surface systems, or site-specific sprinkler systems, or improved scheduling and soil moisture monitoring-e.g. Neibling et al., 2009). But there are some innate



**Figure 2.** Yield required to justify SDI at various investment costs and hay prices. This considers a 15 year infrastructure depreciation and 6 year tape life, not other differences in operating costs.

qualities of water management with SDI which are likely to improve yields if implemented successfully. On the other hand, we would have to say that improvement in yields is likely to be a requirement of SDI in alfalfa, due to the differences in costs compared with less-expensive surface and sprinkler systems (Figure 2).

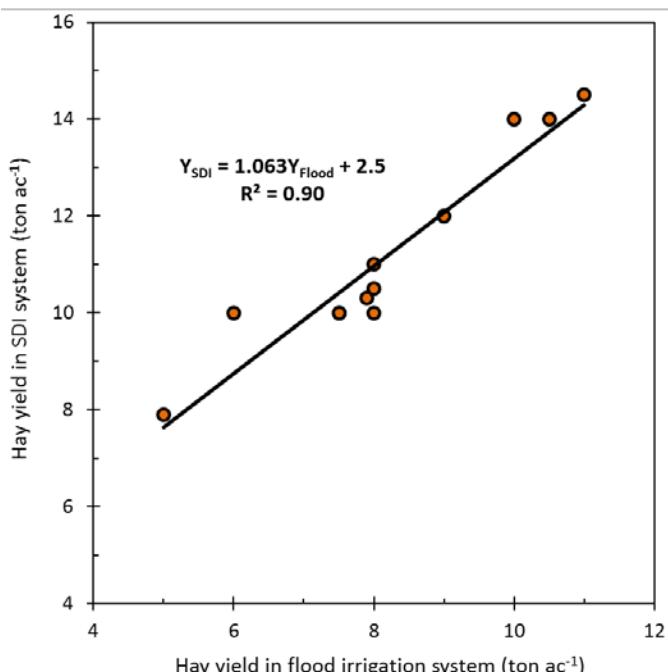
**Costs/Benefits.** The cost of SDI installations in alfalfa fields is clearly been an important disadvantage of SDI systems in alfalfa, and has been the key limiting factor to adaptation of the technique historically. However, these costs can be justified if yields are improved and/or price of the product is sufficient to cover costs (Sandén et al., 2011). During the past 20 years, the industry has seen dramatic increases in the value of alfalfa hay, which exceeded \$200/ton for the first time in 2007, and has been most frequently priced from \$180 to over \$300/ton during the past 8 years (Figure 3). This has fundamentally changed the cost/value equation for growers for SDI and other improvements. In our review of



**Figure 3.** Price of alfalfa hay, California, 1984 through 2014 (USDA-NASS and Hay Market News).

grower investment costs, these have ranged from a low of \$800-\$1,000/acre to nearly \$3000/acre, with typical costs ranging between \$1600-\$2200/acre.

The yield required to justify the cost of SDI in alfalfa can be seen in Figure 2 – modelled with hay prices between approximately \$160 to \$280/ton and investment costs in the \$2,000 range, typically from less than  $\frac{1}{2}$  ton to  $1\frac{1}{2}$  ton is required to justify the system (utilizing a 15 year infrastructure lifespan and a 6 year drip lifetime). This does not include other differences in costs between the system, such as labor, maintenance, gophers, etc. In our survey of growers, they estimate that yields have been improved an average of 2.5 tons/acre compared with their check flood systems (Figure 4).



**Figure 4.** Estimation of yields in SDI systems by growers, compared with their check flood systems on 11 California ranches (survey data).

**Distribution Uniformity over Space.** One of the key advantages of SDI systems, when properly spaced, is to improve distribution uniformity (DU) over a field. Check flood systems, especially, may have built-in problems with uniformity due to greater times available for water infiltration at the top vs. middle vs. bottom of the field, especially with long ‘runs’, sandy soils, or highly variable soils. This is typically not much of a problem in SDI systems, which can apply very close to the same application rate throughout the entire field (although SDI systems must be designed for high DU). Well-tuned sprinkler systems also have this advantage over surface systems, but some sprinkler systems may have distribution problems depending upon the influence of wind,uzzling, and the design of the system. The spatial distribution of water in across the profile is likely an advantage of SDI for alfalfa given its highly distributed broadcast planting pattern. SDI systems particularly have an advantage over check-flood systems at the tail-ends of fields and tops of fields, where stand (and yield) losses are common due to standing water and other irrigation problems associated with flood systems.

**‘Corrugation’ Yield Patterns in SDI Fields.** One problem with SDI systems we have observed is less-than-optimum distribution uniformity on some soil types, depending upon the spacing of lateral SDI lines and water management

(Figure 5). This results in a ‘corrugation’ yield pattern, with alternating higher-and lower-yielding strips, with higher yielding crops immediately over the drip lines – in many cases we have estimated yield losses due to this pattern to be in the 10-20% range, in spite of over-all excellent yield levels in the SDI system over the whole field. While this should be listed as a disadvantage currently (depending upon soil types), this can be addressed through spacing changes (reducing spacing to less than 40”, depending upon soil type), or perhaps timely flood irrigation events. The corrugations are mostly observed during the first year of the stand and become less apparent afterwards.

**Distribution Uniformity over time.** One of the key advantages of SDI in alfalfa is the ability to quickly apply a uniform irrigation to an entire field. Depending upon flow rates, many surface systems require from 2-12 days to irrigate a 80-100 acre field. Similarly wheel-line sprinklers require many days to irrigate a field (note that center pivots can also apply water very quickly to a field). This may not seem important, but in a 26-30 day growth period, this can have a huge effect on average yields over the field due to delays in supplying water to certain sections. Timing limitations means that many parts of a field are not irrigated for many days after water is required, causing a built-in drought period for sections of the field that may last for weeks. This appears to be a major advantage of SDI systems.

**Labor.** SDI systems have the promise of reduced labor requirements, and this has been demonstrated on several farms. Certainly, a well-designed system can be nearly fully automated, compared with many surface systems which require full time irrigators. However, additional labor is likely to be required for scouting for rodent infestations and fixing leaks in the system,

Improvement in Yields in Alfalfa due to SDI may be due to

- Better Distribution Uniformity over the Field
- More Rapid Application of Water over time
- Prevention of wetting-drying patterns in the field, continual supply of water to the plant
- Irrigating closer to harvests
- Irrigating small amounts when needed
- Maintaining oxygen levels in the soil

and fine-tuning irrigation strategies. Additionally, finer management skills are likely to be required in SDI systems to monitor irrigation schedules, water quality, and system performance.

**Rodent Damage.** Rodent damage, particularly the potential for gopher, vole, or squirrel damage, is probably the key practical disadvantage and main barrier of adaptation of SDI currently. Some environments and locations appear to have far greater rodent pressure than others. Gophers in particular, due to the ideal habitat represented by alfalfa (plenty of food, cover, and undisturbed soil) can be devastating to SDI in alfalfa, and several SDI installations have been abandoned due to rodent damage, so its importance should not be underestimated. While rodent damage to alfalfa stands is likely no different in SDI compared with sprinklers (where it is also a significant problem), at least in sprinkler-irrigated fields it does not ruin the irrigation system. Rodent burrows are flooded with surface irrigation methods, reducing the populations of gophers with flood irrigation. However, only SDI is under threat due to chewing on the drip lines and leaks resulting from rodent activity.

A range of techniques can be used to manage rodents. Rodent damage can be reduced by initial soil preparation (deep ripping), and a combination of frequent monitoring, scouting for sources of invasion, use of many techniques including trapping, poisoning, the use of predators (owl boxes), the use of repellents such as Protec-T. Many of these techniques require further evaluation as to their effectiveness, but a high level of management and vigilance should be considered a requirement for effective management of SDI in alfalfa.



**Figure 5.** SDI generally results in excellent Distribution Uniformity throughout the field, as in this Imperial Valley field (left). However, a ‘corrugation’ effect can be seen on some soil types and some lateral spacing, resulting in poorer growth between lateral drip lines, as per this field in Fresno County (right). This may be especially seen during early root development, but can be mitigated by occasional flood irrigations or closer lateral spacing.

**Crop Rotation.** Alfalfa SDI fields would likely be rotated with another crop such as corn, wheat, cotton or tomato over a 6-12 year period, leaving the system in place, so the return on investment can be optimized. Crop rotation may prove to be an important aspect of profitability and viability

of the system as a whole. Many of the growers we spoke with plan their systems to accommodate several crops – either starting with alfalfa or starting with another crop. Systems which install SDI for crops such as tomato have rotated to alfalfa, having paid most or all of the costs of the system with the tomato crop. However, the spacing may not be optimized for both crops. Further research on optimum crop rotations with SDI may be necessary.

**Stand Persistence.** Some growers have theorized that stand persistence can be improved with SDI. Although we do not have clear long-term evidence, there is some preliminary evidence to support this. Stand persistence may be improved due to 1) lack of standing water on the surface, 2) less traffic influence due to traffic on dry surfaces, 3) better ‘tail end’ stands due to better drainage at the ends of fields compared with surface systems, 4) lack of soil cracking on cracking clay soils. Several SDI alfalfa fields have now been in place for over 4-8 years with good success, and an experiment comparing SDI with check flood at El Centro, we have already observed significant tail-end alfalfa stand damage due to flood irrigation, whereas stands are excellent in the SDI field after 2 years of production.

**Water Quality, Evaporative Losses.** The low evaporative losses (due to the low evaporation off of relatively dry soils) is a key advantage of SDI vs. surface or sprinkler systems, when properly designed and operated. Additionally, SDI systems result in zero runoff – water moving off of check flood irrigation fields, which has been a major issue for water quality, since pesticides or particulates can move off of fields (Prichard, 2010). Growers are under tremendous pressure to minimize these sources of pollution, and SDI offers a key advantage for water quality environmental impacts.

**Water Savings.** We will not comment extensively here on the potential for water savings with SDI. However, depending upon the efficiencies of the system to which it is compared, water savings can be substantial, especially on sandy soils. Huttmacher et al. (2001) and others have noted that SDI systems may result in increased yield, which may actually increase water demand. However, since application efficiencies are greater and yields increase, the Water Use Efficiencies of alfalfa under SDI are likely to be greater. Since ET is directly related to yield in alfalfa, no change in actual utilization of water is expected – the major changes would be in the efficiency of application (reduction in runoff, evaporation, etc.)

**Irrigation Scheduling.** SDI offers a key advantage in designing and implementing irrigation schedules with a higher level of control. Growers can choose virtually any irrigation schedule (e.g. 4 hrs/day, 12 hrs/day, every other day, etc.), or ‘spoon feeding’ water and fertilizers to the crop to precisely meet demand. There is significant evidence for increased yields with SDI, which is likely due to the avoidance of periodic drought and ability to continually provide sufficient moisture for alfalfa crops under unsaturated conditions, which in turn results in improving oxygen circulation in the root zone. The capacity to provide water directly to the root zone exactly as needed is a key advantage of SDI.

**Influence of Harvests on Irrigation.** Alfalfa is unique among crops in that harvest scheduling must be considered when designing irrigation methods and management practices. SDI has some key advantages in this regard. In check flood fields (and in many sprinkler irrigated fields), growers must dry down the crop for 7-20 days before, during, and after harvest. Growers have discovered that they can irrigate much more closely to a harvest period with SDI, reducing drought stress effects that result from harvest schedules. Although theoretically, one could

irrigated during harvest, growers have found that to be impractical, and utilize the harvest period to repair SDI systems and control gophers.

**Salinity.** Salinity may be a key limitation for SDI systems. Buildup of soil saline conditions could occur between drip lines, or at different levels of the soil if steps are not taken to control salinity. This can be a major issue in some regions which have high salinity in their irrigation sources, such as the Imperial Valley. Irrigation scheduling in combination with introducing non-SDI methods (sprinklers or flood irrigation) in combination with SDI are important strategies for controlling salinity in saline affected areas. Design and drip line spacing should also account for salinity, in such a way to achieve a certain degree of overlap among the wetted areas, as salts tend to accumulate along the wetted fronts (or fringes). Overlaps among wetted areas are thus intended to keep salt well diluted, thus preventing harmful salt concentrations.

**Need to Retain Diverse Water Application methods.** Our observations have led us to believe that growers should try to retain other methods of water applications in their SDI installations, including the ability to flood irrigate, and/or sprinkle irrigate. Why is this necessary? Sprinkler irrigation is nearly universally recommended for stand establishment of alfalfa, including with surface-irrigation systems, due to the need for small amounts of water applied to the surface and the need to prevent crusting. Drip lines buried 8-12" deep are not likely to supply moisture uniformly to the soil surface for seedling growth. After establishment, an occasional flood (or sprinkler) irrigation is likely to be beneficial on some soil types. Its purposes would be 1) to provide an initial full uniform soil water profile before significant growth to promote deep rooting patterns, 2) Improve crop growth between laterals (see Figure 5), 3) suppress gopher habitat, and 4) to control salinity through leaching

**Key Opportunities for Future Research and Improvement.** Since this method has not been widely adapted in alfalfa, there are a range of opportunities for improvement of this system as applied to alfalfa. Important areas for further research include;

- Innovative techniques for rodent management in alfalfa
- Prediction of optimum spacing and depth of driplines for alfalfa under different soil types
- Irrigation scheduling under SDI systems to maximize yield
- Influence of SDI on quality, longevity of stands.
- Interactions of SDI with controlled traffic
- Ability of SDI to conserve water and perform under deficit (drought) conditions
- Interactions with varieties.
- The performance of SDI under different crop rotations
- Economic returns of SDI under different economic and soil conditions

## Conclusions

Subsurface Drip Irrigation, although currently practiced by a minority of farmers, has the capacity to improve yields and improve water use efficiency. The key mechanisms for improvement in crop performance are likely the ability to 1) maintain continuous water supply and better soil moisture conditions ('spoon feeding') to the crop, 2) Better distribution uniformity over space and time for both water and nutrient applications, 3) prevention of wetting-drying cycles which may result in lack of water during sensitive growth periods as well as lack of oxygen to root systems. Key limitations of SDI methods include cost of installation,

which must be justified by higher yields, and management of rodent damage and water quality. Although one must be cautious about its limitations, the ability of SDI to achieve higher yields in practice should be viewed as an important strategy for increasing water use efficiency of irrigated alfalfa production systems. UC web resources for SDI can be found at:  
<http://alfalfa.ucdavis.edu>

## References

- Hartz, T. and B. Hanson, 2009. Drip Irrigation and Fertigation Management of Processing Tomato. University of California Vegetable Research and Information Center.[http://vric.ucdavis.edu/pdf/TOMATO/tomato\\_drip%20irrigation%20and%20fertigation%20mgmt%20of%20processing%20tomato%202009\\_05.pdf](http://vric.ucdavis.edu/pdf/TOMATO/tomato_drip%20irrigation%20and%20fertigation%20mgmt%20of%20processing%20tomato%202009_05.pdf)
- Hutmacher, et al., 2001. Subsurface Drip and Furrow Irrigation Comparison with Alfalfa in the Imperial Valley. IN Proceedings, 31st California Alfalfa & Forage Symposium, 11-13 December 2001, Modesto, California, UCCE and University of California, Davis, CA 95616 See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Prichard, T. 2010. Preventing Off-site Movement of Pesticides in Alfalfa. IN Proceedings, 2010 California Alfalfa & Forage Symposium and Corn/Cereal Silage Mini-Symposium, Visalia, CA, 1-2 December, 2010. UCCE, University of California, Davis, CA 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Michael, C. 2011. Subsurface Drip in Alfalfa: A grower's experience. In: Proceedings, 2009 Western Alfalfa & Forage Conference, December 2-4, 2009, Reno, Nevada. UCCE, University of California, Davis 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Neibling, H., G. Shewmaker, and G. Falen. 2009. Center Pivot Management for Forage Production. In: Proceedings, 2009 Western Alfalfa & Forage Conference, December 2-4, 2009, Reno, Nevada. UCCE, University of California, Davis 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Orloff, S.B., D.H. Putnam, and K. Bali. 2014. Deficit irrigation of alfalfa and grasses: what are the Impacts/Options. IN In: Proceedings, 2014 California Alfalfa, Forage, and Grain Symposium, Long Beach, CA, 10-12 December, 2014. UC Cooperative Extension, Plant Sciences Department, University of California, Davis, CA 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Putnam, D.H. 2012. Strategies for the Improvement of Water-Use Irrigated Alfalfa Systems. IN In: Proceedings, 2012 California Alfalfa & Forage Conference, Sacramento, CA 10-12 December, 2012. UCCE, University of California, Davis, CA 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Sanden, B., G. Poole, And B. Hanson., 2003. Soil Moisture Monitoring: Does it Pay? In: Proceedings, California Alfalfa and Forage Symposium, 17-19 December, 2003, Monterey, CA, UCCE, University of California, Davis 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>
- Sanden, B., K. Klonsky, D.H. Putnam, L. Schwankl, and K. Bali. 2011. Comparing Costs and Efficiencies of Different Alfalfa Irrigation Systems. IN: Proceedings, 2011 Western Alfalfa & Forage Conference, Las Vegas, NV, 11-13 December, 2011. UCCE, Plant Sciences Department, University of California, Davis, CA 95616. See: <http://alfalfa.ucdavis.edu/+symposium/proceedings/search.aspx>

# **Irrigation strategies for grapevines in the San Joaquin Valley: Comparison of table and wine grape vineyards.**

Larry E. Williams, Kearney Agricultural Center, 9240 S. Riverbend Avenue, Parlier, CA 93648  
and

Department of Viticulture and Enology, University of California, Davis, CA 95616  
Phone (559) 646-6558, FAX (559) 646-6593, [lewwilliams@ucanr.edu](mailto:lewwilliams@ucanr.edu)

## **Introduction**

The San Joaquin Valley has approximately 60% of California's wine grape acreage. The majority of the wine grapes produced in the central/southern portions of the San Joaquin Valley are used for bulk wine production and therefore yield is still important to a grower's profitability. Fruit used to make red wines from these areas typically have low acid, color and tannins but more veggie taste and aroma (Williams, 2012). In recent years efforts have been made to increase the quality of the grapes produced in this area.

Approximately 90% of California's table grape acreage (~ 94,000 bearing acres) is located in the Southern San Joaquin Valley with most of the remaining acreage in the Coachella Valley. In 2013, 117 million box units of table grapes were sold with a crop value of \$1.70 billion (California Table Grape Commission). Recent developments in the table grape industry include the introduction of new cultivars and overhead trellis systems. Fruit quality characteristics for table grapes include among others, large berries,

## **Cultural practices used in the production of wine and table grapes**

Canopies of wine grape vineyards in the Southern San Joaquin Valley are typically a sprawl and the vines are spur pruned and cordon trained. There may be a catch wire located above the cordons. Few cultural practices are performed on the vines and many vineyards are being mechanically harvested to reduce costs.

Most table grape cultivars are spur pruned and cordon trained, with the exception of Crimson Seedless and Thompson Seedless grapevines which are head trained and cane pruned. Previously the typical table grape trellis system consisted of a stake and a cross-arm (T trellis) for most cultivars and locations. More recently vineyards are being planted with various forms of overhead arbor systems. Other practices performed on table grape cultivars are aimed at reducing berry number so that there are more carbohydrates available for the remaining fruit. This includes removing clusters that are poorly shaped or developed or removing berries from individual clusters. This entails the removal of groups of berries from the rachis tips or from the ends of laterals. Removing this fruit may also assist in facilitating the harvest of the remaining clusters. Lastly, leaf removal in the vicinity of the clusters may be performed on many colored cultivars. As light is a requirement for the formation of many of the pigments in the berry's skin, such a procedure will assist in advancing the maturity of the fruit. The removal of shoots without clusters earlier in the growing season will also assist in allowing more light into the fruiting zone and perhaps increase bud fruitfulness

Quality aspects of table grapes include berry size and lack of blemishes (to include sunburn, a browning of the fruit). Berry color of red and black cultivars is also an important fruit

quality characteristic. Gibberellic acid ( $GA_3$ ) has been used since the 1960's to increase the size of seedless table grapes. Many of the seedless cultivars are sprayed with  $GA_3$  at various phenological stages to reduce the number of berries that set and increase cluster lateral length and increase berry size (pre-bloom and at bloom and at berry set, respectively). Girdling (removal of the phloem tissue around the trunk) is used to increase berry size of several seedless table grape cultivars when performed at berry set. Girdling may also be used at berry softening (veraison) to enhance the color of cultivars such as Flame Seedless. The application of ethylene producing products, such as ethrel, at veraison will also enhance the development of color of colored berries.

### **Water Use of grapevines in the San Joaquin Valley**

Water use of Thompson Seedless grapevines grown in a weighing lysimeter at the Kearney Agricultural Research and Extension Center and used for raisin production ranged from 811 to 865 mm (32 – 34 inches) across three years (Williams et al., 2003). The same lysimeter vines farmed as table grapes used a mean of 773 mm (30 inches) across two years (Williams and Ayars, 2005a). It should be pointed out that girdling a grapevine will reduce stomatal conductance as long as the girdle remains open (Williams et al., 2000). Once it heals stomatal conductance will increase to pre-girdle values. The study by Williams and Ayars (2005a) also found that water use will decrease when the vines are girdled and increase to pre-girdle values after it heals. Seasonal water use of table grape vineyards using overhead arbor or gable trellises should be greater than vine's using a smaller trellis system (Williams and Ayars, 2005b). Data collected by the author on Thompson Seedless grapevines trained to an overhead trellis and grown in the weighing lysimeter used between 950 and 1000 mm (37 and 39 inches) of water. The maximum crop coefficient ( $K_c$ ) of those vines was 1.4.

Williams and Ayars (2005b) found that the calculated  $K_c$  across the growing season was a linear function of the amount of shade measured at the soil surface beneath the canopy (also called fraction of ground coverage by others) at solar noon. Subsequently, shaded area was measured beneath the canopy of Merlot grapevines grown Madera County across five growing seasons and a seasonal  $K_c$  determined from the following equation:  $K_c = 0.017 * \text{percent shaded area}$  (equation reported by Williams and Ayars (2005a)). The maximum estimated  $K_c$  in that study was calculated to be approximately 0.8. Estimated  $ET_c$  of those vines from budbreak to the end of October ranged from 663 to 760 mm (26 to 30 inches) of water. The distance between rows in that vineyard was 3.66 m (12 ft.). Vineyard water use of wine grapes using the same trellis (canopy size) but with closer row spacing would be greater.

### **Irrigation strategies**

Numerous factors should be considered when devising an irrigation strategy for the production of table grapes. Most studies conducted on grapevines have indicated that water deficits affect vegetative growth to a greater degree than fruit growth (Williams and Matthews, 1990; Williams et al., 2010a; 2010b). Thus it is important not to stress vines used for table grape production during that period of canopy development. An adequate canopy is a necessity to protect the berries from sunburn. Subsequent to budbreak, shoot growth increases rapidly with the canopy reaching its maximum size sometime between berry set and veraison. Another generalization derived from irrigation studies on grapevines is that vegetative growth is much more affected by water deficits than is photosynthesis. Therefore, once the canopy has

developed sufficient leaf area moderate water deficits could be imposed such that the leaves remain fully functional while the rate of shoot growth is much reduced. This could be appropriate for wine grapes.

The degree to which berry growth is affected by water deficits is dependent upon the time when the water stress is imposed. Berry growth is most susceptible to water stress during Stage I of berry growth (between bloom and 4 to 5 weeks later). It is during this time cell division is occurring in the berry and it is only during Stage I when cell division occurs. The ultimate size of a berry is determined in part by the number of cells, which is a function of cell division. Therefore, if cell division is reduced by water stress during this stage then final berry size is reduced. Extra water applied later on will not overcome a stress imposed during this stage. Cells will initiate growth or elongate during Stages I and III of berry growth. Stage III occurs subsequent to veraison (when berries begin to soften and colored varieties begin to turn color). Growth during Stage III is less susceptible to water deficits than during Stage I. From the above discussion it is apparent that if the production goal is to maximize berry size one should not impose a water stress during the period from bloom to 5 weeks later.

### **Conclusions:**

While it has been demonstrated in numerous studies (Williams, 2012 is one example), that there is an increase in yield per unit applied water as applied water amounts decrease, or an increase in water use efficiency, a wine grape grower's profitability is still based upon the quantity of fruit produced in the southern San Joaquin Valley. Therefore, while sustained deficit irrigation (SDI) or regulated deficit irrigation (RDI) may be one means to increase fruit quality in other grape growing regions, the significant reductions in yields measured in a Merlot vineyard (Williams, 2012) indicate that deficit irrigation may not be economically sustainable in the southern San Joaquin Valley. If water is insufficient to supply an entire season's irrigation demand, the author has found that full irrigation between berry set and veraison, followed by deficit or no irrigation, will maximize yield in the San Joaquin Valley. Conversely, while the greatest opportunity to reduce berry size of wine grapes, if that is the production goal, is during Stage I of berry growth, water deficits between berry set and veraison had the greatest negative effect on yield of 16 red, wine grape cultivars (unpublished data).

Based upon the above discussion (large berries are an important quality characteristic for table grapes), it would appear that the opportunity to save water in table grape vineyards may be minimal. However, it has been found by the author that irrigation may be reduced by 50% four weeks after berry set and have minimal effects on berry size and yield of Flame Seedless grapevines grown in the Coachella Valley or Thompson Seedless grown in the San Joaquin Valley. In addition, color of late ripening table grape cultivars such as Crimson Seedless may also benefit from deficit irrigation from veraison onwards, similar to that of wine grapes grown in cooler climates.

### **Literature Cited**

Williams, L.E. 2012. Interaction of applied water amounts and leaf removal in the fruiting zone on grapevine water relations and productivity of Merlot. *Irrig. Sci.* 30:363-375.

- Williams, L.E. and Ayars, J.E. 2005a. Water use of Thompson Seedless grapevines as affected by the application of gibberellic acid ( $GA_3$ ) and trunk girdling – practices to increase berry size. Agric. For. Meteor. 129: 85-94.
- Williams, L.E. and Ayars J.E. 2005b. Grapevine water use and the crop coefficient are linear functions of the shaded area measured beneath the canopy. Agric. For. Meteor. 132:201-211.
- Williams, L.E., Grimes, D.W. and Phene, C.J. 2010a. The effects of applied water at various fractions of measured evapotranspiration on water relations and vegetative growth of Thompson Seedless. Irrig. Sci. 28: 221-232.
- Williams, L.E., Grimes, D.W. and Phene, C.J. 2010b. The effects of applied water at various fractions of measured evapotranspiration on reproductive growth and water productivity of Thompson Seedless. Irrig. Sci. 28: 233-243.
- Williams, L.E. and Matthews, M.A. 1990 Grapevine. In: ‘Irrigation of Agricultural Crops – Agronomy Monograph No. 30’. Eds. B.A. Stewart and D.R. Nielson). pp. 1019-1059 (ASA-CSSA-SSSA: Madison, WI, USA)
- Williams, L.E., Phene, C.J., Grimes, D.W. and Trout, T.J. 2003 Water use of mature Thompson Seedless grapevines in California. Irrig. Sci. 22: 11-18.
- Williams, L.E., Retzlaff, W.A., Yang, W., Biscay, P.J. and Ebisuda, N. 2000. Effect of girdling on leaf gas exchange, water status and non-structural carbohydrates of field-grown *Vitis vinifera* L. (cv. Flame Seedless). Amer. J. Enol. Vitic. 51: 49-54
- Williams, L.E. 2012. Interaction of applied water amounts and leaf removal in the fruiting zone on grapevine water relations and productivity of Merlot. Irrig. Sci. 30:363-375.



# American Society of Agronomy

## California Chapter

### Session VI

## Practical Application of Nitrogen Management Strategies

**Session Chairs:**

Karen Lowell, NRCS

Richard Smith, UCCE Monterey

## **Resources to Inform Nutrient Management Planning**

**Tim Hartz, Ph.D., University of California, Davis, [tkhartz@ucdavis.edu](mailto:tkhartz@ucdavis.edu), 530-752-1738**

**Daniel Geisseler, Ph.D., University of California, Davis, [dgeisseler@ucdavis.edu](mailto:dgeisseler@ucdavis.edu),  
530-754-9637**

**Danyal Kasapligil, Delavalle Laboratory, Inc., [danyal@dellavallelab.com](mailto:danyal@dellavallelab.com), 831-750-4509**

**Karen Lowell, Ph.D., USDA Natural Resources Conservation Service,  
[karen.lowell@ca.usda.gov](mailto:karen.lowell@ca.usda.gov), 831-424-1036 x119**

### **Sources that contain nutrient values and crop requirements**

#### **FREP Fertilization Guidelines**

These guidelines are based on research results from studies carried out in California and elsewhere. Detailed information is summarized in a user-friendly, easily searched interactive database. Currently available crops include almonds, walnuts, wheat, processing tomatoes, corn, cotton, grapes, rice, broccoli, lettuce, alfalfa, and strawberry. Cauliflower and pistachio currently under development, and more crops will be added as resources allow.

<http://apps.cdfa.ca.gov/frep/docs/Guidelines.html>

#### **FREP Research Database**

This database aims to make the wealth of information contained in FREP research projects readily available, easily understandable, and convenient for growers to implement. Searchable database by crop, keyword or county.

<http://www.cdfa.ca.gov/is/frep/Default.aspx>

#### **USDA Tool to Calculate Nutrient (N, P, K) Removal by Harvested Crop**

Crop Nutrient Tool at following website estimates N, P, and K uptake of various. Need to input yield.

<http://plants.usda.gov/npk/main>

#### **International Plant Nutrition Institute (IPNI) – Crop Nutrient Removal Calculator**

The crop nutrient removal calculator (NRC) estimates crop nutrient removal of nitrogen (N), phosphorus (expressed as P<sub>2</sub>O<sub>5</sub>), potassium (expressed as K<sub>2</sub>O), and sulfur (S) for a broad, and continually expanding, list of field crops.

<http://www.ipni.net/article/IPNI-3346>

## **University of California Resources**

### **UC Nutrient Management for Fruit, Nut and Vegetable Crops**

<http://ucanr.edu/sites/nm/>

Can search by crop or by topic for information. Links to UC publications with nutrient management guidance prepared by UC Farm Advisors and Researchers.

Specific crops:

UC Fruit and Nut Research and Information Center: <http://fruitsandnuts.ucdavis.edu/>

UC Vegetable Research and Information Center: <http://vric.ucdavis.edu/>

A range of other topics also: <http://ucanr.edu/Farming/>

---

### **UC Small Farms website with info re: growing vegetables, many links:**

[http://sfp.ucdavis.edu/pubs/Family\\_Farm\\_Series/Veg/](http://sfp.ucdavis.edu/pubs/Family_Farm_Series/Veg/)

- Guidelines for fertilizer applications based on soil test results for CA veg crops  
[http://sfp.ucdavis.edu/pubs/Family\\_Farm\\_Series/Veg/Fertilizing/vegetables/](http://sfp.ucdavis.edu/pubs/Family_Farm_Series/Veg/Fertilizing/vegetables/)
- Tips on irrigating vegetables  
[http://sfp.ucdavis.edu/pubs/Family\\_Farm\\_Series/Veg/Irrigating/](http://sfp.ucdavis.edu/pubs/Family_Farm_Series/Veg/Irrigating/)

### **UC Cost Studies**<http://coststudies.ucdavis.edu/>

Detailed analysis of the cost to produce wide range of crops in California. These are helpful if you are new to producing a crop and want basic information to begin a nutrient management planning process. Typical application rates for water and fertilizer, as well as equipment, labor, and other management parameters included. The information in these reports is very general and reflects typical grower practice, and should *not* be viewed as UC recommendations. Examples:

- 
- Fresh Market Broccoli SLO 2012  
[http://coststudies.ucdavis.edu/files/Broccoli\\_CC2012.pdf](http://coststudies.ucdavis.edu/files/Broccoli_CC2012.pdf)
  - Avocado, conventional establishment and production 2011  
<http://coststudies.ucdavis.edu/files/2011/AvocadoConventionalVSBSLO2011.pdf>
  - Strawberries 2011  
[http://coststudies.ucdavis.edu/files/Strawberry\\_SC\\_SMV2011.pdf](http://coststudies.ucdavis.edu/files/Strawberry_SC_SMV2011.pdf)

---

### **UC Agricultural Publications**

<http://anrcatalog.ucdavis.edu/>

Wide range of publications by UC Farm Advisors and researchers on many important California crops. Some are available to download, but many must be purchased.

---

### **Additional sources for nutrient management information**

#### **SARE Resources.**

Sustainable Agriculture Research and Education resources, including a bulletin found here that could be very useful for a producer/manager who wants to try to formalize observations to guide future management decisions:

<http://www.sare.org/Learning-Center/Bulletins/National-SARE-Bulletins>

## **UC Extension Resources by County**

Scroll down and click on your county to see what the extension publications are. If there is another county that you know commonly grows your crop, try checking there as well.

[http://ucanr.edu/sites/anrstaff/Cooperative\\_Extension/](http://ucanr.edu/sites/anrstaff/Cooperative_Extension/)

Example of the kind of publications by county, see Monterey County Crop Notes here:

[http://cemonterey.ucanr.edu/news\\_880/Monterey\\_County\\_Crop\\_Notes/](http://cemonterey.ucanr.edu/news_880/Monterey_County_Crop_Notes/)

## **UC Farm Advisor Blogs:**

These are by topic, see them here:

[http://fruitsandnuts.ucdavis.edu/ce/Farm\\_Advisors\\_Blogs/](http://fruitsandnuts.ucdavis.edu/ce/Farm_Advisors_Blogs/)

## **UC Blogs and Newsletters by County for Vegetable Crops**

Links to a range of newsletters and blogs from around the state.<http://vric.ucdavis.edu/main/newsletters.htm>

## **UCCE Topic in Subtropics Newsletter**

A good source for info re: avocado research. Focus seems to be tree crops.

[http://ceriverside.ucanr.edu/news\\_418/Topics\\_in\\_Subtropics/](http://ceriverside.ucanr.edu/news_418/Topics_in_Subtropics/)

## **UC Agriculture and Natural Resources Home Page**

There are a number of resources you can access from here, explore under the headings Farm and Environment for a few Research and Information Centers (virtual centers).

<http://ucanr.org/>

## **Monterey County Water Resources Agency, Nitrogen Management Fact Sheets**

[http://www.mcwra.co.monterey.ca.us/nitrate\\_fact\\_sheets/nitrate\\_fact\\_sheets.php](http://www.mcwra.co.monterey.ca.us/nitrate_fact_sheets/nitrate_fact_sheets.php)

Topics addressed include:

- Fertilizer Management in Coastal Cool-Season Vegetables,
- On-Farm Handling of Fertilizers,
- Water Management in Coastal Cool-Season Vegetables,
- Using the Nitrate Present in Soil and Water in Your Fertilizer Calculations
- On-Farm Nitrogen Determination.

## **Irrigation Water Management**

Irrigation water management is a critical component of nutrient management in irrigated crops. A variety of resources are available to support evaluation and operation of irrigation systems and irrigation scheduling.

- <http://ucanr.edu/sites/irrmgm/>  
Irrigation Management site maintained by University of California Cooperative Extension. Links to a wide range of resources, including educational slide presentations, free publications, and evolving knowledge and technology.
- <http://www.wateright.org/>  
WATERIGHT site was developed by the Center for Irrigation Technology at California State University, Fresno with significant support from the US Bureau of Reclamation. The site contains irrigation scheduling tools, research findings and other educational and management resources.
- <http://www.itrc.org/>  
Irrigation Technology and Resource Center, housed at CalPoly. Website features many examples papers and reports that are available for download, valuable public databases, ongoing project descriptions and variety of online and inperson training opportunities.



# American Society of Agronomy

## California Chapter

### Session VII

## Manure/Compost/ Organic Amendments

### Session Chairs:

Dan Munk, UCCE Fresno

Karen Lowell, NRCS

## **Use of organic matter amendments – a grower-oriented analysis**

Daniel L. Schellenberg, Postdoctoral Scholar  
Department of Plant Sciences, University of California Davis  
One Shields Avenue, Davis, CA95616  
Phone (707) 205-7007, dschel@ucdavis.edu

Patrick H. Brown, Professor  
Department Plant Sciences, University of California Davis  
One Shields Avenue, Davis, CA95616  
Phone (530) 752-0929, phbrown@ucdavis.edu

### **Introduction**

There is a large excess of organic matter amendments including animal manure and green waste in composted and uncomposted forms in California and a lack of knowledge of how these materials may be used to benefit production of permanent crops. An exploratory project was conducted to improve our understanding of the potential benefits and concerns with the use of organic matter amendments. These materials are excellent sources of nutrients and organic matter that could benefit tree and soil health, but significant concerns exist. Focus groups were conducted in the form of group interviews with certified permanent crop advisors (CCAs) while attending the Nitrogen Workshops sponsored by the California Association of Pest Control Advisors (CAPCA) conducted January through March 2014. The goal was to test the validity and rationale of questions for design of the grower mail survey. We also conducted a mixed-mode grower survey with almond growers to approach the problem (Dillman et al., 2008).

### **Focus Groups**

The focus groups consisted of polling participants who remotely responded with clickers (Turning Technologies, Youngstown OH). This technology allows each participant to answer each question once, and then displays the results with the response percentages and the total number of responses. In order to ensure adequate coverage of the CCA service area, focus groups were held in Modesto, Woodland, Fresno and Tulare. Up to 278 total active focus group participants were polled. Results were aggregated to ensure an adequate sample size, and response percentages are reported as weighted means and weighted standard errors.

The first series of questions asked focus group participants if they work with growers of *any* permanent crop that use or do not use organic matter amendments. Response percentages show the use of all forms of organic matter amendments including composted manure (63%), raw manure (39%) and green waste (41%) as well as lagoon water (22%), cover crops (76%) and chopped prunings (95%). The organic matter amendment with the highest use was composted manure with an even greater use of cover crops and chopped prunings. The lowest use was lagoon water perhaps due to the cost & logistics of its delivery or the food safety risk (Table 1).

Additional questions included use of manure and green waste during planting, non-bearing and/or bearing stages, application during postharvest to bloom and/or spring to summer, placement in the tree berm and/or alleyway and management including incorporation, light disk or no-tillage of any permanent crop. Management differences of animal manure and

green waste varied. The practice of no-tillage with animal manure (59%) was lower than green waste (72%). Placement in the tree berm (48% and 55%) and across the whole orchard (36% and 31%) demonstrates growers target organic matter amendments near the root zone. Timing from postharvest to bloom (76% and 77%) aims to maximize the interval between application and harvest. The majority of organic matter amendments were applied at planting and during the non-bearing stage (53% and 40%) as well as at all stages (37% and 47%). Fewer participants reported use during the bearing stage only (10% and 13%) (Table 2).

Participants were also polled on their management of cover crops, chopped prunings and chipped wood. The use of chopped prunings coincided with minimum or no-tillage (90%). Cover crops were either tilled in (54%) after being seeded and grown for biomass or maintained as ground cover under no-tillage (46%). Burning tree wood after orchard life was minimal (6.4%) with the majority of wood being reported as hauled away (72%) after chipping (Table 2).

Finally, participants were asked to rank issues of concern for the use of animal manure and green waste including food safety, cost & logistics and nutrient availability. Food safety was the greatest concern (52%) for animal manure and less of a concern for green waste (38%), while uncertainty in nutrient availability was the secondary concern (42%) for both materials (Table 3). These results suggest approaches that minimize the risk of food safety and enhance nutrient availability are important considerations with cost & logistics also playing a role.

### **Grower Survey**

To understand the use of organic matter amendments specific to almond, a mail survey was developed to reach the population of California almond growers using membership lists provided by the Almond Board of California and by the Blue Diamond Growers (Dillman 2008). The final survey was delivered to 6,237 unique addresses. The survey opened with a question about what areas benefit from the use of organic matter amendments and was followed by questions relevant to the orchard life cycle including practices at planting, non-bearing and bearing stages. An emphasis was made to separate the timing, placement, management and issues of concern for composted and raw manure as well as green waste compost and uncomposted green waste. A question was included about grower access to manure and green waste. The user group is categorized by grower responses indicating the use of organic matter amendments during planting, non-bearing and/or bearing of almond. The avoidance group is categorized by grower responses indicating no use during any stage of orchard growth and development.

Preliminary survey results were gathered and analyzed as of November 30th 2014. The total number of replies was 1657 out of a total of 6,237 mailings for a 26.6% response rate. The number of surveys returned was 989 with 89 completed over the internet and the remainder by mail. There were 398 were opt outs with the remainder as unprocessed mail. The response rate in acreage was higher at 31.9% or 300,157 acres out of ~940,000 reported in the 2013 almond acreage report (NASS, 2013). The participants indicating high or very high use was in San Joaquin, Stanislaus, Merced and Fresno counties.

Growers were asked to rank what benefits including soil biology, tree nutrition and water holding capacity are expected from the use of organic matter amendments. The greatest benefit was attributed to soil biology for both the user and avoidance groups (50% for both) followed by

tree nutrition (38% and 36%). A greater percentage of the user group reported water holding capacity as the least benefit of the three. Food safety was the issue of greatest concern with a greater response from the avoidance (70%) versus user group (58%), followed by nutrient availability as secondary for the user groups (49%) and cost & logistics secondary for the avoidance group (46%). Growers in the user group reported good or better access to manure (66%) compared to green waste (53%). Conversely, the avoidance group reported good or worse access to manure (84%) and green waste (94%). This result suggests there is an access issue.

## **Conclusions**

Growers attributed soil biology benefits to the use of organic matter amendments. They also appeared to use greater amounts of composted compared to raw or uncomposted materials. Grower use of composted materials fits with no-tillage practices and targets greater placement in the tree berm. Composting may resolve the greatest concern of food safety. Yet a secondary concern remains in terms of nutrient availability from the compost as well as how the compost interacts with other fertilizers. This issue may further interact with soil biology. The avoidance group of growers places a greater emphasis on food safety as a concern while reports greater difficulty with access to organic matter amendments in multiple forms.

## **Literature Cited**

- Dillman D.A., Smith J.D., Christian L.M. (2008) Internet, mail and mixed-mode surveys: Tailored design method. 3rd edition ed. John Wiley & Sons Inc., New York, NY.  
 NASS. (2013) Almond acreage report, USDA, Washington, D.C.

## **Tables**

Table 1. Response percentages from focus group participants who were polled if they work with a grower who uses or does not use organic matter amendments in different forms, lagoon water, cover crops and chopped prunings - Data reported as weighted means +/- standard errors.

	Use			Not Used		
Composted Manure	63%	±	6%	37%	±	8%
Raw Manure	39%	±	6%	61%	±	7%
Green Waste	41%	±	2%	59%	±	3%
Cover Crops	76%	±	3%	25%	±	3%
Chopped Prunings	95%	±	2%	5.1%	±	2%
Lagoon Water	22%	±	7%	78%	±	7%

Table 2. Response percentages from the focus group participants who were polled during what stage of orchard development, timing of application, placement and management are used for animal manure or green waste - Data reported as weighted means +/- standard errors.

	Plant and Non-bearing			Bearing Only			All Stages		
Animal Manure	53%	±	11%	10%	±	3%	37%	±	10%
Green Waste	40%	±	6%	13%	±	4%	47%	±	10%
	Postharvest to Bloom			Spring to Summer			All Year		
Animal Manure	76%	±	8%	14%	±	5%	9%	±	4%
Green Waste	77%	±	4%	10%	±	2%	13%	±	4%
	Tree Berm			Alleyway			Whole Orchard		
Animal Manure	48%	±	9%	16%	±	3%	36%	±	11%
Green Waste	55%	±	10%	14%	±	1%	31%	±	11%
	Incorporation			Light Disking			No-tillage		
Animal Manure	20%	±	3%	21%	±	1%	59%	±	4%
Green Waste	17%	±	3%	12%	±	2%	72%	±	6%
Cover Crops	20%	±	1%	34%	±	5%	46%	±	6%
Chopped Prunings	10%	±	3%	7.4%	±	2%	83%	±	4%
	Haul Away			Left in Field			Burn		
Chipped Wood	72%	±	1%	22%	±	5%	6%	±	4%

Table 3. Response percentages from focus group participants for how they would rank food safety, cost & logistics and nutrient availability as the greatest, secondary or least issue of concern with regard to the use of animal manure or green waste - Data reported as weighted means +/- standard errors.

Animal Manure	Food Safety			Cost & Logistics			Nutrient Availability		
Greatest	52%	±	3%	31%	±	3%	17%	±	1%
Secondary	20%	±	3%	38%	±	5%	42%	±	4%
Least	28%	±	4%	30%	±	5%	42%	±	5%
Green Waste	Food Safety			Cost & Logistics			Nutrient Availability		
Greatest	38%	±	5%	38%	±	4%	24%	±	3%
Secondary	23%	±	2%	35%	±	6%	42%	±	6%
Least	39%	±	6%	28%	±	6%	33%	±	7%

## **Implications of timing on N release from organic amendments**

David Crohn

Associate Professor and Cooperative Extension Specialist

Department of Environmental Sciences

University of California, Riverside

Riverside, CA 925021

Phone: 310-903-3733/Fax: 951-827-3993

[David.Crohn@ucr.edu](mailto:David.Crohn@ucr.edu)

Namratha Reddy

Postgraduate Researcher

Department of Environmental Sciences

University of California, Riverside

Riverside, CA 925021

Phone: 951-827-3642

[Namratha.Reddy@ucr.edu](mailto:Namratha.Reddy@ucr.edu)

### **Introduction**

Nitrate pollution is the most frequent reason that wells are closed due to groundwater quality concerns and strict budgeting is increasingly proposed as a means of reducing nitrogen (N) leaching rates. Viewed annually this is a simple concept; inputs can be balanced against outputs. The picture becomes much more complex when in-season dynamics are considered. One difficulty is that most soil N cycles through organic forms that remain largely unavailable to plants until decomposition releases inorganic N back into the soil. Once in the soil plants must compete with decomposer microbes for access to available N before it is lost to leaching or denitrification. To help understand how quickly N is mineralized from organic materials we developed an approach based on soil temperature, material carbon to nitrogen (C:N) ratios, and the rate at which decomposers break down materials as evidenced by associated carbon dioxide ( $\text{CO}_2$ ) evolution rates (Crohn 2014).

### **Model Description**

The two-equation strategy (Crohn and Mathews, 2013) assumes that decomposition happens simultaneously from two classes of organic residual matter, labile, or rapidly decomposable, and recalcitrant. The approach considers both C decomposition and N mineralization using related but separate equations. In the first equation, labile and recalcitrant C (organic matter) fractions break down at separate rates for each material. These decay rates are easily parameterized by measuring the  $\text{CO}_2$  that is given off during an incubation experiment. The decay rates are also adjusted for temperature effects so that the model can be applied throughout the year (Crohn and Valenzuela-Solano 2003).

A second equation represents N dynamics. As with C, both labile and recalcitrant N pools are explicitly represented. A fixed amount of N is released for each unit of organic N that is mineralized from each pool. Such a first order approach is standard for representing N mineralization, but it does not permit immobilization to be represented (Benbi and Richter, 2002). We include immobilization by simultaneously removing a fraction of inorganic N for every unit of C that is decomposed and placing it back into the organic N pools. This immobilized fraction is a function of the physiology and growth of the microbes engaged in the decomposition activity. The amount of inorganic N returned to organic forms therefore corresponds to the C:N ratio of the microbial decomposers and their microbial efficiency which is the fraction of decomposed carbon used by microbes for growth and reproduction, rather than for energy.

### Applying the Model

The model has been applied successfully to eight plant litter types taken from the literature with C:N ratios averaging 17.1 (Crohn, 2014; Sullivan et al. 2004). The model has been tested on our own laboratory incubations of five manures and six certified organic fertilizers. The manures had average C:N ratios of 14.6 while the average C:N ratio for the fertilizers was 4.6. Sixty day incubations were conducted on each material at 13, 23, and 33 °C. Carbon was fitted to the data with ease for all materials.

Fertilizers, plant residues and manures behaved differently when N dynamics were considered (Crohn and Mathews, 2013). The N dynamics of the manures and plant residues could be represented quite well, though with a different parameterization than the plant litter (Figure 1). The fit to the fertilizer data was not as effective as the manure data. This is likely because the C:N ratio of the fertilizers was similar to that of the decomposer microbes, a situation that makes the immobilization component of the model less meaningful. For this reason we believe that the approach is best for materials with C:N ratios above approximately 10 to 12. The fertilizer data fit a standard two-compartment first-order decay function quite well, however. Release curves for certified organic fertilizers should therefore be determined by laboratories directly from destructive sampling during controlled incubations. This is feasible because such fertilizers are much more consistent in their properties than are composts, unprocessed manures, and similar products.

For other materials, an approach based on CO<sub>2</sub> evolution measurements could be applied by commercial laboratories to estimate release rates from a wide variety of materials. Once the nitrogen components are fully parameterized, laboratories would need to measure the C:N ratios of materials and then to incubate them in order to parameterize their C decomposition rates. For laboratories, there are a number of advantages to an approach based on CO<sub>2</sub> evolution rates. This alternative is compelling because CO<sub>2</sub> is much easier to measure than soil inorganic N. CO<sub>2</sub> can be measured quickly in the headspace above the soil while inorganic N measures require destructive sampling. Sample uniformity is assured for CO<sub>2</sub> measures but not for inorganic N. In addition, CO<sub>2</sub> is conserved in the headspace once it is generated while inorganic N can be

steadily lost through denitrification during incubation experiments. To save time it may be that other laboratory measures, perhaps a form of proximate C analysis, could be used to estimate decomposition rates without the need for incubations (Valenzuela-Solano and Crohn, 2006). Once parameterized, a calculator can be constructed to give guidance as to the influence of a wide variety of materials on farm short- and medium-term N budgets. Typically relevant materials include:

- Incorporated or mulched composts
- Uncomposted greenwastes
- Manures
- Cover crops
- Post-harvest plant litter
- Roots
- Timber harvest slash

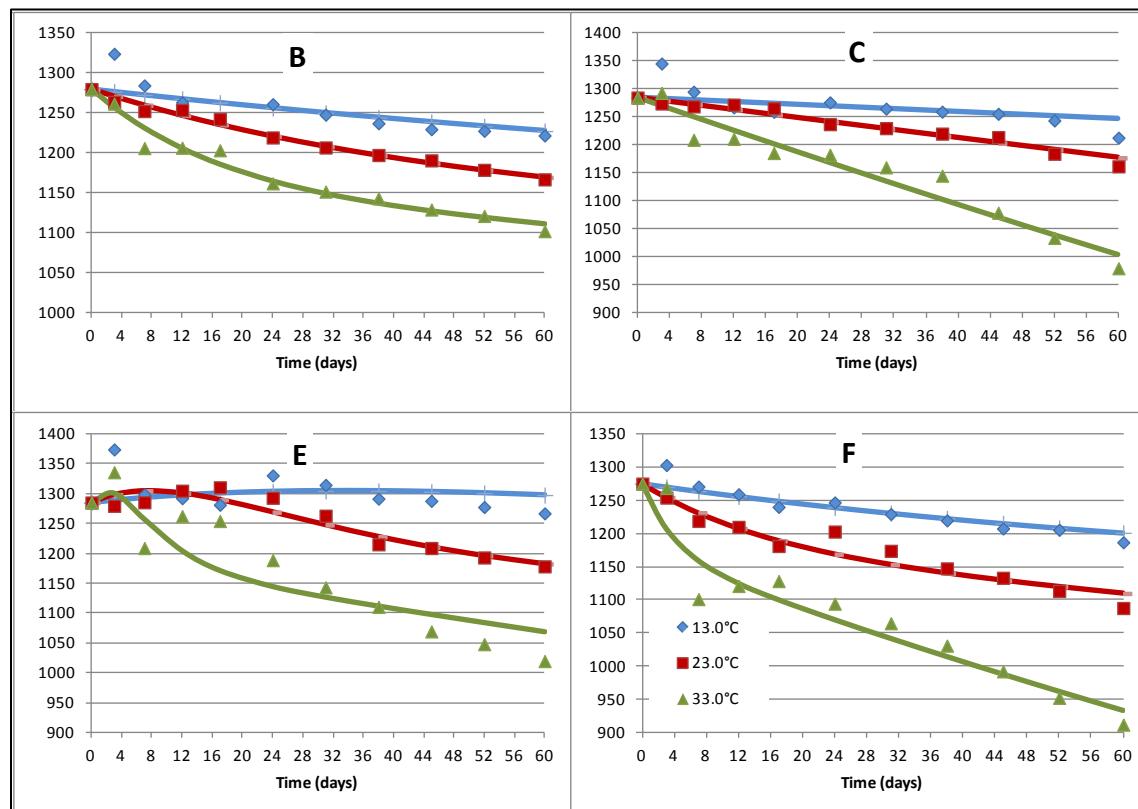


Figure 1. Fitting the net N mineralization of four of the studied manure at three temperatures based on C decomposition rates (Crohn and Mathews, 2013).

The N contained in these materials can be quite significant. A calculator would allow for N contributions from these materials to be anticipated so that fertilizers can be properly adjusted.

Appropriate fertilizer rates can save farmers money while conserving groundwater quality. Many of these materials will initially tie up N. This can actually increase the need for fertilizers, a requirement that can also be anticipated by the calculator. Without proper planning the addition of fertilizers to meet this immobilization demand can increase both costs *and* pollution since the immobilized N will be eventually be returned to leachable forms. Because the calculator can estimate the release of N on a daily basis, results can be integrated into an operations in-season fertilizer supply schedule. Of course, such a calculator necessarily presents an estimate and soil analysis will always be a prudent additional management tool.

### Current work

Having considered manures and certified organic fertilizers, we are now evaluating the model's performance with five different composts. All treatments have been incorporated at 300 kg N ha<sup>-1</sup> into sandy loam soil at constant temperatures of 15, 25, and 35 °C. The experiment is being replicated using a silty clay loam soil though only at 25 °C temperature due to limited incubator space. Our hypothesis is that soil texture will affect CO<sub>2</sub> evolution rates and their associated decay constants, but that the N components of the model will be less affected since C decay is the principal instrument driving the N release and immobilization processes.

### References

- Benbi, D. K. and J. Richter (2002). "A critical review of some approaches to modelling nitrogen mineralization." Biology and Fertility of Soils 35(3): 168-183.
- Crohn, D. 2014. A function describing nitrogen availability from organic sources. I International Symposium on Organic Matter Management and Compost Use in Horticulture 1018. Adelaide, South Australia, Australia. pp. 295-305.
- Crohn, D. M. and M. C. Mathews. 2013. Optimization of organic fertilizer schedules. 21<sup>st</sup> Annual FREP Conference. October 29-30. Fresno, CA. pp. 39-44.
- Crohn, D. M., and C. Valenzuela-Solano. 2003. Modeling temperature effects on decomposition. Journal of environmental engineering 129(12): 1149-1156.
- Sullivan, D.M., Nartea, T.J., Bary, A.I., Cogger, C.G., Myhre, E.A., 2004. Nitrogen Availability and Decomposition of Urban Yard Trimmings in Soil. Soil Science 169, 697-707.
- Valenzuela-Solano, C. and Crohn, D. M. 2006. Is the release of N from decomposing organic mulches determined mainly by their chemical composition? Soil Biology and Biochemistry. 38(2): 377-384.

## **Improving soil health and reducing on-farm waste though a large scale compost program**

Bob Martin, General Manager, Rio Farms LLC

P.O. Box 605 King City, CA 93930

Phone: 831-385-6225 x112 [chilibob@riofarms.com](mailto:chilibob@riofarms.com)

Jocelyn Gretz, Director Environmental Science & Resources, Rio Farms LLC

P.O. Box 605 King City, CA 93930

Phone: 831-385-6225 x151 [jocelyngretz@riofarms.com](mailto:jocelyngretz@riofarms.com)

### **Introduction**

Rio Farms is a family-owned vegetable farming company that was established in 1978 by Allen, David & Steven Gill. The company grows about 20 different vegetables on over 17,000 acres and is listed as one of the top 12 vegetable growers in the nation, with growing regions in King City, CA, Oxnard, CA and Yuma, AZ. The composting program was established in 2000 as a solution to an on-site onion waste problem. Fifteen years later, the program has grown to produce 20,000 tons of compost each year that is applied to fields in the King City region. Growers have observed improved soil tilth, drainage and overall soil health.

### **Composting program**

Rio Farms is a supplier and sister company to Gills Onions, a processor of fresh onion products based in Oxnard, CA. Each year hundreds of acres of onions are grown in the King City region, and a small percentage of the harvest is damaged and unusable. Prior to 2000, growers hauled culled onions back onto fields, but after time this spread diseases such as pink root and impaired future growing conditions. In addition, there was a significant cost in equipment, staff time, and greenhouse gas emissions involved with hauling onions back out onto the fields.

In 2000, General Manager Bob Martin decided to initiate a composting program to reduce the issues listed above and create a more beneficial soil amendment. The company set aside 10 acres of farmland dedicated to windrow composting. Culled onions were mixed with locally sourced products such as waste leafy green product, spent mushroom substrate, grape pomace, and green waste. After compost is created, it is blended with gypsum before applying to fields at 3-4 tons/acre. Recently, because of strict food safety demands, Keith Day Company and Gabilan Ag Services has taken over management of the program. In the past 15 years, the program has grown from generating 8,000 tons to now 20,000 tons of compost per year spread on the company's fields in King City.

### **Regulatory & Food Safety Considerations**

Although composting is one of the oldest forms of soil amendments, there are a number of regulatory and food safety related considerations that a vegetable grower must comply with

when running a composting program. Compost is regulated by California Integrated Waste Management Board (CIWMB) Regulations (Title CCR, Chapter 3.1) and enforced by Monterey County. Under these rules, compost must be maintained under aerobic conditions for a minimum of 131°F for 15 days or longer with a minimum of 5 turns. At Rio Farms, the composting process is much longer, lasting 3 or more months. Composting happens year-round but peaks when culled onions are available from September through April. Testing is required for fecal coliforms, salmonella, E. coli and metals using an FDA/EPA/ AOAC methods at an accredited laboratory, with samples coming from individual lots no larger than 5,000 cubic yards. In addition, compost must be applied a minimum of 45 days before the crop is harvested (CalRecycle, 2014).

Due to additional food safety concerns, the Leafy Greens Marketing Agreement and individual buyers (often going above and beyond LGMA requirements) also list additional best management practices such as proximity to harvested fields and cleaning of equipment (LGMA, 2013). The mushroom substrate is pre-heat treated to kill all pathogens before arriving on site; this includes two phases of heat treatment over 160°F over 3 week period. Standard Operating Procedures are required to describe all of the steps taken to maintain compost safety and quality, and records of turning, temperature, application information and other practices must be kept for at least 2 years.

Compost is starting to be regulated by the California Air Resources Board in Antelope Valley Air Pollution Control District, Mojave Desert Air Quality Management District, San Joaquin Valley Air Pollution Control District, and South Coast Air Quality Management District. Although diverting compostable materials from landfills saves considerable amount of greenhouse gases, CARB is concerned about the VOCs / reactive organic gases, particulate matter, and ammonia created in the production of compost (CARB, 2011).

The cost of running a compost operation is considerable and include: taking valuable farmland out of production, staff time, equipment investment (turner, loader, water truck, spreader), lab testing fees and fuel to turn compost and spread on fields. Other concerns particular to onions are mobile onion skins in windy conditions and odor management.

## **Benefits**

Rio Farms has seen a number of benefits from the addition of compost to their operation. Compost can also serve as a direct source of nutrients, however nutrient availability is difficult to time for plant uptake – both agronomically and logically. Agronomically, temperature, soil moisture, and carbon content affect the timing of nutrient availability in compost. Logistically for a large operation, spreading compost is most efficiently done during the off season from November-February when most fields in a given ranch are not planted (i.e. save fuel by applying to entire ranch at once). This may mean that compost application may happen months before a given field is planted, resulting in reduced direct crop nutrient availability. The 45 day pre-harvest interval regulation the release of nutrients also influences grower compost application decisions.

Composting has served as a waste reduction strategy, reducing the spreading of pathogens on fields, reduced fuel use and associated greenhouse gas emissions from spreading onions, and reusing locally available products has provided a pathway for the waste stream for the company and other businesses. Compost increases soil organic matter, which in turn increases soil water-holding capacity & infiltration, and cation exchange capacity. In particular, growers at Rio Farms have especially observed improvements in the calcium to magnesium ratio, greatly improving soil tilth, especially drainage on two problematic ranches. Organic matter also helps with aggregate formation by polysaccharides and glomalin, suppressing plant pathogens and feeding soil microbial populations.

Composting is a traditional and organic farming practice that can make agronomic and business sense, even for large conventional growers. There are significant costs associated with running a compost program, including complying with regulations and food safety practices, however maintaining and enhancing soil quality is the basis for healthy food, productive farmland and is the basis for sustainable agriculture.

### **Literature Cited**

CalRecycle. 2014. Cal Recycle Composting Operations - Regulatory Requirements.  
Webpage: <http://www.calrecycle.ca.gov/laws/Regulations/Title14/ch31a5.htm>

CARB. 2011. California Air Resources Board, Compost Emissions Work Group,  
Website: <http://www.arb.ca.gov/cc/compost/compost.htm>

LGMA. 2013. Leafy Greens Marketing Agreement. Food Safety Practices.  
Webpage: <http://www.lgma.ca.gov/food-safety-practices#downloads>



# American Society of Agronomy

## California Chapter

### Session VIII

## Salinity Response/Management

### Session Chairs:

Steve Grattan, UC Davis/UCCE

Bob Hutmacher, UC  
Davis/UCCE

# **Overview of CV SALTS and Development of Salinity Management Programs to Protect Irrigated Crops<sup>1,2</sup>**

John B. Dickey, Principal Scientist and Owner, PlanTierra LLC,  
611 Del Oro Pl., Davis, CA 95616  
Phone (530) 554-9500, [jdickey@plantierra.com](mailto:jdickey@plantierra.com)

## **Introduction**

Sustainable management of salt in Central Valley water and agricultural systems has been studied at many levels for decades. One facet of this management is the influence of water quality regulations on discharge of salt to waters, and the resulting usability of those waters for irrigation of agricultural crops. Although salinity has technically been regulated for decades, regulatory approaches to salt were often piecemeal, incorporated into water quality permits used to regulate industrial and municipal discharges. Agricultural discharge of salinity was also regulated, for example by the 2004 Lower San Joaquin River Total Maximum Daily Load (TMDL) for Salt and Boron. In the last few years, the Central Valley Regional Water Quality Control Board (RB) has proposed to develop amendments to the Water Quality Control Plans for the Sacramento River, San Joaquin River, and the Tulare Lake Basin to protect beneficial uses of waters, uses that might otherwise be impaired by salt and nitrate.

“Beneficial uses” for water are defined by the RB and protected by their basin plans. In the case of salinity, it is generally the AGR beneficial use (agricultural irrigation) that is impaired when the yield or quality of salt-sensitive crops (e.g., almonds) is reduced by water that is too saline. Avoiding such crop damage is therefore what is often implied when controlling salinity levels to protect beneficial uses of California waters.

In 2006, the RB convened a diverse group of stakeholders (the Central Valley Salinity Alternatives for Long-Term Sustainability initiative, or CV-SALTS) to collaboratively develop solutions to salt and nitrate problems. Irrigators, drainers, and food processors are among the participants. Increasingly, as regulatory questions related to these constituents arise, they are routed into this process for resolution. Since agriculture uses a large proportion of the Central Valley’s developed water, the majority of salt moving through the system passes through agricultural irrigation systems and soils at some point. Some of the ways in which irrigated agriculture is being considered, and some of the ways it may be affected, are summarized in this paper.

---

<sup>1</sup> Dickey, J. 2015. Overview of CV Salts and development of salinity programs to protect irrigated crops. California Plant & Soil Conference, Feb. 4-5, 2015. Fresno, CA.

<sup>2</sup> This is a technical communication, relating technical aspects of and observations regarding the CV-SALTS Program, as they pertain to crop production. It is not an official, or unofficial, statement of State of California or other public policy.

## **Technical Work by CV-SALTS**

CV-SALTS has produced technical and regulatory studies to help underpin future basin plan amendments. These will frame technical approaches embodied in the basin plan amendments, affecting the regulatory approach to agricultural and other discharges to waters, as well as protecting agricultural irrigation uses of water. Some examples of these outcomes include:

1. Evaluation of salt and nitrate contributions from overlying lands to groundwater, along with the long-term effects on groundwater quality
2. Development of approaches to supply safe drinking water to disadvantaged communities dependent on groundwater with unsafe levels of nitrate
3. Definition of acceptable levels of crop protection from salinity; methodology to identify common crops that merit protection in specific geographies; methodology to identify waters affecting those crops
4. Approaches to restricting salt and nitrate entering groundwater from overlying, irrigated lands, and entering surface water in surface return flows (drainage)
5. De-designation of unusable water bodies (e.g., aquifers and agricultural drains) as drinking water, so that they no longer need to be protected for this purpose
6. Setting of salinity standards for the Lower San Joaquin River, which effectively cap the amount of salt that can be carried out of the valley by this route; evaluation of how these standards will affect sensitive crops, and how specific ions (e.g., boron, chloride) ought to be considered when setting a salinity standard.
7. Developing large-scale, long-term plans that may involve construction and operation of desalters in, and export of brine from the Central Valley.

Documentation of other items is available at <http://www.cvsalinity.org/> and [http://www.waterboards.ca.gov/centralvalley/water\\_issues/salinity/](http://www.waterboards.ca.gov/centralvalley/water_issues/salinity/).

## SODIUM DISTRIBUTION AND PHYSIOLOGY IN PISTACHIO

Jessie Godfrey, PhD Student  
*Department of Plant Sciences*  
*University of California, Davis*  
jmgodfrey@ucdavis.edu  
510 847 7664

**Collaborators:**  
Maciej Zwieniecki\*, Steve Grattan\*\*, Louise Ferguson\*  
\**Department of Plant Sciences*  
\*\**Department of Land Air and Water Resources*  
*University of California, Davis*

**SUMMARY:** When exposed to salinity, pistachio trees exclude a large percentage of any sodium in soil water completely, and extract much of the sodium that is not excluded along their transpiration streams, sequestering it into root, stem, and lower leaf tissues. Additionally, although exclusion is most effective at high concentrations of applied sodium, further dilution through dispersal offers no protection to photosynthesizing and growing leaves at concentrations so high that they overwhelm a tree's retrieval system.

**INTRODUCTION:** Pistachio growers, as managers of both a salt tolerant crop and a highly valued commodity, are able to maintain economically sound production despite expansion into marginally saline soils or the use of marginally saline irrigation water. Nonetheless, the physiological mechanisms that provide pistachio tolerance to salts remain largely unexplored. In a region where surface water availability and groundwater salinity are highly variable, improving our physiological understanding of this crop provides opportunities to meet environmental challenges with fresh perspective. The objectives of our research are to generate specific knowledge about the physiological limits of particular rootstocks, scions, and their combinations, as well as general knowledge about the mechanisms of salinity tolerance common to all pistachios. Our overall goal is to strengthen the industry by identifying potential breeding strategies and developing management tools that will help to sustain yields under saline conditions.

*Defining Pistachio Salinity ( $\text{NaCl}$ ) Tolerance:* Species that have evolved under saline conditions have adapted mechanisms for salt management that allow them to maintain or even improve their growth rates under conditions of highly concentrated  $\text{NaCl}$  (Flowers and Colmer 2008). Though pistachio does not exhibit extreme halophytic tolerance mechanisms like excretion through salt glands or salt bladders, the commercially prevalent 'Kerman' scion does not begin to show reductions in growth until roughly 40-80mM  $\text{NaCl}$  or 4-8dS/m ECw(Behboudian *et al.* 1986, Ferguson *et al.* 2002, Pichionni 1990). This indicates some capacity for accommodation that exceeds that of most glycophytic crop plants (Maas and Hoffman 1997) and with the exception of dates, all other commercially viable tree crops (Hanson *et al.* 2006).

*Components of Salinity ( $\text{NaCl}$ ) Tolerance:* The same gene, salt over sensitive gene (SOS1), is responsible for both reversing the passive channel flow of  $\text{Na}^+$  from soil into root cells and actively loading  $\text{Na}^+$  from root xylem parenchyma cells into the xylem (Adolf *et al* 2013). Expression of this one gene thus both limits and, if the passive rate of uptake exceeds the active rate of exclusion, guarantees whole plant exposure to sodium. The positive implication of guaranteed whole plant exposure is the allowance of an energetically efficient (Raven, 1985, Munns 2002) osmotic gradient that favors water movement from root to transpiring tissues despite low soil water potentials. The negative implication for many plants is that

photosynthesizing leaf blades at the end of the transpiration stream tend to disproportionately accumulate inorganic osmolytes (Møller and Tester 2007).

Some degree of salinity tolerance may thus be derived from any process that reduces accumulation in mature leaf tissues while still allowing for low cost osmotic adjustment. For many plants, it seems that one key process is xylem retrieval. Increasing the expression of a Na<sup>+</sup>-specific xylem retrieval gene (HKT gene family) in both wheat (Munns *et al.* 2012) and arabidopsis (Sunarpi *et al.* 2005, Horie *et al.* 2009) has been shown to increase Na<sup>+</sup> tolerance. In barley, Wolf demonstrated that significant quantities of Na<sup>+</sup> are removed along the transpiration stream resulting in decreases in xylem sap [Na<sup>+</sup>] from 10mM at the plant base to 2mM at the leaf (Wolf *et al.* 1991). When the salt balance is assessed in lupine, Na<sup>+</sup> has also been shown to decrease along the transpiration stream (Jeschke *et al.* 1992). If a similar xylem retrieval mechanism varies from one pistachio rootstock to another, the corresponding delivery of Na<sup>+</sup> to transpiring leaves may help to explain variations in tolerance conferred to scions. Rootstock helps explain Na<sup>+</sup> delivery to leaves in two more salt sensitive tree crops: avocado (Mickelbart *et al.* 2007) and citrus, though citrus shows more dramatic variations in leaf Na<sup>+</sup> accumulation scion to scion (Lloyd *et al.* 1990).

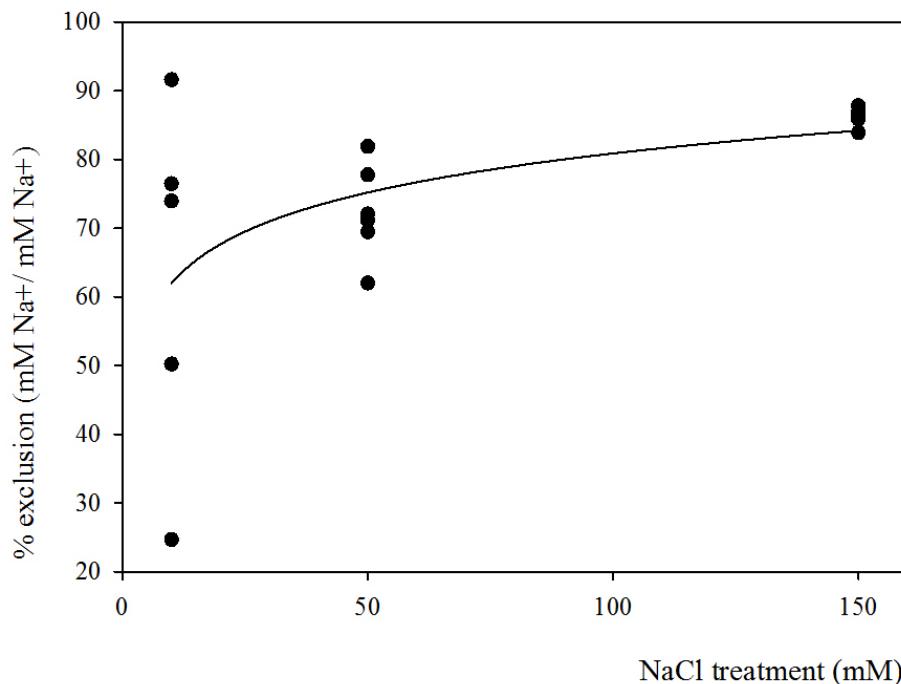
*Starch and Salinity (and Frost):* Once sodium is dispersed by xylem unloading or deposited in leaves, a species' or tissues' capacity to transport salts into cell vacuoles and there accommodate them provides a mechanism of salinity tolerance in and of itself. Vacuolar accumulation is a means of maintaining the homeostatic Na<sup>+</sup> concentrations in the cytoplasm necessary for enzymatic and membrane function (Gorham *et al.* 1990, Maathius and Amtmann 1999). The upregulation of Na<sup>+</sup>/H<sup>+</sup> antiporters (NHX gene family) at the tonoplast has been shown to increase salt tolerance in several species including tomatoes (Zhang and Blumwald 2001), common buckwheat (Chen *et al.* 2008), and arabidopsis (Bassil *et al.* 2012). The drawback of vacuolar accumulation of inorganic osmolytes is that although they are energetically cheap themselves, they must be accompanied by an in-kind cytoplasmic accumulation of energetically expensive *organic* osmolytes (Yeo 1983, Raven 1985, Munns 2002), potentially expensive enough to significantly deplete carbohydrate reserves. Current work from our lab suggests that the common freeze thaw events characteristic of milder winters reduce the carbohydrate storage of Mediterranean species like pistachio between their transition into dormancy in the fall and leafout in the spring (Sperling *et al.* unpublished). If it is indeed over-drafted starch banks that are to blame for patchy events of poor leafout, what is being termed 'Winter Juvenile Tree Dieback' (Kallsen 2013), it may be that salt plays a crucial part in the story.

In apples, the relationship between drought-generated declining midday stem water potentials and increasing sorbitol:starch ratios in leaves (Naschitz *et al.* 2010) very clearly demonstrates that starch is being degraded so that solutes may be formed. The same paper also documents that starch concentration in branches is *greater* with a light crop because carbohydrates are not being mobilized for fruit production. A recent paper on drought stress and carbohydrate dynamics in forest tree species makes a related observation—drought stress consumes starch for osmotic adjustment but also conserves starch, comparatively, due to reductions in growth (Klein *et al.* 2014). The result is a balanced account.

It is reasonable to assume that, because xylem tension can be imposed by salinity stress as well as by drought stress, the two stresses may have similar consequences for carbohydrate storage. In both cases living plant cells are battling the soil for water and in both cases accumulating osmolytes helps the cells win (Wyn Jones and Storey 1978, Munns 2002). It is also reasonable to hypothesize that the most interesting moment in this carbohydrate data is the tipping point, the point at which investment in continued growth alongside osmotic adjustment limits long term viability or productivity more than investment in osmotic adjustment alone. This has particular relevance when carbohydrate storage is further tasked with responding to more frequent night freeze-day thaw events, as may be the case with ‘Winter Juvenile Tree Dieback’ in pistachios.

**PRELIMINARY RESULTS:** We found that xylem sap extracted from stem segments cut just above the root crown had a sodium concentration up to 85% lower than that of soil water (Figure 1). Averages were 63, 72, and 86 percent exclusion and standard errors were 11.72, 2.81, and 0.66 for the 10, 50, and 150mM treatments, respectively. The higher variation in lower treatments is due to our calculation of percent exclusion, for which xylem sap values were in the numerator and soil water sodium concentrations were in the denominator—smaller denominators led to greater variability; larger denominators led to lesser variability.

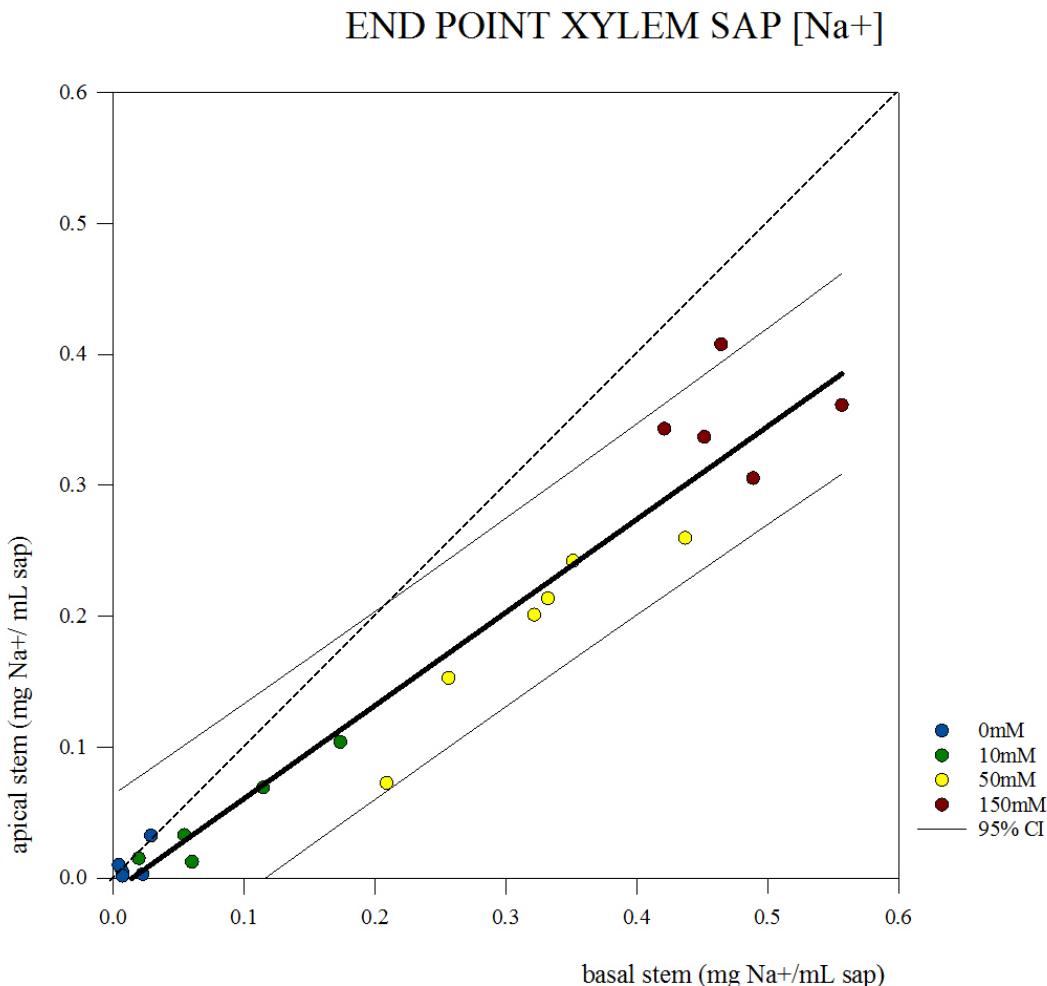
### PERCENT Na<sup>+</sup>EXCLUSION FROM STEM XYLEM SAP



**Figure 1**Percent exclusion values by treatment were calculated by dividing basal xylem sap concentration in mM by soil water sodium concentration in mM.

Preliminary findings in the UCB1 rootstock also indicate that Na<sup>+</sup> not excluded is retrieved along the transpiration stream and deposited in adjacent tissue. The setup was a completely randomized design of 32 trees in a soil medium (UC Mix C) irrigated to drainage at 1600h each day with one of four NaCl solutions: 0mM, 10mM, 50mM, and 150 mM (roughly 0, 1, 5, and 15 dS/m). We selected these concentrations to approximate the conditions leading to 100% (0

mM and 10mM), 90% (50mM), and 50% relative productivity observed in the 2002 Ferguson study. The 10mM treatment was included to confirm that there are no beneficial effects of very low NaCl application. 35 days after the start of treatments, measurements of basal and apical vacuum-extracted (Secchi and Zwieniecki 2012) xylem sap [Na<sup>+</sup>] were significantly different for the 50 and 150 mM treatments with two-tailed p-values of 0.014 and 0.001, respectively. For a visual comparison, the 1:1 line diverges up from the 95% confidence interval of the regression correlating basal and apical xylem sap at higher applied NaCl concentrations, when apical sap is the dependent variable (Figure 2).

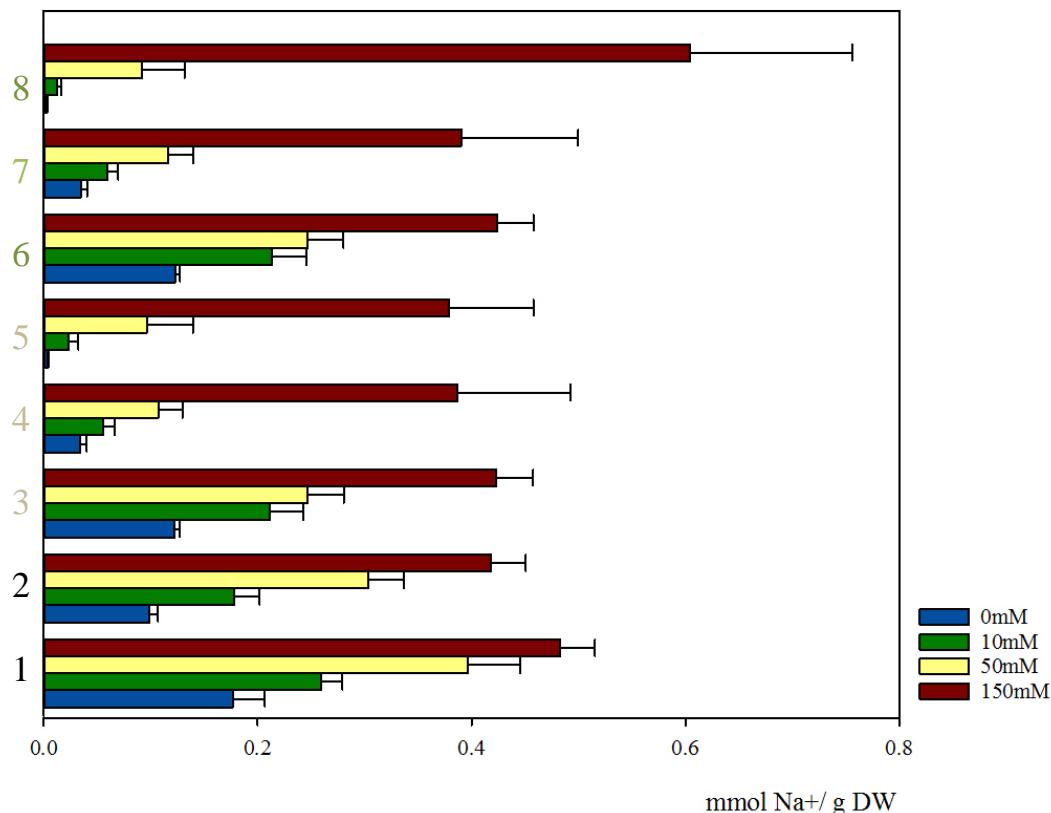


**Figure 2**The bold solid line is the regression correlating basal and apical stem xylem sap [Na<sup>+</sup>] after 35 days of irrigation with 0, 10, 50, and 150 mM NaCl (approximately 0, 1, 5, and 15 dS/m). The dashed line is the 1:1 line. The softer solid lines border the 95% confidence interval.

The observation of declining xylem sap [Na<sup>+</sup>] up the stem is complemented by observations of declining tissue [Na<sup>+</sup>] along the transpiration stream in each tissue type—roots, stems, and leaves—for all but the 150mM treatment (Figure 3). With the exception of roots in the 50mM treatment, categorically ranking location confirms significantly negative slopes up the transpiration stream for all tissue types in the 0, 10, and 50mM treatments (data not shown). The slope does not differ significantly from zero in the 150mM treatment. This lack of deviation suggests that at 150mM

NaCl, retrieval and sequestration are no longer adequately diluting delivery of Na<sup>+</sup> to the apical tissues where photosynthesis and growth are most concentrated.

### END POINT [Na<sup>+</sup>] IN ALL TISSUES



**Figure 3** Tissue [Na<sup>+</sup>] up the stem of UCB1 rootstocks after 35 days of irrigation with 0, 10, 50, and 150 mM NaCl. Error bars reflect standard error. Along the y-axis, numbers correspond with tissues as follows: 1 = fine roots, 2 = support roots, 3 = root crown, 4 = midstem, 5 = apical meristem, 6 = old leaves, 7 = mature leaves, 8 = immature leaves. Note that in all but the 150mM treatment, tissue-type [Na<sup>+</sup>] declines up the transpiration stream. Root tissues are labeled on the y-axis in black, stem tissues in brown, leaf tissues in green.

**CONCLUSIONS AND FUTURE DIRECTIONS:** Xylem sap and tissue ion analyses offer a definitive focus for experiments comparing rootstocks. The maximum exclusion values and extraction rates for not only sodium, but also other harmful inorganic solutes like chloride, are potential screening targets for breeders. More data is forthcoming.

Measurements of sodium concentration in stem tissues collected at multiple heights also offer a potential new tool for assessing salinity's infringement upon a tree's safety margin. The retrieval systems of trees that continue to exhibit tissue concentration declines up the stem are operational and offering some degree of protection to photosynthesizing leaves. This should be true regardless of rootstock or scion. Whether or not operational systems of xylem retrieval are useful for predicting yield reductions must of course be validated in the field. However, samples collected over the summer of 2014 from a tank study we conducted here at UC Davis and in the fall of 2014 from an 11-year field trial established and managed by UC crop extension specialist Blake Sanden will offer more insight in the near future.

## WORKS CITED:

- Bassil, E., A. Coku, and E. Blumwald. 2012. Cellular ion homeostasis: emerging roles of intracellular Na<sup>+</sup>/H<sup>+</sup> antiporters in plant growth and development. *J.Exp. Bot.* 63.16: 5727-5740.
- Behboudian, M.H., R.R. Walker, and E. Torokfalvy. 1986. Effects of water stress and salinity on photosynthesis of pistachio. *Scientia Horticulturae* 29: 251-261.
- Chen, L.H., B. Zhang, and Z.Q. Xu. 2008. Salt tolerance conferred by overexpression of *Arabidopsis* vacuolar Na<sup>+</sup>/H<sup>+</sup> antiporter gene AtNHX1 in common buckwheat (*Fagopyrum esculentum*). *Transgenic Res.* 17.1: 121-132.
- Ferguson, L., J.A. Poss, S.R. Grattan, C.M. Grieve, D. Wang, C. Wilson, T.J. Donovan, and C.T. Chao. 2002. *J. Am. Soc. Hortic. Sci.* 127.2: 194-199.
- Flowers, T.J. and T.D. Colmer. 2008. Salinity tolerance in halophytes. *New Phytol.* 179: 945-963.
- Gorham J., R.G. Wyn Jones, and A. Bristol. 1990. Partical discrimination in rye and triticale. *J. Exp. Bot.* 41: 609-614.
- Hanson, B., S.R. Grattan, and A. Fulton. 2006. Crop Salt Tolerance. In: Agricultural Salinity and Drainage. UCANR Publ. 3375. UC Irrigation Program, UCR, Riverside, CA. p. 21.
- Horie, T., F. Hauser and J.I. Schroeder. 2009. HKT transporter-mediated salinity resistance mechanisms in *Arabidopsis* and monocot crop plants. *Trends Plant Sci.* 14.12: 660-668.
- Kaalsen, C. 2012. Winter Juvenile Tree Dieback (WJTD)—A Problem in Pistachio in the San Joaquin Valley. *Kern Pistachio Notes August 2012.* UCANR. [http://cekern.ucanr.edu/news\\_80/Pistachio\\_Notes\\_Newsletter/?newsitem=44108](http://cekern.ucanr.edu/news_80/Pistachio_Notes_Newsletter/?newsitem=44108) (accessed 14 Jan. 2015).
- Klein, T., G. Hoch, D. Yakir, and C. Körner. 2014. Drought stress, growth and nonstructural carbohydrate dynamics of pine trees in a semi-arid forest. *Tree Physiol.* 00: 1-12.
- Lloyd, A., P.E. Kriedman and A. Aspinall. 1990. Contrast between Citrus species in response to salinization: an analysis of photosynthesis and water relations for different rootstock-scion combinations. *Physiol. Plantarum* 78: 236-246.
- Maas, E.V. and G.J. Hoffman. 1997. Crop salt tolerance—current assessment. *J. Irr. Drain. Div.-ASCE.* 103: 115-134.
- Mathius, F.J.M. and A. Amtmann. 1999. K<sup>+</sup> nutrition and Na<sup>+</sup> toxicity: the basis of cellular K<sup>+</sup>/Na<sup>+</sup> ratios. *Annals of Botany* 84: 123-133.
- Mickelbart, M.V., S. Melser and M.L. Arpaia. 2007. Salinity-induced changes in ion concentrations of 'Haas' avocado trees on three rootstocks. *Journal Plant Nutr.* 30: 105-122.
- Møller, I.S. and M. Tester. 2007. Salinity tolerance of *Arabidopsis*: a good model for cereals? *Trends Plant Sci.* 12: 534-540.
- Munns, R. 2002. Comparative physiology of salt and water stress. *Plant Cell Environ.* 25: 239-250.
- Munns, R., R.A. James, B. Xu, A. Athman, S.J. Conn, C. Jordans, C.S. Byrt, R.A. Hare, S.D. Tyerman, M. Tester, D. Plett and M. Gillham. 2012. Wheat grain yield on saline soils is improved by an ancestral Na<sup>+</sup> transporter gene. *Nat. Biotechnol.* 30.4: 360-365.
- Naschitz, S., A. Naor, S. Genish, S. Wolf and E.E. Goldschmidt. 2010. Internal management of non-structural carbohydrate resources in apple leaves and branch wood under a broad range of sink and source manipulations. *Tree Physiol.* 30.6: 715-727.

- Picchioni, G.A., S. Miyamoto, and J.B. Storey. 1990. Salt effects on growth and ion uptake of pistachio rootstocks. *J. Am. Hortic. Sci.* 115: 647-653.
- Raven, J.A. 1985. Regulation of pH and generation of osmolarity in vascular plants: a cost-benefit analysis in relation to efficiency of use of energy, nitrogen and water. *New Phytol.* 101: 25-77.
- Secchi, F. and M. Zwieniecki. 2012. Analysis of xylem sap from functional (nonembolized) and nonfunctional (embolized) vessels of *Populus nigra*: chemistry of refilling. *Plant Physiol.* 160.2: 955-964.
- Sunarpi, T.H., J. Motoda, M. Kubo, H. Yang, K. Yoda, R. Horie, W.-Y. Chan, H.-Y. Leung, K. Hattori, M. Konomi, M. Osumi, M. Yamagami, J.I. Schroeder, and N. Oozumi. 2005. Enhanced salt tolerance mediated by AtHKT1 transporter-induced Na<sup>+</sup> unloading from xylem vessels to xylem parenchyma cells. *The Plant Journal* 44: 928-938.
- Wolf, O., R. Munns, M.L. Tonnet, and W.D. Jeschke. 1991. The role of the stem in the partitioning of Na<sup>+</sup> and K<sup>+</sup> in salt-treated barley. *J. Exp. Bot.* 42: 697-704.
- Wyn Jones, R.G. and R. Storey. 1978. Salt stress and comparative physiology in the Graminae. IV. Comparison of salt stress in *Spartina x tonsendii* and three barley cultivars. *Aust.J. Plant Physiol.* 5: 839-850.
- Yeo, A.R. 1983. Salinity resistance: physiologies and prices. *Physiol. Plantarum* 58: 214-222.
- Zhang HX and E Blumwald (2001). Transgenic salt-tolerant tomato plants accumulate salt in foliage but not in fruit. *Nat. Biotech.* 19: 765-768.

## **Physiology of Salinity Stress in Almond How do Rootstocks, Cultivars and Ionic Composition Make a Difference?**

Umit Baris Kutman, Department of Plant Sciences, University of California, Davis  
One Shields Avenue, Davis, CA, 95616  
Phone (530) 400-1035, bkutman@ucdavis.edu

Steve Grattan, Department of Land, Air and Water Resources, University of California, Davis  
One Shields Avenue, Davis, CA, 95616  
Phone (530) 752-4618, srgrattan@ucdavis.edu

Patrick Brown, Department of Plant Sciences, University of California, Davis  
One Shields Avenue, Davis, CA, 95616  
Phone (530) 752-0929, phbrown@ucdavis.edu

### **Introduction**

Soil salinity as an abiotic stress factor for plants precedes any human activity. However, this problem is aggravated by anthropogenic activities, especially irrigated agriculture in semi-arid regions (Letey 2000). According to recent estimates, 10-20% of the 250 million ha of irrigated land in the world is currently degraded due to secondary salinization (Schoups et al. 2005; Munns and Tester 2008; Marschner 2012). California is prone to salinization due to low annual precipitation, high evapotranspiration rates and use of irrigation waters with a substantial salt content. About 2 million ha of irrigated cropland in California, corresponding to more than half of the total, are affected by salt stress to varying degrees (Letey 2000; Schoups et al. 2005). Drought worsens the situation by reducing the availability of surface water for irrigation and increasing the dependence of farmers on low-quality groundwater.

Almond is classified as a very salt-sensitive crop with a threshold EC of 1.5 dS/m (Bernstein et al. 1956). This threshold is based on very old data and does not take genotypic differences into account. Field observations indicate the presence of a wide diversity among the available rootstocks and cultivars with respect to salinity tolerance. However, the physiology of salinity stress and the basis for such genotypic differences are not understood. In this project, the salinity tolerance of selected rootstocks and cultivars was studied by monitoring growth and toxicity symptoms. The physiological mechanisms conferring different levels of salt tolerance and the relative importance of specific Na and Cl toxicities were investigated to provide the information needed to optimize almond breeding for salt tolerance.

### **Materials and Methods**

A 4-replicate pot experiment was conducted under field conditions with young grafted almond trees. Calcined clay with excellent drainage and aeration properties was used as growth medium. Trees were always irrigated with a complete nutrient solution containing salts at different levels. A leaching fraction of 25% or more was aimed at to maintain the mineral and salt levels in the pots. The main salinizing agent was NaCl. While the control solution was free of NaCl, the low-salt and high-salt solutions contained 20 mM and 40 mM NaCl, respectively. To study the toxic effects of Na and Cl in isolation from each other, KCl and Na<sub>2</sub>SO<sub>4</sub> were used as alternative salts. Nemaguard, Hansen536, Empyrean-1 and Viking were selected as the rootstocks while Nonpareil, Mission, Monterey and Fritz were selected as the cultivars of interest.

Trees were photographed periodically and the images were analyzed by ImageJ to estimate the canopy size and monitor the growth. Additional growth data were obtained from trunk diameter measurements. Mature leaf samples were collected periodically for mineral analysis. Trunk strip samples were also taken from high-salt trees to study the trunk accumulation of Na and Cl. Whole-plant evapotranspiration (ET) measurements by weight and carbon isotope discrimination analysis were used to evaluate salinity-induced water stress.

## Results and Discussion

There was a great degree of variation among the rootstocks in terms of salinity tolerance. Trees grafted on Nemaguard were the first ones to exhibit necrosis in mature leaves. Under severe stress, defoliation followed necrosis. The loss of leaves also resulted in reduced canopy size (Fig. 1). The timing and severity of symptoms depended on the salinity level. Trees on Hansen536 were clearly more salt-tolerant and reduced growth was only observed in the third month after treatment at the high salt level, while trees on Empyrean-1 and Viking were totally free of symptoms and continued to grow well throughout the season (Fig. 1).

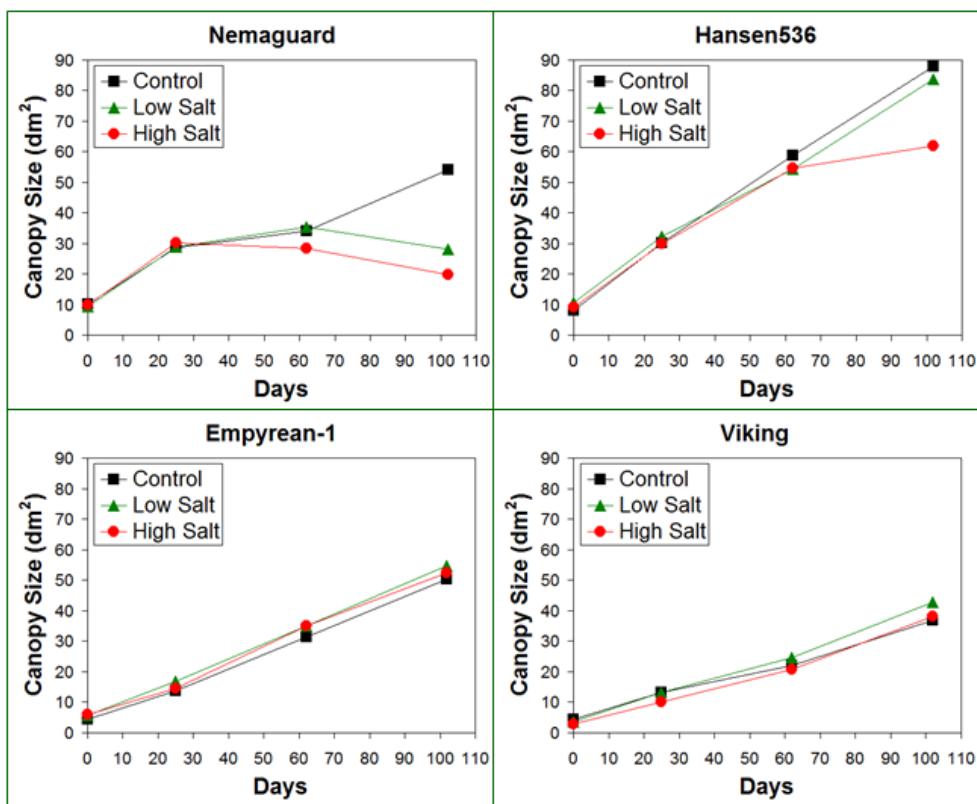


Fig. 1: Canopy size of Nonpareil almonds grafted on 4 different rootstocks and grown at 3 different salt levels (control: 0 mM NaCl; low salt: 20 mM NaCl; high salt: 40 mM NaCl)

From field observations, Fritz was expected to be more sensitive to salinity stress than Nonpareil. However, in this experimental setup, the severity of symptoms was more dependent on the rootstock selection than the cultivars themselves. When grafted on Nemaguard, both cultivars were heavily affected by high-salt treatment, but when grafted on Hansen536, both remained unaffected for a longer time (Fig. 2), possibly because Cl was the main cause of toxicity here and they did not differ from each other in leaf Cl accumulation.

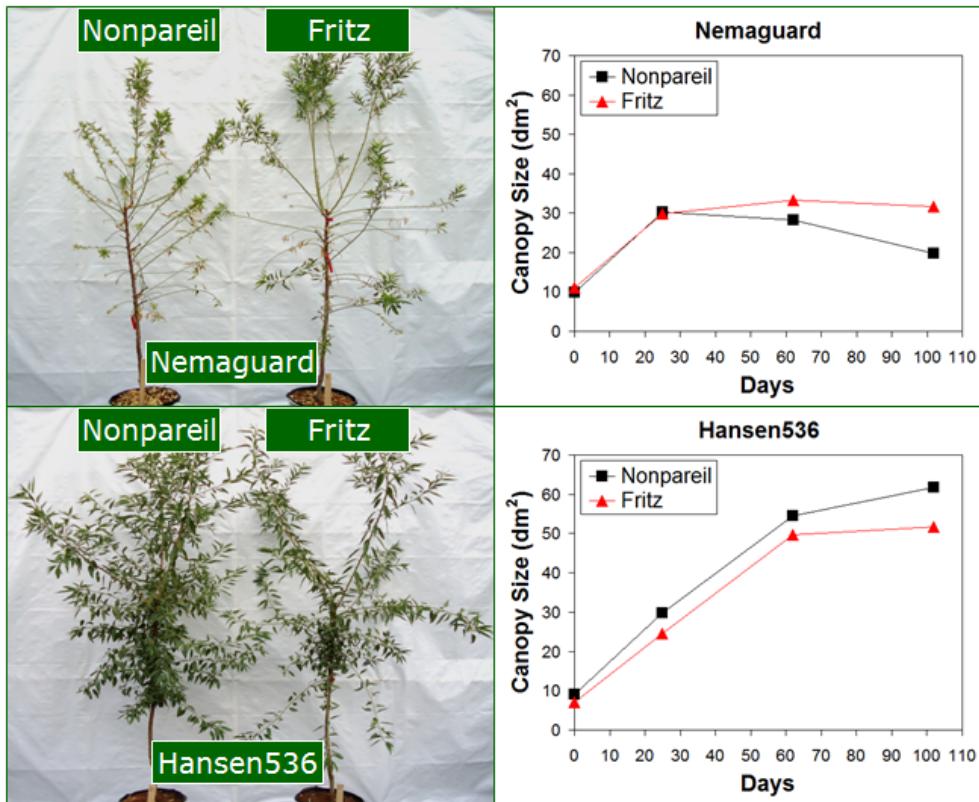


Fig. 2: Effects of high salt treatment (40 mM NaCl) on Nonpareil and Fritz trees grafted on Nemaguard (top) or Hansen536 (bottom)

In the salt-type study, KCl appeared to be even more toxic than NaCl while Na<sub>2</sub>SO<sub>4</sub> did not adversely affect the canopy growth and not cause any significant toxicity symptom (Fig. 3). Leaf Cl levels were higher in KCl-treated trees than in NaCl-treated ones, probably due to stimulation of Cl uptake by excessively high K levels. These results showed that Cl<sup>-</sup> was the predominant toxic ion in the system.

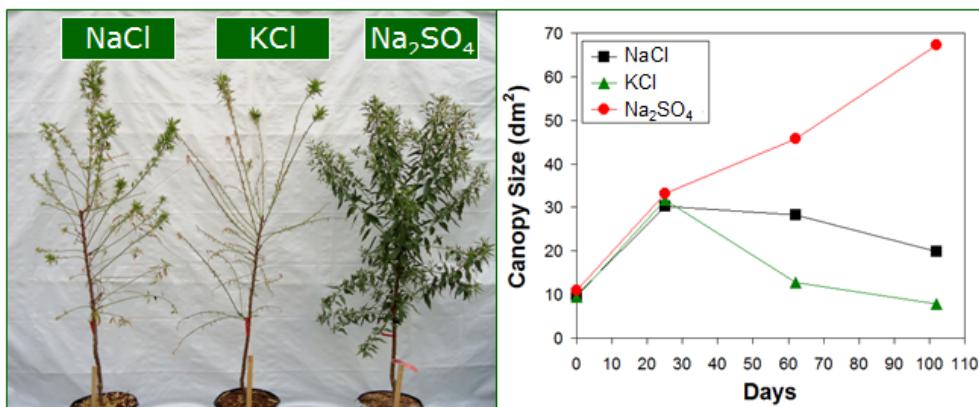


Fig. 3: Effects of different salts at high level (NaCl, KCl and Na<sub>2</sub>SO<sub>4</sub>; all supplying 40 mM Na and/or Cl) on Nonpareil trees grafted on Nemaguard

Whole-plant ET measurements revealed that the ET was not affected significantly by salt treatments unless there was extensive necrosis or defoliation due to ionic toxicity, indicating that salt-induced water stress was not significant. Under water deficit, plants are known to lose their ability to discriminate against <sup>13</sup>C. Carbon isotope discrimination

analysis of mature leaves showed that this was not the case here, further supporting the idea that specific ion toxicities were mainly responsible for the observed effects.

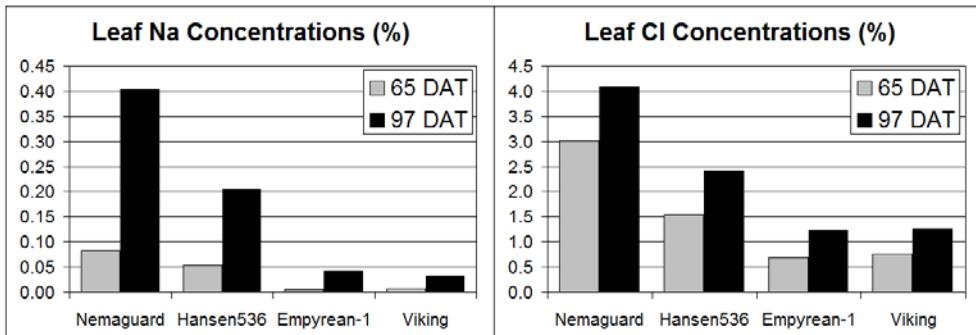


Fig. 4: Na and Cl concentrations of mature leaves of Nonpareil trees on 4 different rootstocks 65 and 97 days after high salt treatment (40 mM NaCl)

The leaf accumulation of Na and Cl was significantly affected by the rootstock genotype (Fig. 4). In parallel with the observed symptoms, trees on Nemaguard accumulated much higher levels of Na and Cl in its leaves than trees on Hansen536, which had higher leaf Na and Cl concentrations than trees on Empyrean-1 or Viking. On all rootstocks, the leaf Cl levels were on average by one order of magnitude higher than the leaf Na levels, suggesting that Na is more efficiently excluded from the leaves and therefore needs longer time than Cl to reach toxic levels.

Although the leaf Cl concentrations measured in different cultivars grafted on Nemaguard were not significantly different, the leaf Na concentrations were. Remarkably lower Na levels were measured in leaves of Nonpareil than in leaves of Fritz trees.

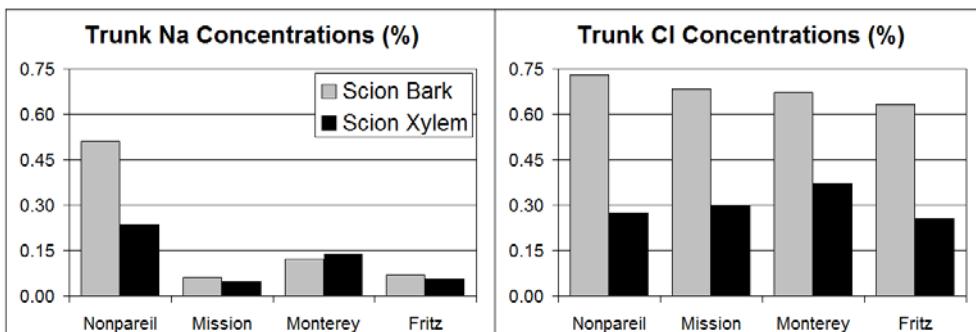


Fig. 5: Na and Cl concentrations of trunk (scion bark and scion xylem) samples taken from Nonpareil trees on 4 different rootstocks 3 months after high salt treatment (40 mM NaCl)

In order to investigate how cultivars grafted on the same rootstock can accumulate different levels of ions in their leaves, trunk strip samples were analyzed (Fig. 5). Both the scion bark and scion xylem were very rich in Na in Nonpareil but not in Mission or Fritz trees, indicating that Nonpareil had the ability to store a significant portion of absorbed Na in the trunk and thus exclude it from the leaves. Trunk Cl levels, however, were not significantly different among cultivars.

## Conclusions

At practically relevant EC levels, specific ion toxicities are primarily responsible for salt damage to almonds whereas salinity-induced water stress may not be an important component of stress in well-irrigated almond trees. Severe toxicity causes extensive necrosis

and partial or complete defoliation of trees while it limits secondary growth. There is a great degree of variation in salinity tolerance of rootstocks. The most common rootstock, Nemaguard, is the most salt-sensitive one. Hansen536 is relatively more tolerant, and Empyrean-1 and Viking perform remarkably well under salinity stress. When NaCl is used as salinizing agent, Cl accumulates to toxic levels in leaves much faster than Na. Salt tolerance is well correlated with the exclusion of toxic ions from leaves. Limited root uptake of these ions is a critical tolerance mechanism. Another tolerance mechanism, which may explain the differences in Na tolerances of cultivars, is the trunk accumulation of Na. Nonpareil is exceptionally good at this whereas Fritz and Mission lack this ability.

## References

- Bernstein, L., Brown, J.W. and Hayward, H.E. 1956. Influence of rootstock on growth and salt accumulation in stone-fruit trees and almonds. Proc. Am. Soc. Hort. Sci. 68:86-95.
- Letey, J. 2000. Soil salinity poses challenges for sustainable agriculture and wildlife. Calif. Agric. 54:43-48.
- Marschner, P. 2012. Marschner's Mineral Nutrition of Higher Plants, 3<sup>rd</sup> ed. Academic Press, Elsevier, USA.
- Munns, R. and Tester, M. 2008. Mechanisms of Salinity Tolerance. Annu. Rev. Plant Biol. 59:651-81.
- Schoups, G., Hopmans, J.W., Young, C.A., Vrugt, J.A., Wallender, W.W., Tanji, K.K. and Panday, S. 2005. Sustainability of irrigated agriculture in the San Joaquin Valley California. PNAS 12:15352-15365.



# American Society of Agronomy

## California Chapter

### Session IX

## Monitoring Options: Measure to Manage

**Session Chairs:**

Bob Hutmacher, UC  
Davis/UCCE

Steve Grattan, UC Davis/UCCE

## **Imperial Valley salinity management program**

Khaled Bali  
UCCE Imperial County  
760-352-9474  
[kmbali@ucanr.edu](mailto:kmbali@ucanr.edu)

# **Infrared Thermometry – Smartfield System Capabilities and Experiences**

Tom R. Speed, VP of Agronomic Services, Smartfield

2601 SE Loop 289, Lubbock, Tx 79404

Phone (806)-798-9800), [www.smartfield.com](http://www.smartfield.com), [tom.speed@smartfield.com](mailto:tom.speed@smartfield.com)

## **Introduction**

Smartfield is an agricultural technology company focused on the continuous (24 hours/day) direct monitoring of plants during the growing season. Through this monitoring, real-time actions are created which are highly accretive. Further, the processes using Smartfield's proprietary tools have been tested by many entities including major seed companies, universities, government agencies, producers and trusted advisors. The processes have proven to be adaptable to every crop tested (row crops, trees, vegetables, fruits, vineyards) in all environments including field production, test plots and greenhouses.

Optimum plant canopy temperatures have been developed through many years of lab and field studies by USDA researchers. By collecting continuous canopy temperatures, Smartfield has been able to quantify these canopy temperatures into stress indexes. Through proprietary algorithms, the final yield can be forecasted based on the accumulated plant stress throughout the season.

## **Competitive Advantages**

The unique differentiating factors for Smartfield include 1) direct plant based monitoring where many other tools measure the environment around the plants without knowing the absolute reaction of the crop to the environment and crop inputs, 2) patented technology and processes whereby competition can't duplicate Smartfield technology and methods, 3) backbone to capture and parse millions of data points into usable/actionable information 4) tools are easy to use, 5) the data generated from the tools is accessible anywhere through online connectivity, 6) modular tools where enhancements are easily added without rendering earlier tools obsolete, 7) specific crop yields have been accurately predicted 4-6 weeks in advance of harvest within a range of +/- 5%.

## **Methodology**

The predominant measure used is plant stress as indicated through canopy temperatures. Smartfield measures stress and populates proprietary algorithms to initiate actions or create usable information. Stress may be affected by water, topical treatments or disease. The information can be pushed to or accessed by customers, depending on preference. Such actions are timely and therefore introduce a high level of efficiency to precision agriculture. Many times the usable information is measuring the level of stress between different treatment plans in the same field thus better optimizing management practices.

## **Example data**

Canopy temperatures (CT) demonstrate there is a continuum between these well watered and drought conditions. The table below shows data from a cotton variety that received from 0.25 inches to 0.00 inches daily. This represents two extreme conditions as well as two intermediate treatments. The highest water treatment is equal to the daily ET measured (grass

reference) at this site. The CT responds proportionally to the available moisture. The optimal leaf temperature for cotton is 82-83F and the treatment that stays most near the optimal temperature, for the longest time period has made the highest yields.

Date	Max Air Temp (F)	Max CT (F) 0.25"	Max CT (F) 0.20"	Max CT (F) 0.12"	Max CT (F) 0.00"
Aug. 30, 2013	98.7	85.9	87.2	93.5	96.6
Aug. 31, 2013	100.0	86.1	87.3	93.7	98.1
Sept. 1, 2013	99.6	86.3	88.4	95.2	100.3

The table below expresses the data as max air temp (-) (MAT) minus the max CT (MCT). As the plant has access to additional moisture, greater (air – CT) differences are measured. The plant is reacting to the environment, with the water resources it has, and tries to stay most near the optimal temperature for as long as it can. As the available water decreases, the plant cannot cool itself sufficiently, transpiration decreases and metabolic activity decreases concomitantly.

Date	Max Air Temp (F)	MAT - MCT 0.25"	MAT - MCT 0.20"	MAT - MCT 0.12"	MAT - MCT 0.00"
Aug. 30, 2013	98.7	12.8	11.5	5.2	2.1
Aug. 31, 2013	100.0	13.9	12.7	6.3	1.9
Sept. 1, 2013	99.6	13.3	11.2	4.4	-0.7

## Tools

The core tools utilized include a base station/complete weather station and wireless field sensors. Additional tools have been developed to gain information or automate processes. These include:

SmartDrip (initiates irrigation based on pre-determined stress thresholds), Remote Pressure and Flow readings, Plant stress alerts via text or email and complete equipment diagnostics to monitor system performance.

## Strategic Focus

Commercial- Commercial entities have the R & D capabilities to develop and test new genetics, traits and crop protection products. Smartfield tools have helped differentiate product performance based on differences in plant stress.

Consumers/Producers- Allow trusted advisors/farm managers to make better in-season decisions.

Forecasting- Domestic or international yield prediction by crop can be available 4-6 weeks in advance of harvest.

## Conclusion

Our experience has shown that continuous and parallel or simultaneous canopy temperature needs to be captured from treatments or different field areas for greatest utility. By

utilizing in-field wireless IR sensors, season long canopy data can easily be obtained to quantify stress levels by growth stage, leading to better production decisions.

# **Soil Moisture Charts as a Tool for Producer Irrigation Decision Making - NRCS Approach in CA**

Dan Johnson, USDA/NRCS  
430 G Street, Davis, CA 95616  
Phone (530) 792-5625, dan.johnson@ca.usda.gov

NRCS provides technical and financial assistance to producers to encourage and enable adoption of improved irrigation practices. We've been successful with conversions to irrigation systems resulting in improved distribution uniformity but success has been limited in improving how irrigation timing and amount decisions are made. We are expanding the role and use of soil moisture charts (figure 1) in our program delivery to accelerate adoption of practices that lead to more informed irrigation decision-making. (Note, as presented here, data used to generate soil moisture charts can be generated by direct soil moisture measurement, indirectly using climate based crop water use models and a root zone water budget, or both.)

## **NRCS Irrigation Scheduling Objectives**

As a resource agency, NRCS's focus is to assist producers control the amount of deep percolation through their irrigation timing and amount decisions. In addition, we're encouraging regulated deficit irrigation where it's appropriate and meets producer production objectives. NRCS recognizes that optimizing crop performance is a producer objective and must be considered in any irrigation scheduling strategy.

## **Our Typical Approach to Assisting Producers with Irrigation Scheduling**

Traditionally our approach to advising producers with irrigation scheduling is to begin by advising them to adopt some form of the following process or practices which typically includes assisting them with acquiring and using various record keeping sheets, equations, spreadsheets and other tools to collect and process data:

1. Determine how much available water your soil can hold.
2. Establish your MAD or allowable soil dryness to decide when to irrigate.
3. Track or measure soil moisture depletion between irrigation events.
4. Replace the amount depleted (irrigate) to just refill the root zone.
5. Keep and review irrigation records to influence future scheduling decisions.

We've had limited success with getting producers to fully adopt this process on a sustained basis. There are a number of reasons but we believe the most common include:

1. It is a complex process. Many producers go away not fully understanding how to carry out each element or how all the elements fit together to lead toward irrigation decisions.
2. The discussion has not been enough to generate sustained enthusiasm or to overcome existing biases with producers. We're asking producers to take on some new tasks and potentially do something different from what they believe has been "working" for them.
3. They don't see specifically how this data collection and calculations can fit into the realities and constraints they face in the daily farming operation.

## Soil Moisture Charts as a Tool for Educating and Motivating Producers

While the aforementioned steps or process are necessary we may have been presenting them before the producer is ready for them. Instead of beginning the discussion talking about the data they need and how to collect it we're beginning to talk first about the outcome, or how the data can be used. Soil moisture charts provide an illustration of this outcome. Graphic displays of soil moisture change with time are generated by several proprietary computer based and on-line soil moisture monitoring programs (figure 1). Similar non-proprietary charts have been developed over the years. Follow the old adage "a picture's worth a thousand words" we're beginning to consider them for more than as just a way of displaying soil moisture sensor results. When populated with what we believe are the crucial elements, they communicate the information the producer needs to make optimal irrigation timing and amount decisions.



Figure 1

Describing soil moisture charts as representations of what actually happens in their root zone, we've begun using generic, unit-less charts in our initial discussions with producers to illustrate desirable and undesirable root zone moisture conditions and how these relate to the producer's irrigation timing and amount decisions.

We "build" the chart as we discuss it to maximize understanding and to be able to focus on each important element of the chart. Starting with a blank chart we ask the producer to graphically show how, not worrying about actual values, their root zone water content changes with time in the days following an irrigation event (figure 2). We then ask how their soil water content changes in response to irrigation (figure 3). They acknowledge that this wetting and drying cycle continues throughout the irrigation season (figure 4).

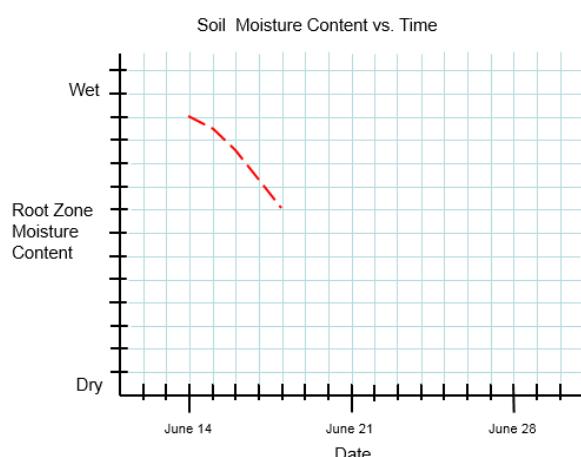


Figure 2

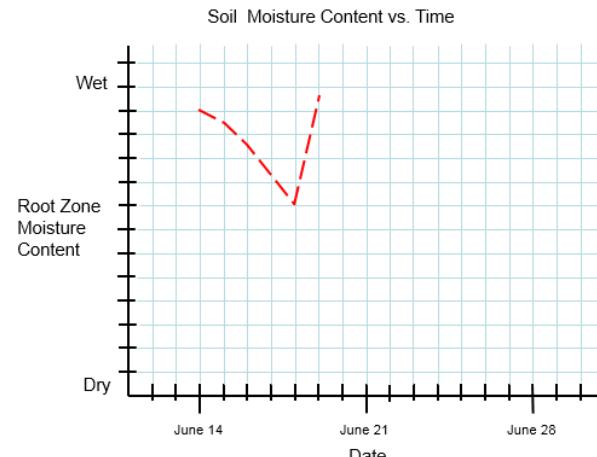


Figure 3

Next we ask them if there is a root zone “dryness” at which crop water stress will begin to occur. Most agree that there is. We then tell them this dryness level can be quantified (figure 5).

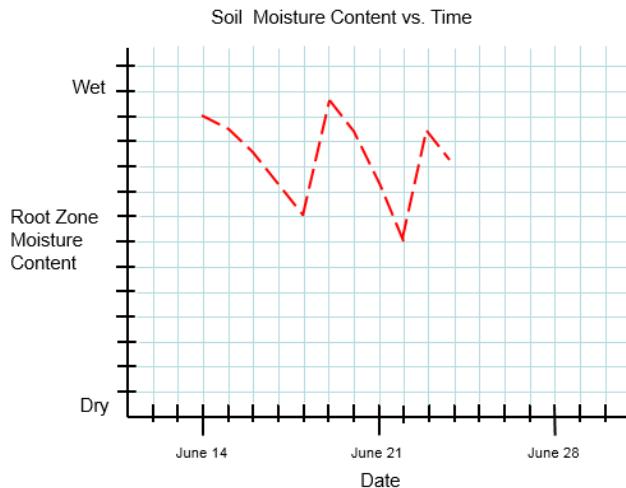


Figure 4

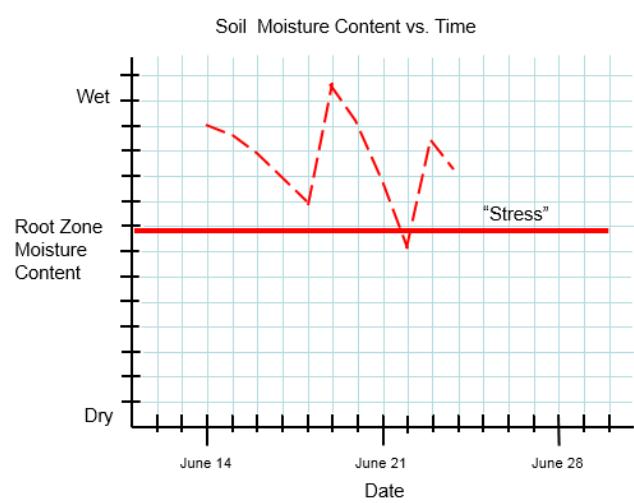


Figure 5

Then we ask them if there are limits as to much water their root zone can hold before they start losing water to deep percolation. Again they agree, and again, we tell them we can help quantify this moisture level (figure 6). We've just introduced them to the soil property “field capacity”.

Finally, we discuss the value of recording irrigation dates and amounts applied (figure 7). Displaying this data on the chart allows them to easily see the consequences (good and bad) of their timing and amount decisions. Makes it easy to draw conclusions on what they might change for future irrigations.

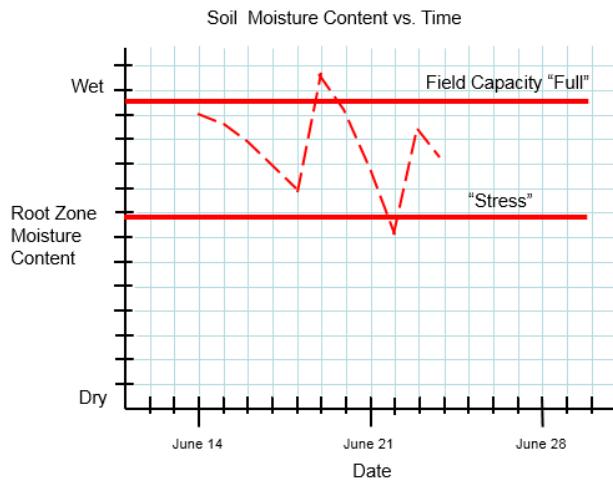


Figure 6

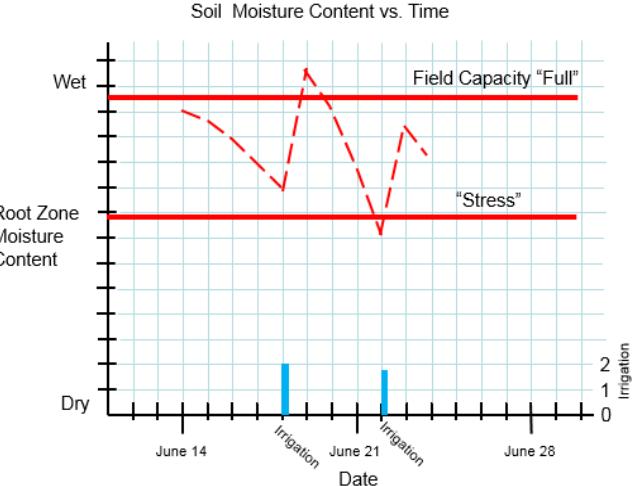


Figure 7

Having gone through this exercise we believe producers will have a better understanding and, perhaps more importantly, appreciation for quantitative scheduling principles and better prepared to discuss the details of how to apply them. We want them to conclude that “if I’m not tracking it I don’t really know if my soil moisture objectives are being met.” They should be more apt to spend the time and resources to do what has to be done to collect and systematically use data to help make irrigation timing and amount decisions.

### **Soil Moisture Charts as a Producer (User) Tool**

NRCS encourages producers to use any irrigation scheduling tool or combination of tools they prefer, are likely to use and that enables them to consider the current root zone water status when deciding when and how much water to apply. NRCS is accelerating our promotion of the use of soil water charts. They address water management and crop production objectives, and we believe producers are likely to use them due to their utility and user friendliness in enabling them to rapidly:

- Check the soil moisture status in relation to their “too wet” or “too dry” levels (figure 8).
- Evaluate the cumulative ET or soil drying trend in consideration of the next irrigation event (figure 9).
- Draw the conclusions with the need for little or no additional number crunching.
- Evaluate irrigation timing and amount compromises that may be necessary considering other field operations and farming constraints.

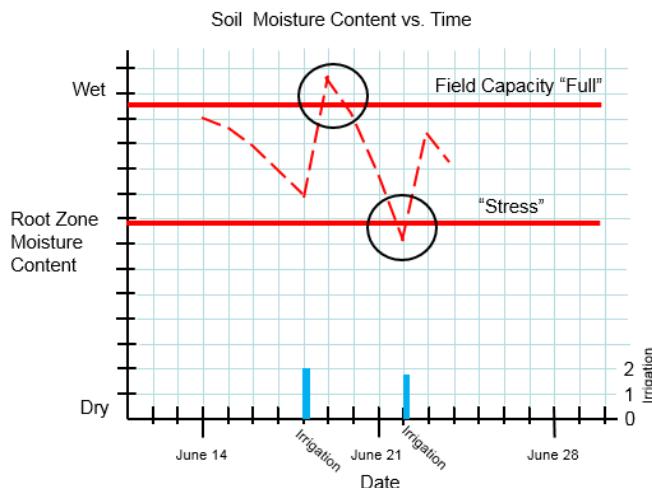


Figure 8

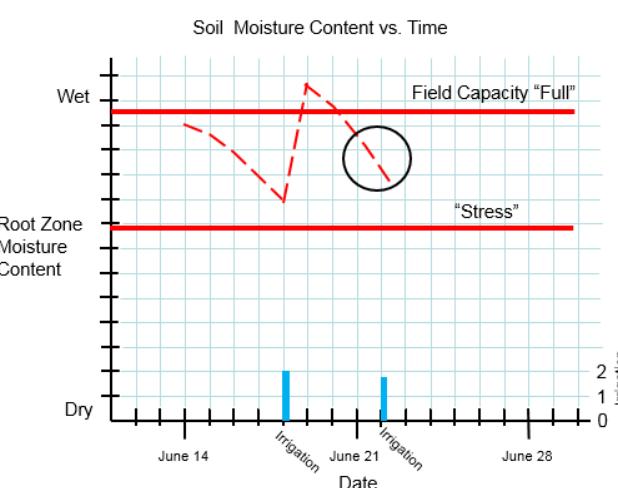


Figure 9

### **Soil Moisture Charts as a Standard Platform for Education and Technology Transfer**

Charts may help us increase the use of guidelines developed from ongoing research by applying it in context of the producer’s decision making process. For example, by illustrating conditions to be avoided that may lead to poor soil aeration (figure 10) or by illustrating the objective of encouraging some stress such as for regulated deficit irrigation (RDI) (figure 11) producers can decide what irrigation timing and amount choices to make to achieve these objectives.

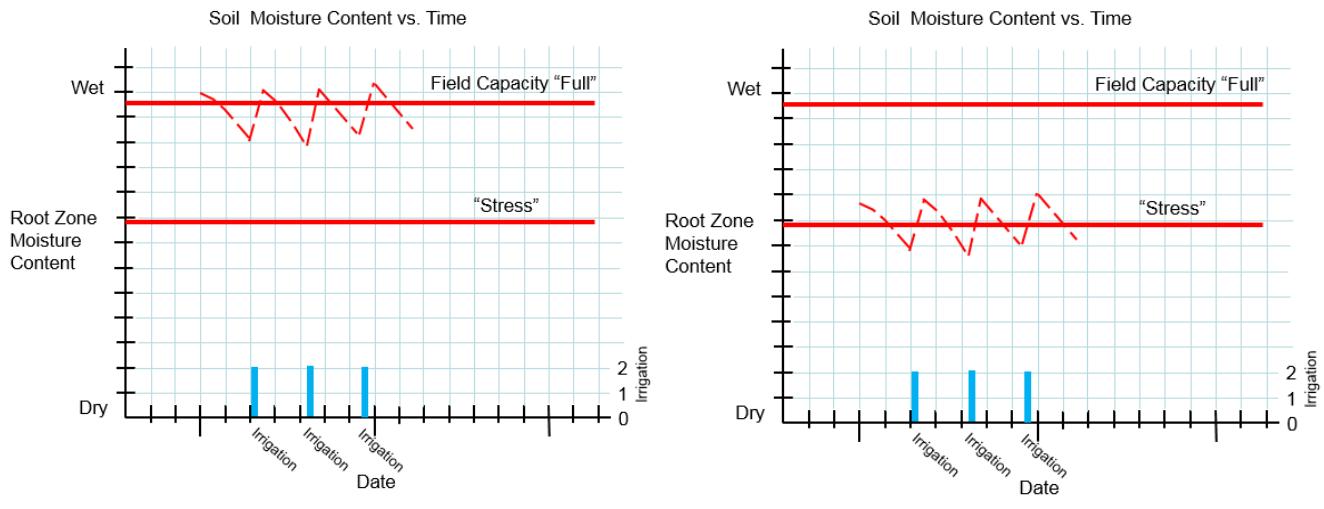


Figure 10

Figure 11

Producers are exposed to an array of technologies, services, guidance and methodologies all with the potential to help enable them to optimize irrigation decisions. Some provide all the information the producer might need. Most provide just some of the needed elements, pieces of the puzzle. Many producers are confused on how to proceed. Considering soil moisture charts as an information outcome, NRCS has begun using them as the common platform on which we relate, integrate or otherwise organize the role these technologies and methodologies can play in the producer's irrigation decision making process. The producer is then in a better position to evaluate alternative technologies, services, methods and to identify the pieces that are missing.

### **Availability of Data and Charts to the Producer**

Practically speaking, technology is necessary to collect, store, process and display the relatively frequent soil moisture measurements/estimates needed to develop soil moisture charts. This technology comes at a cost and there's still a lot to learn regarding its proper selection and use. However, considering current water supply, ground water quality, regulatory and other influences, we believe the use of technology is feasible for a large cross section of producers. We advise producers that they need to be patient and diligent in making a soil moisture monitoring and data processing/display "system" work for them. It's a process that should pay off for them in the long run.

### **Summary / Conclusions**

The root zone is where the producer puts the water with the intent of it being stored for future use. Crops respond to root zone moisture levels. It seems reasonable that good management includes monitoring the fate of infiltrated water and soil moisture change in response to ET and irrigation. We believe charts are an underutilized tool in their ability to illustrate the interaction between soil water status, field capacity, crop stress levels, and irrigation data, and to serve as a tool to educate and inform producers and others about how all of these factors should fit together to influence irrigation decisions. Soil moisture charts allow producers to quickly evaluate root zone water status as it relates to "too wet" and "too dry" water levels. Any need to change their irrigation strategy is identified and future irrigation events can be planned in the context of farming operations.



# American Society of Agronomy

## California Chapter

### Session X

## Management and Mitigation of Nitrate in Crop Production

**Session Chairs:**

Eric Ellison, Koch Industries

Richard Smith, UCCE Monterey

## **Remediation of tile drainage and surface runoff using denitrification bioreactors**

T.K. Hartz, Extension Specialist, Department of Plant Sciences, University of California,  
1 Shields Ave. Davis, CA 95616, 530 752-1738, [tkhartz@ucdavis.edu](mailto:tkhartz@ucdavis.edu)

Richard Smith, UCCE Vegetable Crops Farm Advisor, Monterey, San Benito and Santa Cruz Counties, 1432 Abbott Street, Salinas, CA 93901, 831 759-7357, [rifsmith@ucdavis.edu](mailto:rifsmith@ucdavis.edu)

Mike Cahn, UCCE Irrigation Farm Advisor, Monterey, San Benito and Santa Cruz Counties, 1432 Abbott Street, Salinas, CA 93901, 831 759-7377, [mdcahn@ucdavis.edu](mailto:mdcahn@ucdavis.edu)

Laura Tourte, UCCE Farm Management Farm Advisor, Monterey, San Benito and Santa Cruz Counties, 1432 Freedom Boulevard, Watsonville, CA 95076, 831 763-8005, [ljtourte@ucdavis.edu](mailto:ljtourte@ucdavis.edu)

### **Introduction**

Vegetable production on the Central Coast faces an unprecedented challenge from environmental water quality regulation. Maintaining surface runoff from vegetable fields below the Federal drinking water standard of 10 PPM NO<sub>3</sub>-N presents a challenge, particularly if the irrigation water used is above this nitrate level. Extensive monitoring in recent years has shown that runoff NO<sub>3</sub>-N closely mirrors the irrigation water source, and that common conservation practices (vegetated ditches, buffer strips or tailwater ponds) have minimal effect on runoff NO<sub>3</sub>-N concentration. Limiting the NO<sub>3</sub>-N concentration of tile drain effluent to 10 PPM is even more problematic. NO<sub>3</sub>-N concentration in the soil solution typically runs 3-5 times higher than soil NO<sub>3</sub>-N expressed on a dry soil basis; this is because the solution phase weighs no more than 20-35% of dry soil, depending on texture. With vegetable crop root zones commonly containing 20+ PPM NO<sub>3</sub>-N on a dry soil basis, soil solution leaching from the root zone is typically several-fold higher.

While better fertilizer management practices can reduce the nutrient load in agricultural wastewater, it is clear that some remediation will also be needed to consistently meet desired environmental levels. Of the techniques that have been considered for the remediation of agricultural wastewater, biological denitrification (BD) appears to be the most promising. BD is a passive process in which bacteria reduce NO<sub>3</sub><sup>-</sup> to gaseous N compounds (mostly N<sub>2</sub>). The requirements for BD to occur are an anaerobic environment, the presence of bacteria capable of this transformation, and labile carbon to power bacterial growth and act as a terminal electron acceptor in the reduction of NO<sub>3</sub>-N. This process occurs naturally in wetlands, but limited availability of labile carbon limits the rate at which denitrification occurs, making the use of wetlands to remediate agricultural wastewater problematic.

An alternative approach to harnessing BD is the use of a denitrification bioreactor. A bioreactor consists of a chamber filled with an organic waste material through which agricultural wastewater flows. The organic waste material (most often wood chips) supplies labile carbon while providing a physical matrix on which the

denitrifying bacteria can grow. Bioreactors have been evaluated in various agricultural areas around the world, with reasonably consistent success. This project was conducted to evaluate the performance of wood chip denitrification bioreactors in removing NO<sub>3</sub>-N from tile drain effluent and surface runoff from vegetable fields in the Salinas Valley.

## Methods

Two pilot-scale denitrification bioreactors (sites 1 and 2) were constructed in 2011 on tile-drained commercial vegetable farms in the Salinas Valley. Pits were dug, lined with polyethylene sheeting, and filled with chipped wood waste obtained from the Monterey Regional Waste Management District. Pumps were installed in the collection sumps of the farms' tile drain systems. Tile drain effluent was continuously pumped into the bioreactors at a rate to provide approximately 2 days of residence time in the reactors (based on total porosity) before the water was released into the drainage ditch that normally received the tile drainage. A third bioreactor (site 3) was constructed in 2012 to treat surface runoff. Because runoff contains a substantial sediment load, a pretreatment system using polyacrylamide (PAM) was necessary to remove sediment and prevent fouling of the bioreactor. To determine the rates of denitrification achieved inlet and outlet NO<sub>3</sub>-N concentrations were determined several times per week year-around (sites 1 and 2) or just during the irrigation season (site 3) through fall, 2013.

In bioreactor research conducted throughout the world, wood chip bioreactors have been shown to be carbon-limited (the rate of denitrification is limited by the microbial availability of carbon). To test whether our bioreactors were carbon-limited, we injected methanol (a soluble, easily degradable carbon source widely used in municipal wastewater treatment to stimulate denitrification) at 20 PPM C into the site 1 and 2 bioreactors during alternate months of the 2013 irrigation season. Methanol injection did increase denitrification rate, confirming a carbon limitation.

In 2014, additional study of carbon enrichment was undertaken. Six laboratory-scale bioreactors were fabricated from 6" diameter PVC pipe. These bioreactors were filled with aged wood chips from the field bioreactors. We evaluated the effect of injecting varying concentrations of carbon from two sources, methanol or glycerin. Our interest in glycerin stemmed from the fact that it is a byproduct of biodiesel fuel refining, and as such may become widely available in California at a competitive price; glycerin also has no safety concerns regarding flammability or toxicity, potential problems with methanol. Following this lab testing we conducted additional carbon enrichment trials at the site 1 field bioreactor in summer, 2014.

## Results

Sampling over the 2011, 2012 and 2013 irrigation seasons showed that the denitrification rate averaged 8-11 PPM NO<sub>3</sub>-N denitrified per day of residence time in the bioreactors; higher rates were observed with surface water treatment, probably due to higher water temperature (Fig. 1). These denitrification rates were similar to those reported from bioreactor studies in other areas of the country, and substantially higher than that typically achieved in constructed wetlands. However, the high initial NO<sub>3</sub>-N concentrations observed, particularly in tile drain water (often > 100 PPM), would require extended treatment time, and therefore would require very large bioreactors to meet environmentally desirable NO<sub>3</sub>-N concentration.

The injection of carbon from methanol into the site 1 and 2 bioreactors in 2013 increased denitrification rates, confirming that the wood chips were unable to supply sufficient labile carbon to maximize denitrification. In the laboratory-scale bioreactors carbon enrichment using either methanol or glycerin increased denitrification in proportion to the amount of C injected. Carbon from methanol was somewhat more effective than from glycerin, offsetting the higher cost of methanol. In 2014 methanol injection into the site 1 bioreactor demonstrated that near-complete denitrification was possible, provided sufficient C was injected to accommodate the inlet  $\text{NO}_3\text{-N}$  load (Fig. 2). At the highest rate of C enrichment inlet  $\text{NO}_3\text{-N}$  concentration of approximately 180 PPM was reduced to an average of 4 PPM in 2 days of bioreactor residence time.

Economic analysis suggested that operating wood chip bioreactors in a passive mode (no carbon enrichment) would cost approximately \$1.50-2.00 per lb  $\text{NO}_3\text{-N}$  denitrified. The chemical cost of carbon enrichment would be in that same range, but C enrichment controlled by real-time inlet  $\text{NO}_3\text{-N}$  monitoring could maximize system efficiency, minimize the bioreactor size requirement, and achieve consistent outlet water quality.

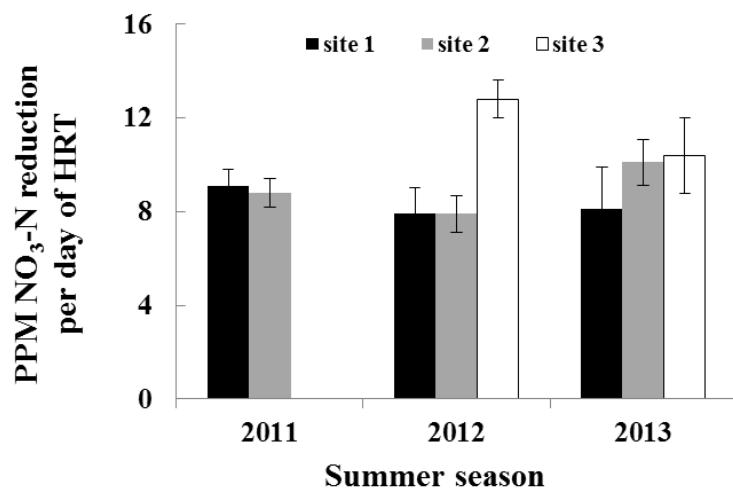


Fig. 1. Mean denitrification per day of hydraulic residence time (HRT) achieved over the summer seasons (June - September) in the bioreactors; bars represent the standard error of measurement. 2013 means for sites 1 and 2 do not reflect sampling during methanol injection.

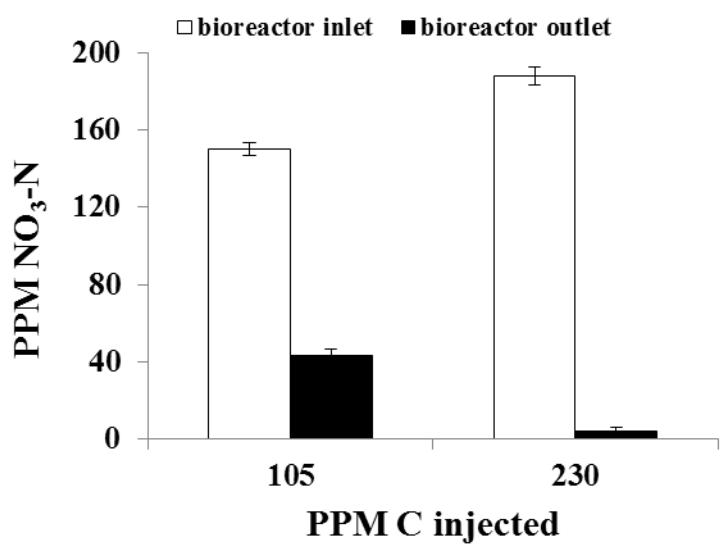


Fig. 2. Effects of methanol enrichment on denitrification in the site 1 bioreactor during the 2014 summer season; bars represent the standard error of measurement.

## Fertilizer value of N in irrigation water for coastal vegetable production

Michael Cahn, UC Cooperative Extension, Monterey County  
1432 Abbott St, Salinas CA 93901  
Phone 831-759-7377, FAX 831-758-3018, [mdcahn@ucanr.edu](mailto:mdcahn@ucanr.edu)

Laura Murphy, UC Cooperative Extension, Monterey County  
1432 Abbott St, Salinas CA 93901  
Phone 831-759-7365, FAX 831-758-3018, [mismurphy@ucanr.edu](mailto:mismurphy@ucanr.edu)

Richard Smith, UC Cooperative Extension, Monterey County  
1432 Abbott St, Salinas CA 93901  
Phone 831-759-7357, FAX 831-758-3018, [rifsmith@ucanr.edu](mailto:rifsmith@ucanr.edu)

Tim Hartz, Dept. of Plant Science  
One Shields Avenue, Davis, CA 95616-8780  
Phone 530-752-1738, [tkhartz@ucdavis.edu](mailto:tkhartz@ucdavis.edu)

### Background

Irrigation water from many wells on the central coast contains a significant amount of nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ). Recycled water from the Monterey County Regional Water Pollution Control Agency (MRWPCA) is the sole source for irrigating approximately 12,000 acres of prime Monterey County farmland, and is high in both  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ . Growers historically have been reluctant to modify their N fertilization practices on the basis of irrigation water N content because it is unclear how one can reliably calculate the ‘fertilizer value’ of this N. This issue has taken on added significance with the adoption of the new ‘Ag Order’ by the Central Coast Region Water Quality Control Board during March, 2012. The revised Ag Order requires vegetable growers to report the total amount of nitrogen applied to crop land, including N contained in irrigation water.

A limited body of research documents the efficiency of crop uptake of N from irrigation water (Bauder et al., 2011, Hopkins et al., 2007, Vavrina et al., 1998) upon which to base an estimate of ‘fertilizer value’ under normal irrigation and N management practices. Central coast vegetable growers have several concerns with a simplistic concentration  $\times$  volume approach to estimating the fertilizer value of ambient N in irrigation water. High N water sources, including both groundwater and recycled water, often also have significant levels of sodium and chloride. It is unclear what portion of the N in the irrigation water applied to leach salts should be credited as N value to the crop since that water would percolate below the root zone. Similarly, variation in irrigation uniformity in a field also affects the portion of N in irrigation water that can be credited as N value to a crop since some areas of a field would have more deep percolation than other areas. Crops such as lettuce and broccoli, with characteristically different rooting depths, may also have varying abilities to utilize ambient N contained in applied irrigation water. A further concern is that relatively low N concentrations in irrigation water may not significantly contribute to crop N uptake under normal production conditions. In fertilized vegetable root

zones, soil water  $\text{NO}_3\text{-N}$  concentration is typically 50-150 PPM. In growers' minds, it is uncertain that the addition of water with a much lower N concentration represents a significant net benefit to crop N nutrition.

An additional concern is specific to MRWPCA recycled water used to irrigate vegetables and berries grown on the central coast. A major portion of the N in this water is in the  $\text{NH}_4^+$  form. Because  $\text{NH}_4^+$  is a cation, it would be less likely to leach than  $\text{NO}_3^-$  and therefore may have more fertilizer value than  $\text{NO}_3\text{-N}$ .

The objective of this study was to address some of these concerns by conducting replicated field trials to evaluate the ability of lettuce and broccoli to recover N in irrigation water over a range of concentrations.

### **Field trials**

Replicated field trials simulating irrigation water with varying concentrations of N were conducted at the USDA Spence research facility near Salinas, CA. Trials consisted of summer and fall harvested lettuce crops (trials 1 and 2) in 2013 and a summer broccoli crop (trial 3) in 2014. Well water at the facility contained approximately 2 to 3 PPM  $\text{NO}_3\text{-N}$ . Water N treatments ranged from 2 to 42 ppm  $\text{NO}_3\text{-N}$  in the irrigation water (Table 1) and were compared to an unfertilized control and a fertilized standard treatment (seasonal total of 150 lb N/acre applied in 5 fertigations to lettuce and 220 lbs N/acre applied by 4 fertigations to broccoli). In addition, a treatment to evaluate crop N recovery from water dominated by  $\text{NH}_4\text{-N}$  was included (Table 1). Lettuce and broccoli crops were planted in 2 rows on 40-inch wide beds and germinated with overhead sprinklers. Individual plots measured 45 ft  $\times$  4 beds. The trial followed a randomized complete block design with 4 replications of each treatment. Treatments were initiated approximately 30 days after seeding and after installing surface drip tape. Water-powered proportional injectors were used to enrich all drip applied water to target concentrations of treatments. Injected  $\text{NO}_3\text{-N}$  was a blend of  $\text{Ca}(\text{NO}_3)_2$  and  $\text{NaNO}_3$  to maintain a consistent Ca:Na in the irrigation water. Injected  $\text{NH}_4\text{-N}$  was in the form of  $\text{NH}_4\text{SO}_4$ . An emitter inserted into the drip lines collected a composite water sample from each N treatment to confirm that target N concentrations were attained (Table 1). To observe the interaction of irrigation efficiency and crop nitrogen recovery, each N treatment was evaluated at two levels of applied water [Trial 1: applied water = 110% and 170% of crop evapotranspiration (ET), Trial 2: applied water = 120% and 210% of crop ET, Trial 3: applied water = 110% and 180% of crop ET]. Plots were harvested at crop maturity to assess the above ground biomass yield in lettuce and the above ground biomass yield and marketable crown yield in broccoli. The harvest area for assessing biomass yield was the center 2 beds  $\times$  30 feet. The N content of biomass subsamples was determined for each plot so that N recovery efficiency (NRE) could be calculated.

### **Results and discussion**

The average  $\text{NO}_3$  and  $\text{NH}_4$  concentrations of the irrigation treatments were very close to the target concentrations (Table 1), confirming that the methodology used to simulate irrigation water with different nitrate concentrations was accurate and reliable.

Results of the summer and fall trials demonstrated that the N concentration of the irrigation water significantly affected lettuce plant size, N content of tissue and biomass yield (Figure 1), and confirmed that a significant portion of the N in the irrigation water was taken up

by the lettuce and broccoli crops (Figures 2 - 4). Even relatively low concentrations of  $\text{NO}_3\text{-N}$  in the irrigation water were utilized by the crops.

The response of biomass yield, plant weight and plant N uptake to N concentration of the water treatments was greater during the summer than the fall lettuce crops, presumably because the N demand of the crop was greatest during the summer when growth was most rapid. The average biomass yield (88,697 lbs/acre) of the highest N rate (175 lbs N/acre) of the summer crop was 37% greater than the average biomass yield (64,791 lbs/acre) of the highest N rate (195 lbs N/acre) for the fall crop. Also, N uptake at the highest N rate was 42 lbs N/acre greater for the summer than the fall crop (Figures 2 and 3). In contrast, the plant tissue N content (at the highest N rate) was highest in the fall crop, indicating that the fall crop was taking up N, but grew at a slower rate than the summer crop.

The volume of water applied to the lettuce crops did not affect the recovery of N from the water treatments, demonstrating that all of the applied water could be credited as having N value to the crop. All treatments fit similar quadratic relationships for the fall and summer lettuce crops, and the broccoli crop grown in year 2 (Figures 2 - 4). Although the N rate of the fertigation treatment was higher than the N rates of the water treatments, the data from all treatments fit the same quadratic response curve ( $R^2 = 0.99$ ,  $p < 0.0001$ ) which suggests that the crop recovery of N from the water and fertilizer would be similar at the same N rates.

The volume of water applied to the broccoli crop affected recovery of N from the water treatments and the standard fertigation treatment (Figure 4). N recovery was significantly lower for all treatments receiving applied water equivalent to 180% of Crop ET compared to treatments receiving applied water equivalent to 110% of Crop ET. However, the reduction in N recovery between the water and fertigation treatments was similar, again suggesting that crop uptake of water and fertilizer sources of N are equivalent.

Average N recovery efficiency (NRE) was determined for each trial from the slope of a linear plot of the amount of N applied and crop N uptake. Crop recovery of N from the water treatments averaged 86% during the summer and 41% during the fall lettuce crops, and was 100% for the broccoli 110% ET treatment and 67% for the 180% ET treatment. As mentioned before, the higher recovery of lettuce grown during the summer reflects the fact that the crop grew more vigorously than during the fall. The high recovery rate for broccoli presumably resulted from the combination of a high N demand and because N rates for the water treatments were at the steepest part of the N response curve. The source of N in the irrigation water ( $\text{NH}_4$  vs  $\text{NO}_3$ ) had no significant effect on N recovery by the crop.

The results of the 3 field trials demonstrated that ambient N in irrigation water has fertilizer value for cool season vegetable crops, such as lettuce and broccoli, even with a concentration as low as 10 ppm N. The trials also showed that the source of N ( $\text{NH}_4$  vs  $\text{NO}_3$ ) did not affect crop recovery. Presumably  $\text{NH}_4$  would quickly transform to  $\text{NO}_3$  when added to the soil. Also, the volume of water applied did not affect the recovery rate of N from a water source more than from fertilizer, suggesting that all water applied containing N had fertilizer value for the crops. These results were attained under a well-managed drip irrigation system, with a high application uniformity and frequent irrigations (2 to 3 times per week) so that

irrigation volumes were small, which likely minimized leaching losses even under high ET application rates. It is possible that under poor water management or less efficient irrigation methods (e.g. furrow), recovery of N would be less than was reported in these trials, but it is unlikely that the differences in recovery between fertilizer and water sources of N would be significant.

### **Conclusions**

The results of the 3 replicated field trials demonstrated that N in irrigation water has fertilizer value for both shallow and deep rooted vegetable crops, such as lettuce and broccoli, even when the concentration in the water is less than 20 ppm N. The trials also showed that the source of N ( $\text{NH}_4$  vs  $\text{NO}_3$ ) did not affect crop recovery. The volume of water applied did not affect the recovery rate of N from an ambient source more than from a fertilizer source of N, suggesting that all water applied containing N had fertilizer value to the crops.

### **Literature Cited**

- Bauder, T.A., R.M. Waskom, P.L. Sutherland and J.G. Davis. 2011. Irrigation water quality criteria. Colorado State Univ. Fact Sheet 506.
- Hopkins, B.G., D.A. Horneck, R.G. Stevens, J.A. Ellsworth and D.M. Sullivan. 2007. Managing irrigation water quality for crop production in the Pacific Northwest. Publication PNW 597-E.
- Vavrina, C.S., G.J. Hochmuth, J.A. Cornell and S.M. Olson. 1998. Nitrogen fertilization of Florida-grown tomato transplants: Seasonal variation in greenhouse and field performance. HortScience 33:251-254.

### **Acknowledgements**

We are grateful for the assistance of UCCE Staff Research Associates Barry Farrara, Thomas Lockhart, and Patricia Love. Sharon Benzen and David Lara of the USDA-ARS in Salinas, are also acknowledged for assistance with replicated trials. Funding was provided by CDFA-FREP.

Table 1. Measured  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  concentrations of irrigation water treatments (trial 1, summer harvest)

#	Irrigation water treatments	<u>Measured N concentration<sup>x</sup></u>		
		-----	ppm	-----
1	Unfertilized Control	3.1	0.2	3.4
2	Fertilized Standard	3.1	0.2	3.4
3	12 ppm $\text{NO}_3\text{-N}$	12.8	0.4	13.1
4	22 ppm $\text{NO}_3\text{-N}$	22.3	0.6	22.8
5	42 ppm $\text{NO}_3\text{-N}$	41.9	1.1	42.9
6	42 ppm N (30 ppm $\text{NH}_4\text{-N}$ )	13.2	27.3	40.5

<sup>x</sup>Average of 17 irrigations

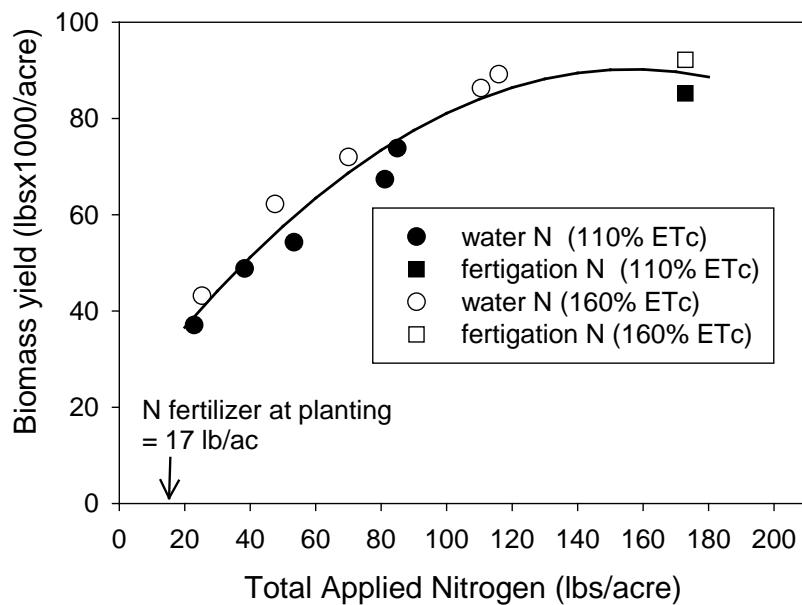


Figure 1. Applied nitrogen (irrigation water and fertilizer) effects on biomass yield (trial 1, summer lettuce).

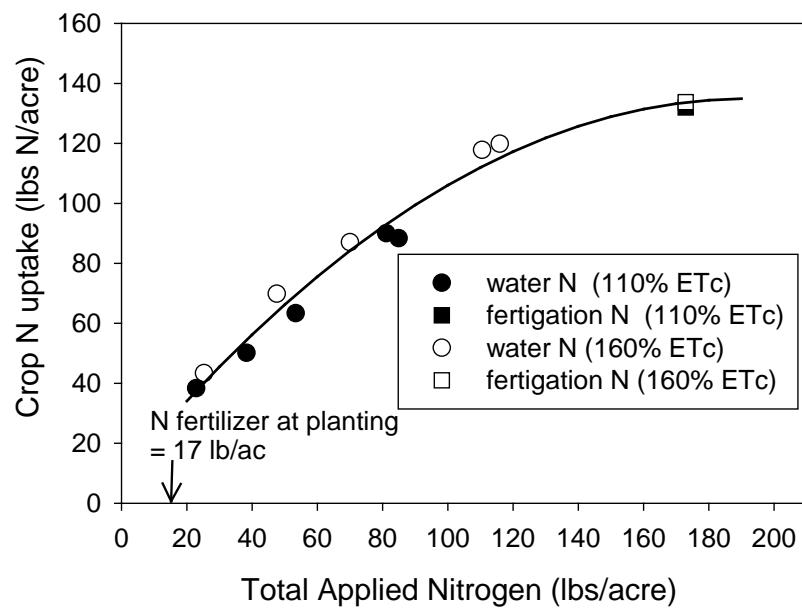


Figure 2. Applied nitrogen (irrigation water and fertilizer sources) effects on crop N recovery (trial 1, summer lettuce).

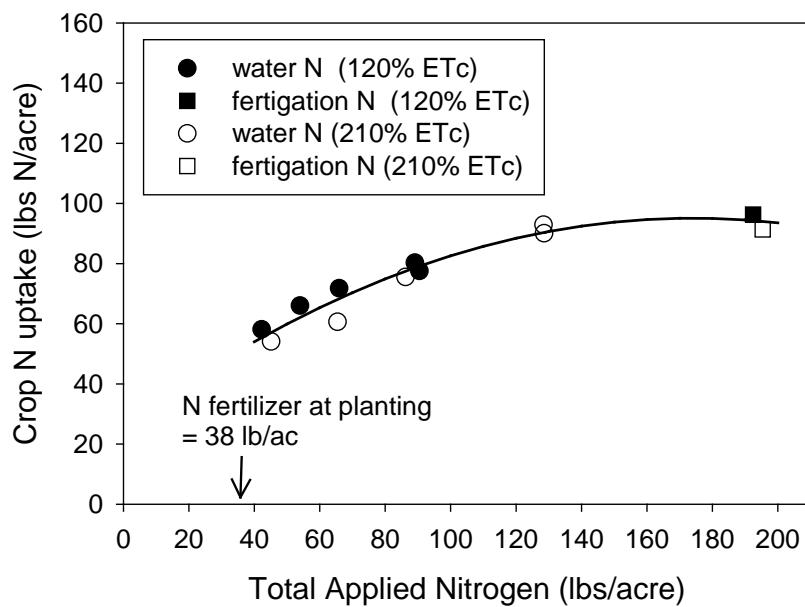


Figure 3. Applied nitrogen (irrigation water and fertilizer sources) effects on crop N uptake (trial 2, fall lettuce).

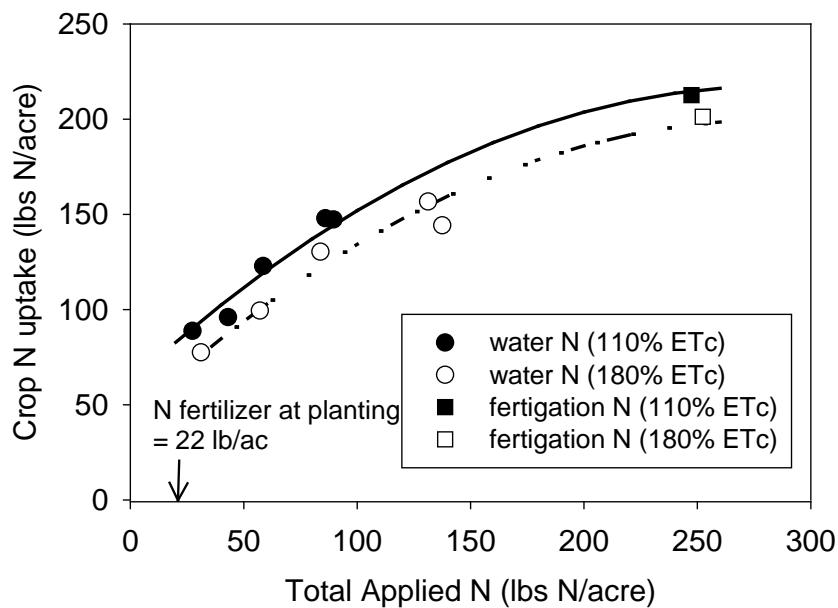


Figure 4. Applied nitrogen (irrigation water and fertilizer) on crop N recovery (trial 3, summer broccoli).

## Nitrogen Management in Almond

P. H. Brown, Sebastian Saa-Silva and Saiful Muhammad  
Plant Sciences, University of California, Davis  
One Shields Avenue, Davis, CA 95616  
Phone (530) 752-0929, phbrown@ucdavis.edu

### Introduction

Evidence from the 2007 CDFA-FREP nutrition focus group and survey of industry leading consultants, growers and Farm Advisors suggests that our current approach to managing nutrition in Almond is inadequate to meet production goals. Ninety % of growers and consultants felt that UC Critical Values (CVs), especially for N and K, were not appropriate for current yield levels and that the link between the results of leaf and soil sampling and specific fertilizer recommendations is poor. In general CVs are inadequate tools for nutrient management in high value crops as CVs can only indicate a deficiency. Further this approach does not provide information on how to respond to deficiency. The protocol of CVs are based on leaf sampling in July and hence limits the in season nutrient adjustment for current crops.

In other crops nutrient managements are based on model of plant growth and nutrient demand curves that guide the quantity and timing of fertilizer application. However nutrient demand curves have not been developed for almond.

To develop a phenology and yield based nutrient demand curves that guide the timing and rate of fertilizer application, a large experiment was initiated in 2008 in Belridge, Kern county under fan jet and drip irrigations with four rates of nitrogen (N) 125, 200, 275 and 350lb/ac applied with two N fertilizer sources-UAN 32 and CAN 17. UAN 32, CAN 17 were applied in four fertigation cycles in February, April, June and postharvest as 20, 30, 30 and 20% of the total respectively while SOP was applied as granule in winter. 768 trees were monitored individually for yield and yield related parameters and in season leaf and fruit nutrient and fruit biomass.

Whole tree nutrients were estimated by excavating trees from the four N rate treatments at the beginning and end of two seasons while nutrient remobilization and storage were determined by multiple in-season core sampling of tree perennial organs-roots, trunk, canopy and small branches. N supply had significant yield effect from 2009 and treatment effects increased in the later years of the experiment. N and K export in fruits by 1000lb kernel yield ranged from 53lb to 74lb and 51lb to 83lb for N and K rate treatments respectively. In adequately fertilized trees and average N removal of 68 lb N and 80 lb K per 1000 lb kernel yield was observed. This value includes all of the N and K required to grow all fruit parts. Over 85% of the total N and 70-75% of the total K was accumulated in fruit by mid-June. Fruits were the greatest sink for N and other nutrients and 90% of total tree N was partitioned to fruits. Although leaves were the second greatest sink for N (about 6% of total tree N) N from leaves were either remobilized to perennial organs at senescence or re-entered in soil as a result of leaf fall. The demand for N for new perennial wood growth varied from 20-30 lbs per acre per year

A computer model has been developed that guides growers through decision-making process to develop a nitrogen management strategy for Almonds. The information supporting this program will be presented and the program will be demonstrated.



## **2015 Poster Abstracts**

### **Poster Chairs:**

Anne Collins Burkholder,  
Dellavalle Lab

Eric Ellison, Koch Industries  
Scott Stoddard, UCCE Merced

## Potassium and magnesium in irrigation water quality assessment

C.J. Smith<sup>1</sup>, J.D. Oster<sup>2</sup>, G. Sposito<sup>3</sup>

### ABSTRACT

Problems with soil physical properties caused by wastewaters with high concentrations of K have been reported in both Australia and California. A review of the literature dating back to the 1930s supports the general conclusion that the relative order of deleterious effect on soil hydraulic properties of the four common cations in soils is Na > K > Mg > Ca. Based on laboratory data for a Sodosol soil from the Riverina Region of Australia [a calcareous soil having pH > 8 and with over 50 % of the clay minerals being smectites (e.g. montmorillonite)] irrigated with winery wastewater, the deleterious effect of K was about one-third of that of Na, while the concentration of Mg needed to be about an order of magnitude larger than Ca to have the same beneficial effect. The Cation Ratio of Structural Stability (CROSS), a generalized Sodium Adsorption Ratio incorporating all four cations, takes these differences into account:

$$\text{CROSS} = (\text{Na} + \text{aK}) / ((\text{Ca} + \text{bMg})/2)^{0.5}$$

We used the Sodosol laboratory data to obtain a value of  $0.335 \pm 0.038$  for the coefficient of K that accounts for its lesser deleterious effect as compared with Na, while the value for the coefficient of Mg was  $0.0758 \pm 0.0012$  to account for its lesser beneficial effect as compared with Ca. We propose that CROSS can serve as an improved irrigation water quality parameter to assess the influences of SAR, PAR, and total electrolyte concentration (salinity) of irrigation and soil waters on the hydraulic conductivity and other properties of soils related to permeability.

### INTRODUCTION

Wastewaters generated by agriculture and municipalities are being re-used increasingly for irrigation. This partially mitigates severe water shortages and is a means of avoiding wastewater discharge to surface waters while producing economic returns. Wastewaters generated by agriculture --- dairies, wineries, and olive and tomato processing plants, as well as drainage water --- pose risks related to the flow of water through soils and crop growth because of higher concentrations of K and Mg and higher salinity. Recent studies have documented problems with water infiltration caused by high levels of K in applied waters in Australia (Rengasamy and Marchuk, 2011; Smiles and Smith, 2004) and California (Nat Dellavalle, personal communication, 2010).

One reason the effect of K on soil hydraulic properties has not traditionally been taken into consideration is that Na concentrations in salt-affected soils and groundwaters are usually much higher than those of K, but the most important reason is that the authors of Handbook 60 (U.S. Salinity Laboratory staff, 1954) concluded 60 years ago that "exchangeable K has only a slight or no adverse effect upon the physical properties of soils." based on laboratory studies they had conducted on seven soils adjusted to various levels of exchangeable sodium and exchangeable potassium. Quirk and Schofield (1955) published results showing a decrease in the hydraulic conductivity of soil pads equilibrated with concentrated Cl solutions of Na, K, Mg, and Ca when leached with a series of more dilute Cl solutions of the same cation, in the following order: Na > K > Mg > Ca. They defined the cation concentration at which a 10 -15 % reduction in saturated hydraulic conductivity occurred as the threshold electrolyte concentration (TEC), reporting TEC values of Na, K, Mg and Ca of 250, 67, 2.0 and 0.6 mmolc/L, respectively. Since this early work, both positive and negative effects of K on soil hydraulic conductivity have been reported (Chen et al., 1983; Keren, 1984; Rengasamy and Marchuk, 2011). Marchuk et al. (2012) characterized changes in pore architecture, using X-ray tomography, and found a well-developed pore structure in soils having sufficiently high concentration of exchangeable Ca and Mg, whereas soils dominated by Na and K had isolated pore clusters surrounded by pores filled with dispersed clay particles. They also found that clay dispersion decreased in the order Na > K > Mg > Ca.

Magnesium has long been considered to have effects similar to Ca on soil physical properties (Keren, 1984; Levy, 2012). The U.S. Salinity Laboratory Staff (1954) grouped these two bivalent cations together as promoting and maintaining good soil structure. Bresler et al. (1982) remarked that this customary grouping may not reflect the true status of Mg, which is masked by the typically two- to five-fold greater concentration of Ca over Mg in irrigation and soil waters. Rengasamy et al. (1984) concluded that, at low electrolyte concentrations, Mg had the greatest effect on saturated hydraulic conductivity, a point also made by Keren (1984), Sumner (1993), and Levy (2012). Use of gypsum on silt loam soils with exchangeable Mg levels near 36 % reduced runoff under surface irrigation conditions (Vyshpolsky et al., 2010). In experiments conducted on soils from the cornbelt in the U.S., Dontsova and Norton (2002) reported Mg-treated soils had half the final infiltration rate as Ca-treated soils for two of the four soils they studied. In summary, the available literature supports the premise that, under certain conditions both K and Mg can have deleterious effects on soil hydraulic properties that are usually related to clay particle dispersion.

<sup>1</sup> CSIRO Land and Water, PO Box 1666, Canberra ACT 2601, Australia, [cjsmith2752@gmail.com](mailto:cjsmith2752@gmail.com)

<sup>2</sup> Department of Environmental Science, University of California, Riverside CA 92506, [james.oster@ucr.edu](mailto:james.oster@ucr.edu)

<sup>3</sup> Department of Environmental Science, University of California, Berkeley CA 94720-3114. [gsposito@berkeley.edu](mailto:gsposito@berkeley.edu)

## MOVING BEYOND SAR

The Sodium Adsorption Ratio (SAR) has long been the standard measure of the potential sodium hazard of irrigation water (U.S. Salinity Laboratory Staff, 1954):

$$\text{SAR} = \text{Na}/((\text{Ca} + \text{Mg})/2)^{0.5}$$

where ion concentrations are in mmol/L. The SAR is closely related to the exchangeable sodium percentage: the two are approximately equal for  $\text{SAR} < 40$ . The authors of Handbook 60 (U.S. Salinity Laboratory Staff, 1954) also defined the Potassium Adsorption Ratio (PAR) with K concentration replacing Na, but there are no water quality guidelines based on PAR in the current standard reference publications related to water quality assessment (Tyagi and Minhas, 1998; Wallender and Tanji, 2012).

Smiles and Smith (2004), recognizing the possibility of a synergistic effect of monovalent cations on soil hydraulic properties, proposed that SAR be replaced by the Monovalent Cation Adsorption Ratio (MCAR) to assess irrigation water quality:

$$\text{MCAR} = (\text{Na} + \text{K} + \text{NH}_4)/((\text{Ca} + \text{Mg})/2)^{0.5}$$

These authors pointed out the need to apply MCAR carefully, because K can become strongly adsorbed in soils, whereas  $\text{NH}_4$  may be only ephemeral in soil, becoming rapidly oxidized to  $\text{NO}_3^-$ . Indeed, under conditions favorable to rapid nitrification, Intrawech et al. (1982) found that ammonium-based fertilizers had no measurable influence on soil structure during a 10-year field study conducted in Kansas under cropped conditions.

In MCAR, no relative distinction is made between Na and K in promoting soil clay dispersion, or between Ca and Mg in promoting soil clay flocculation. Considering differences in the flocculating power of cations having the same valence (Sposito, 2008), Marchuk and Rengasamy (2010) proposed Cation Ratio of Structural Stability (CROSS) that incorporates such differing effects as an alternative to MCAR.

$$\text{CROSS} = (\text{Na} + a\text{K})/((\text{Ca} + b\text{Mg})/2)^{0.5}$$

where the coefficient of K ( $a$ ) is a measure of its dispersing power relative to Na, and the coefficient of Mg ( $b$ ) is a measure of its flocculating power relative to Ca. Based on relative flocculating power of K, Mg, and Ca for four soils, Rengasamy and Marchuk (2011) obtained a value of 0.56 for  $a$  and 0.60 for  $b$ . Since the electrolyte concentration required to cause flocculation of soil clays is usually considerably greater than that which results in clay dispersion (Quirk, 2001), we used the TEC values reported by Quirk and Schofield (1955) to obtain a value of 0.26 for  $a$  and 0.30 for  $b$ .

We (Smith et al., 2014) tested CROSS using laboratory data reported by Arienzo et al. (2012) for a Sodosol from the Riverina region of Australia which had been irrigated with winery wastewater. This soil is high (> 50 %) in smectite clay minerals and has alkaline pH (> 8) with clay loam texture overlying a medium clay texture in its subsurface layer. The methods of Quirk and Schofield (1955) were used to assess the effects of SAR, PAR and electrolyte concentration on the saturated hydraulic conductivity of soil columns. The TEC values we calculated with these data are listed in Table 1. The correlation between MCAR and TEC (Fig. 1A) was very poor ( $R^2 = 0.09$ ). The value of  $R^2$  increased to 0.64 when 0.56 was used for  $a$  and 0.60 for  $b$  – coefficients derived from the relative flocculating power of K, Mg, and Ca. The value of  $R^2$  was even higher (0.82) when the  $a$  and  $b$  values were based on dispersion:  $a = 0.26$  and  $b = 0.30$ .

We applied an optimization technique to provide best-fit values of  $a$  and  $b$  (Duan et al., 1993; Rosenbrock, 1960) using the data in Table 1. The resulting values of  $a$  and  $b$  were 0.335 (s.e. 0.038) and 0.0758 (s.e. = 0.012). The resulting relationship (Fig. 1B) between CROSS and TEC ( $R^2 = 0.95$ ) is the most robust relationship with TEC that can be obtained from the data in Table 1. The resulting CROSS equation is:

$$\text{CROSS} = (\text{Na} + 0.335 (\pm 0.038) \text{K})/((\text{Ca} + 0.0758 (\pm 0.012) \text{Mg})/2)^{0.5}$$

Thus the deleterious effect of K was about one-third of that of Na, and the concentration of Mg needs to be about 13 times larger than Ca to have the same beneficial effect.

## CONCLUSION

We draw the same conclusion as have others: that the relative order of deleterious effect of the common cations on soil hydraulic properties is:  $\text{Na} > \text{K} > \text{Mg} > \text{Ca}$  and we propose use of the coefficients in CROSS which take these differences into account. The coefficients were based on TEC values for the four cations at which the saturated hydraulic conductivity begins to decline significantly for Sodosol soil from the Riverina region of Australia. The utility of the CROSS as a water quality parameter, and the coefficients we obtained to use in this equation must be tested on other soils and for waters that contain either  $\text{NH}_4^+$ , known to impair soil hydraulic properties if nitrification is slow, or  $\text{SO}_4^{2-}$ , because the coefficients for K and Mg may be influenced by  $\text{SO}_4^{2-}$  ion-pair formation with K and Mg.

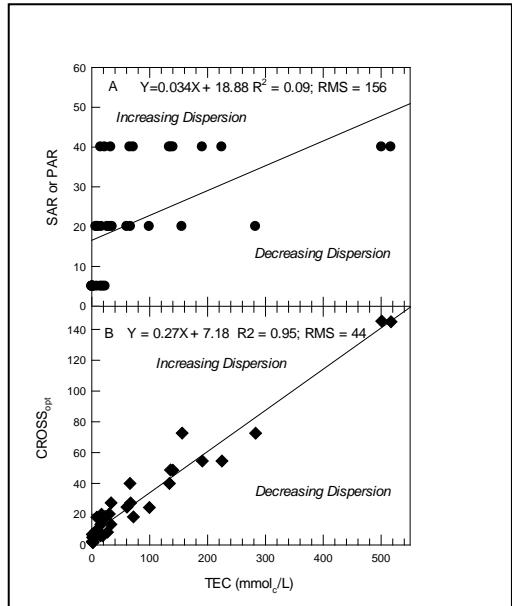
## ADDENDUM – WHY CATIONS OF THE SAME VALENCE CAN HAVE DIFFERENT EFFECTS ON SOILS

The basic issue is the relationship between soil particle flocculation and cation adsorption. Diffuse double layer theory (Sposito, 2008) states that only cation valence matters in this relationship, and hence all cations of a given valence should bind to soil particles in the same way, although monovalent cations would behave differently from bivalent cations. However, if cations of the same valence bind with differing strengths to soil particles because of differing degrees of covalency in their binding, this will affect their flocculation (Sposito, 2008). Recently, Marchuk and Rengasamy (2011) proposed a new geochemical parameter for estimating the degree of non-covalency in cation binding, the ionicity index, as a measure of the tendency of a cation to bind weakly to soil particles. They showed that their ionicity index is strongly correlated with clay dispersion for a wide variety of soil clays, with the ordering: Na > K > Mg > Ca. The ionicity index goes beyond diffuse double layer theory by saying that the degree of non-covalency in cation binding also is important, not just electrostatics based solely on cation valence. In this way, it distinguishes Na from K, and Ca from Mg, as is observed experimentally. We suggest, therefore, that the reason for the observed differences many studies have reported for soil response to applied water composition with varying Na, K, Ca, or Mg concentrations is related not only to the valence of the cations, as is well known, but also to their ionicity index.

Table 1. Sodium (SAR) and potassium adsorption ratio (PAR), threshold concentration (TEC, mmol/L) and cation concentrations (mmol/L) in applied water leading to a 15 % reduction in the saturated hydraulic conductivity of surface and subsurface layers in a calcareous soil from the Riverina region of Australia (Arienzo et al., 2012).

Soil layer	SAR or PAR	TEC	K	Na	Mg	Ca
Surface	SAR40 Ca	66.0	0.00	61.30	0.00	4.70
Surface	PAR40 Ca	15.5	15.21	0.00	0.00	0.29
Surface	SAR20 Ca	30.2	0.00	26.70	0.00	3.50
Surface	PAR20 Ca	9.6	9.18	0.00	0.00	0.42
Surface	SAR5 Ca	2.0	0.00	1.76	0.00	0.24
Surface	PAR5 Ca	2.0	1.76	0.00	0.00	0.24
Subsurface	SAR40 Ca	134.0	0.00	116.90	0.00	17.10
Subsurface	PAR40 Ca	32.9	31.65	0.00	0.00	1.25
Subsurface	SAR20 Ca	16.7	0.00	15.50	0.00	1.20
Subsurface	PAR20 Ca	26.9	24.92	0.00	0.00	1.98
Subsurface	SAR5 Ca	1.5	0.00	1.35	0.00	0.15
Subsurface	PAR5 Ca	1.5	1.35	0.00	0.00	0.15
Surface	SAR40 Ca+ Mg	191	0.00	159.30	15.85	15.85
Surface	PAR40 Ca+ Mg	22.6	22.00	0.00	0.30	0.30
Surface	SAR20 Ca+Mg	66.9	0.00	52.95	6.98	6.98
Surface	PAR20 Ca+Mg	10.7	10.18	0.00	0.26	0.26
Surface	SAR5 Ca+ Mg	1.5	0.00	1.35	0.07	0.07
Surface	PAR5 Ca+ Mg	2	1.76	0.00	0.12	0.12
Subsurface	SAR40 Ca+ Mg	224.8	0.00	183.00	20.90	20.90
Subsurface	PAR40 Ca+ Mg	71.9	66.40	0.00	2.75	2.75
Subsurface	SAR20 Ca+ Mg	33.3	0.00	29.10	2.10	2.10
Subsurface	PAR20 Ca+ Mg	7.1	6.87	0.00	0.12	0.12
Subsurface	SAR5 Ca+ Mg	1	0.00	0.93	0.03	0.03
Subsurface	PAR5 Ca+ Mg	1	0.93	0.00	0.03	0.03
Surface	SAR40 Mg	517.0	0.00	357.00	160.00	0.00
Surface	PAR40 Mg	140.0	121.50	0.00	18.50	0.00
Surface	SAR20 Mg	283.0	0.00	158.00	125.00	0.00
Surface	PAR20 Mg	99.5	73.00	0.00	26.50	0.00
Surface	SAR5 Mg	23.2	0.00	12.00	11.20	0.00
Surface	PAR5 Mg	18.9	10.30	0.00	8.60	0.00
Subsurface	SAR40 Mg	501.0	0.00	349.00	152.00	0.00
Subsurface	PAR40 Mg	136.0	118.50	0.00	17.50	0.00
Subsurface	SAR20 Mg	156.0	0.00	103.00	53.00	0.00
Subsurface	PAR20 Mg	60.7	49.00	0.00	11.70	0.00
Subsurface	SAR5 Mg	8.7	0.00	5.90	2.80	0.00
Subsurface	PAR5 Mg	15.1	8.85	0.00	6.25	0.00

Figure 1. Correlation between Sodium (SAR; A) and Potassium Adsorption Ratio (PAR; A) or Cation Ratio of Structural Stability (Cross; B) based on the threshold concentration (TEC, mmol<sub>c</sub>/L) that caused a 15 % reduction in the relative saturated hydraulic conductivity of a calcareous soil from the Riverina region of Australia (Arienzo et al., 2012). RMS represents the root-mean-square value.



## REFERENCES

- Arienzo, M., Christen, E.W., Jayawardane, N.S., Quayle, W.C., 2012. The relative effects of sodium and potassium on soil hydraulic conductivity and implications for winery wastewater management. *Geoderma* 173-174, 303-310.
- Bresler, E., McNeal, B. L., Carter, D. L., 1982. Saline and Sodic Soils. Springer-Verlag, Berlin, Germany.
- Chen, Y., Banin, A., Borochovitch, A., 1983. Effects of Potassium on soil structure in relation to hydraulic conductivity. *Geoderma* 30, 135-147.
- Dellavalle, N., 2010. Private communication. Dellavalle Laboratory Inc., 1910 W McKinley Ave, Fresno, CA 93728.
- Dontsova, K.M., Norton, L.D., 2002. Clay dispersion, infiltration, and erosion as influenced by exchangeable Ca and Mg. *Soil Sci.* 167, 184-193.
- Duan, Q. Y., Gupta, V. K., Sorooshian, S., 1993. Shuffled complex evolution approach for effective and efficient global minimization. *J. Optimiz. Theory Appl.* 76(3), 501–521.
- Intrawech, A., Stone, L.R., Ellis, Jr, R., Whitney, D.A., 1982. Influence of fertilizer nitrogen source on soil physical and chemical properties. *Soil Sci. Soc. Am. J.* 46:832-836.
- Keren, R., 1984. Potassium, magnesium, and boron in soils under saline and sodic conditions. In: Shainberg, L., Shalheveth, J. (Ed.) 1984. *Soil Salinity under Irrigation: Processes and Management*. Springer-Verlag, Berlin, Germany. pp. 77-99.
- Levy, G. J., 2012. Sodicity. In: Huang, P. M., Li, Y., Sumner, M. E. (Eds.) *Handbook of Soil Sciences*. 2nd Ed. Resource Management and Environmental Impacts. CRC Press, Boca Raton, FL. Chap. 18.
- Marchuk, A.G., Rengasamy, P., 2010. Cation ratio of soil structural stability (CROSS). 19<sup>th</sup> World Congress of Soil Science, Soil Solutions for a Changing World. 1-6 August, Brisbane, Australia. 9-11.
- Marchuk, A., Rengasamy, P., 2011. Clay behaviour in suspension is related to the iconicity of clay-cation bonds. *App. Clay Sci.* 53, 754-759.
- Marchuk, A., Rengasamy, P., McNeill, A., Kumar, A., 2012. Nature of the clay-cation bond affects soil structure as verified by X-ray computed tomography. *Soil Res.* 50, 638-644.
- Quirk, J.P., 2001. The significance of the threshold and turbidity concentrations in relation to sodicity and microstructure. *Aust. J. Soil Res.* 39, 1185-1217.
- Quirk, J.P., Schofield, R.K., 1955. The effect of electrolyte concentration on soil permeability. *J. Soil Sci.* 6, 163-178.
- Rengasamy, P., Greene, R.S.B., Ford, G.W., Mehanni, A.H., 1984. Identification of dispersive behaviour and management of red-brown earths. *Aust. J. Soil Res.* 22, 413–431.
- Rengasamy, P. and Marchuk, A. 2011. Cation ratio of soils structural stability (CROSS). *Soil Res.* 49, 280-285.
- Smiles, D.E., Smith, C.J., 2004. A survey of the cation content of piggery effluents and some consequences of their use to irrigate soils. *Aust. J. Soil Res.* 42, 231-246.
- Smith, C.J., Oster, J.D., Sposito, G. Potassium and magnesium in irrigation water quality assessment. *Agric. Water Manage.* (20140 . <http://dx.doi.org/10.1016/j.agwat.2014.09.003>
- Sposito, G., 2008. *The Chemistry of Soils*. 2<sup>nd</sup> Ed. Oxford University Press, New York.
- Sumner, M.E., 1993. Sodic soils: New perspectives. *Aust. J. Soil Res.* 31, 683-750.
- Tyagi, N.K., Minhas, P.S., 1998. Agricultural salinity management in India. Director, Central Soil Salinity Research Institute. Karnal 132001, India.
- U.S. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Handbook No. 60. US Department of Agriculture, Washington, DC.
- Wallender, W.W., Tanji, K.K., 2012. Agricultural Salinity Assessment and Management. ASCE Manuals and Reports on Engineering Practice No. 71. ASCE, Reston, VA. Vyshpolsky F., Mukhamedjanov, K., Bekbaev, U., Ibatullin, S., Yuldashev, T., Noble, A.D., Mirzabaev, A., Aw-Hassan, A., Qadir, M., 2010. *Agric. Water Manage.* 97, 1277-1286.

# **Impact of Salinity on Biological Nitrogen Fixation in Alfalfa (*Medicago sativa*) and its Response to Applied Mineral Nitrogen**

Sangeeta Bansal<sup>1</sup>, Sharon E. Benes<sup>1</sup>, Daniel H. Putnam<sup>2</sup>, Stephen R. Grattan<sup>3</sup> and John T. Bushoven<sup>1</sup>

<sup>1</sup>Dept. of Plant Science, California State University, Fresno;

<sup>2</sup>Dept. of Plant Sciences and <sup>3</sup>Dept. of Land, Air and Water Resources; University of California, Davis

<sup>1</sup>Address: 2415 E San Ramon Ave. M/S AS72. Fresno, CA 93740

Telephone: 559-278-2255, Fax: 559-278-7413

E-mail: sbansal88@mail.fresnostate.edu

As irrigation water supplies become scarce in California, more saline water will likely be used to irrigate field crops and forages such as alfalfa. A valid research question to ask is how salinity impacts biological nitrogen fixation (BNF) and its contribution toward fulfilling the nitrogen requirements of alfalfa. Our greenhouse study consisted of two experiments. The main experiment utilized inoculated seed (dusted with *Sinorhizobium meliloti* bacteria) of variety CUF101 sown into 40 cm deep pots containing washed sand and irrigated with water of either low salinity (LS = 1.5 dS/m EC<sub>w</sub>) or high salinity (HS = 6.4 dS/m EC<sub>w</sub>, emergence phase; 7.5dS/m EC<sub>w</sub>, mature plant phase) with three nitrogen levels, 0 ppm, 18.7 ppm (=1/12 Hoagland's N), and 112 ppm (=1/2 Hoagland's N) NO<sub>3</sub>-N. For Phase I (emergence), fifty seeds were sown in each pot, emergence percentages were determined and the plants were then thinned to 2 per pot. The adjusted emergence percentage at LS (1.5 dS/m) was 99%, while for HS (6.4 dS/mEC<sub>w</sub>), only 49% of the plants emerged within 30 days. Emergence difference at LS and HS salinity levels in both inoculated and non-inoculated treatments was statistically significant ( $P<0.05$ ). For Phase II, the alfalfa was harvested every three to four weeks to determine shoot dry weight, total N and Na<sup>+</sup> content. For inoculated treatments, shoot dry matter was significantly higher ( $P\leq0.05$ ) at the N3 level as compared to N1, but the effect of salinity was not statistically significant. Root dry matter was three times higher for the N3 plants as compared to N1 level, and salinity significantly decreased root growth ( $P<0.05$ ). The N3 level numerically reduced the number of root nodules and the N3 nodules appeared less active based on color, but these effects were not significant. Non-inoculated alfalfa had less response to N fertilizer application, particularly in the HS treatment. Tissue nitrogen data will also be discussed.

**Title:** Genetic Variability within a Representative ‘Kerman’ x ‘Peters’ Pistachio (*Pistacia vera* L.) Orchard

**Authors:** A. Nwangwu, E. Bhardwaj, and J.T. Bushoven

**Contact Name:** John Bushoven

**Affiliation:** Department of Plant Science, California State University, Fresno

**Address:** 2415 East San Ramon Ave M/S AS72, Fresno, CA 93740

**Telephone, fax, and e-mail:** 559.977.8392 j.bushoven@csufresno.edu

**Genetic Variability within a Representative ‘Kerman’ x ‘Peters’ Pistachio (*Pistacia vera* L.) Orchard**

A. Nwangwu, E. Bhardwaj, and J.T. Bushoven  
Department of Plant Science, California State University, Fresno

In 2013 there were approximately 250,000 acres of pistachios (*Pistacia vera*) grown in 22 counties throughout California. Many of these orchards are planted primarily with male *P. vera* ‘Peters’, and female ‘Kerman’ trees. In recent years growers have observed spatial and temporal variation in growth and fruiting density in these orchards. Field analyses of Fresno State’s pistachio orchard confirmed the presence of such phenotypic variations, which may be due to prevailing environmental conditions, rootstock variability, or perhaps random mutagenesis that occurred during scion clonal propagation over the past 50 years. The objective of this study was to examine the latter possibility as the presence of superior/inferior ‘Kerman’ trees is not well documented. Recent studies have demonstrated that RAPD markers are marginally more informative than Inter Simple Sequence Repeats (ISSR) in the assessment of genetic diversity in Iranian pistachio cultivars. This is due to the poly-allelic nature of RAPD markers and their distribution throughout the genome and association with functionally important loci. Therefore, this present study utilized RAPD markers to assess genotypic variability in this orchard. Genomic DNA was extracted with a DNeasy® Plant Mini kit and confirmed by the purity index A260/A280 using a NanoDrop2000 spectrophotometer. The method of Williams, *et al.*, (1990) was used for RAPD reactions with minor modifications. Polymerase chain reaction amplified products were separated with gel electrophoresis and analysed under UV light using a novel GelRed stain. Preliminary data suggest the presence of polymorphisms, and the results of these analyses will be presented. These data are widely applicable to California’s pistachio industry, especially in light of increasing agriculture water use restrictions, and the resulting increase in acreage planted to pistachio.

Title: Screening the San Joaquin Valley for glyphosate-resistant Palmer amaranth in perennial and annual cropping systems

Authors: Eduardo Padilla<sup>1</sup>, Sonia Rios<sup>2</sup>, Steve Wright<sup>3</sup>, and Anil Shrestha<sup>1</sup>

Affiliation: <sup>1</sup>California State University Fresno, <sup>2</sup>UCCE Riverside/San Diego Co., <sup>3</sup>UCCE Tulare/Kings Co.,

Address: 5241 North Maple Avenue, Fresno, CA 93740

Phone and email: (559) 310-0686, eduardopadilla@ymail.com

**Abstract:** Glyphosate has been a popular herbicide for weed management in agriculture cropping systems and non-crop areas for more than a decade. Heavy reliance on a single mode of action can increase the risk of weed species evolving resistance to the herbicide. Glyphosate-resistant (GR) populations of Palmer amaranth have been confirmed throughout the southeast United States since 2005. Since 2012, growers in California's San Joaquin Valley (SJV) have observed poor control of Palmer amaranth in glyphosate-tolerant corn (*Zea mays L.*) and cotton (*Gossypium hirsutum L.*). Palmer Amaranth (*Amaranthus palmeri*) is one of the most difficult weeds to control because of its competitive ability, C4 photosynthesis, high water use efficiency and drought tolerance, rapid growth rate, and prolific seed production. However, it is not known if these are cases of GR populations or application of glyphosate at more tolerant stages of the weed. Palmer amaranth seeds from 6 annual and biannual cropping systems from different locations of the SJV were collected for evaluation of glyphosate resistance. The SJV Palmer amaranth populations have been evaluated against a known GR and a glyphosate-susceptible (GS) population from New Mexico. The experimental design was a 4 by 9 factorial randomized complete block with four replications. The 4 populations and the 9 herbicide doses were the factors. Glyphosate treatments were administrated at the 5- to 8- leaf stage at 0.5x, 1x, 1.5x, 2x, 2.5x, 3x, 3.5x, and 4x rates with a control, where 1x= 840 g ae ha<sup>-1</sup> (labeled rate). The study was repeated. All the SJV populations had 100% mortality at the 840 g ae ha<sup>-1</sup> rate of glyphosate in both studies and therefore deemed to be GS. However there was a significant difference ( $P < 0.05$ ) between the two studies in the biomass. Collectively, these studies will provide information on whether the reported lack of control in the SJV Palmer amaranth populations are cases of GR populations or due to tolerance to glyphosate at later growth stages.

**Title:** Effect of Light Intensity on the Efficacy of Some Post-Emergent Herbicides on Different Biotypes of Hairy Fleabane from the Central Valley

**Authors:** Mala To, Anil Shrestha

**Contact Name:** Mala To

**Affiliation:** California State University, Fresno

**Address:** 2415 E. San Ramon Ave. M/S AS72, Fresno, Ca, 93740-8033

**Telephone, fax, and e-mail:**  
(559) 579-3794  
Malato21@yahoo.com

**ABSTRACT:**

Effect of Light Intensity on the Efficacy of Some Post-Emergent Herbicides on Different Biotypes of Hairy Fleabane from the Central Valley

Mala To\* and Anil Shrestha

<sup>1</sup>California State University, Fresno, Fresno, Ca., USA, <sup>2</sup>University of California Cooperative Extension, Monterey County, Ca., USA

\*Corresponding author: malato21@yahoo.com

This study evaluated the effect of light intensity on the efficacy of glyphosate (28 oz/ac), glufosinate (82 oz/ac), saflufenacil (1 oz/ac), and pyraflufen (4 oz/ac) on glyphosate-resistant (GR), glyphosate + paraquat-resistant (GPR), and glyphosate-susceptible (GS) hairy fleabane (*Conyza bonariensis* L.) plants. Adjuvants in the form of either methylated seed oil, crop oil concentrate, and/or ammonium sulfate were added to the treatments as per herbicide label specifications. The treatments were applied at the 5- to 8-leaf stage of the plants. The plants were then exposed for 48h to four different light intensities in mini-tents made of shade cloth of different shade levels [0% (complete darkness), 50% of full sun, 70% of full sun and 100% (full sun)] in an open field and then returned to the greenhouse and kept for an additional 28 days. The results showed that light intensity had no effect on the efficacy of the herbicides. However, the herbicides had differential effect on the biotypes. Glufosinate controlled 100% of all three biotypes. Saflufenacil controlled 46, 55, and 58% of the GR, GPR, and GS plants, respectively. Glyphosate controlled 29, 38, and 100% of the GR, GPR, and GS plants, respectively. Pyraflufen had less than 5% control of any of plants. Almost 50% of the saflufenacil-treated plants regrew at all levels of light. Although light intensity had no effect on plant mortality, injury symptoms were greater at the 100% and 70% than at the 50% and 0% light levels in the saflufenacil and pyraflufen treatments. In conclusion, light intensity did not influence herbicide efficacy against hairy fleabane. Glufosinate was the most effective treatment for control of all three biotypes.

Title: The Nitrate Assimilation Capacity of Sudan Grass (*Sorghum bicolor*)

Authors: R. Rathee, D. Bacon, D. Goorahoo, and J.T. Bushoven

Contact Name: John T. Bushoven

Affiliation: Department of Plant Science, California State University, Fresno

Address: 2415 East San Ramon Ave, M/S AS72, Fresno, CA 93740

Telephone, fax, and e-mail: 559.278.7391 j bushoven@csufresno.edu

### **The Nitrate Assimilation Capacity of Sudan Grass (*Sorghum bicolor*)**

R. Rathee, D. Bacon, D. Goorahoo, and J.T. Bushoven

Department of Plant Science, California State University, Fresno

Efforts to minimize potential nitrate ( $\text{NO}_3^-$ ) contamination of groundwater from the industrial, waste treatment plant, and dairy effluent include cultivation of nitrogen (N) scavenging crops, commonly referred to as “bio-filters”. Sudan grass (*Sorghum bicolor*) is often considered as a good species for such systems, and the goal of this research was to determine the N assimilation capacity of this species. The assimilation of inorganic N by plants is a complex process wherein  $\text{NO}_3^-$  is first reduced to nitrite ( $\text{NO}_2^-$ ) by Nitrate Reductase (NR), and then to ammonium ( $\text{NH}_4^+$ ) by Nitrite Reductase (NiR). As  $\text{NO}_2^-$  is toxic to plant cells,  $\text{NO}_3^-$  reduction does not occur unless sufficient endogenous energy and carbon skeletons are present to carry this reaction to assimilation of  $\text{NH}_4^+$  into amino acids. Thus the reaction catalyzed by NR is often considered the “rate-limiting” step in N assimilation. Therefore, we assessed the capacity of *S. bicolor* roots and shoots to reduce  $\text{NO}_3^-$  via NR. Micro-stands of *S. bicolor* were cultured hydroponically at a range of  $\text{NO}_3^-$  concentrations in a modified  $\frac{1}{2}$  strength Hoagland’s solution. After two weeks Nitrate Reductase activity (NRA) of roots and shoots was determined via an *in vivo* assay adopted from Hageman and Reed. The results of this study suggest that *S. bicolor*’s capacity to reduce  $\text{NO}_3^-$  via NR is greater at lower  $\text{NO}_3^-$  concentrations for both shoots (7 ppm) and roots (2.8 ppm). Excess  $\text{NO}_3^-$  in the roots appears to be transported to the leaves wherein it is then reduced. Leaf NRA increased as the concentration increased from 0 to 7 ppm but decreased when the concentration exceeded 7 ppm. These data are important for use in nitrogen management efforts.

Title: Comparison of Crop Load Management Systems and Differential Regulated Deficit Irrigation on Vegetative Compensation, Whole Canopy Photosynthesis, and Vine Performance in Procumbent *Vitis Vinifera* L. in a Warm Climate

Authors: Andrew Beebe, James A. Kennedy, S. Kaan Kurtural

Contact Name: Andrew Beebe

Affiliation: Fresno State

Address: 2360 E. Barstow Ave, Fresno, CA 93740 USA

Telephone, fax, and e-mail: (559)278-2414, (559)278-4795, kkurtural@csufresno.edu

#### ABSTRACT:

This study was designed to evaluate the interactive effects of different pruning systems and regulated deficit irrigation on 'Merlot' grapevines. Irrigation treatments were sustained deficit irrigation of control (SDI) where vines were maintained at a mid-day leaf water potential ( $\psi$ ) of -1.2MPa and were irrigated to 80% of evapotranspiration (ET<sub>0</sub>) from bud break until harvest, and regulated deficit irrigation (ROI) that received 80% of ET<sub>0</sub> from bud break to fruit set, where after 50% ET<sub>0</sub> was replaced to maintain ( $\psi$ ) at -1.4MPa until veraison, but not thereafter. Three pruning systems have been applied, including the control treatment of hand pruned California sprawl system with 40 spurs retained (HP), mechanically box-pruned single high-wire system at 4-inch spur high (SHMP), and cane pruning system with four 8-node canes (CP). Treatments were arranged factorially with three blocks. Canopy architecture, yield components, berry chemical composition, yield efficiency, and the phenolic compositions of wine were measured. The leaf layer of CP was 17% and 14% higher than that of SHMP and HP, respectively. The yields of HP and CP were 28% higher compared to SHMP. CP produced grapes with highest Brix and pH with lowest acidity. There was no difference on pruning weight between the pruning systems but the crop load of SHMP was 34% and 41% lower than that of CP and HP, respectively. The phenolics measured included anthocyanins, proanthocyanidins, flavonols, flavan-3-ols and non-flavanoid compounds. The deficit irrigation did not affect the canopy architecture, yield components, fruit compositions, yield efficiency, and main phenolic compositions in wine. This project provides applied information about the optimum crop load management and deficit irrigation strategies on maintaining or increasing yield and phenolic concentrations.

**Title: A Comparison of Automated Thinner vs. Hand Thinning of Lettuce in the Salinas Valley**

**Authors: Elizabeth G. Mosqueda, Richard F. Smith, Anil Shrestha**

**Contact Name: Elizabeth G. Mosqueda**

**Affiliation: California State University, Fresno**

**Address: 2415 E. San Ramon Ave. M/S AS72, Fresno, Ca, 93740-8033**

**Telephone, fax, and e-mail:**

**(831)676-6983**

**Lillisa5@mail.fresnostate.edu**

**ABSTRACT:**

**A Comparison of Automated Thinner with Hand Thinning of Lettuce in the Salinas Valley**

*Elizabeth Mosqueda<sup>1</sup>, Richard Smith<sup>2</sup>, and Anil Shrestha<sup>1</sup>*

<sup>1</sup>*California State University, Fresno, Fresno, Ca., USA,* <sup>2</sup>*University of California Cooperative Extension, Monterey County, Ca., USA*

*\*Corresponding author: Elizabeth\_mosqueda@ymail.com*

Labor shortages in recent years have impacted the agriculture industry in California, one such example is lettuce production. In 2012, lettuce growers in the Salinas Valley began using automated lettuce thinners to compensate for these labor shortages. However, the efficacy of these machines has not been adequately compared to manual methods. Therefore, a study was performed in summer 2014 to compare the efficiency of these implements with hand thinning. The experiment was conducted at seven locations in Salinas. The experimental design was a randomized complete block with each location as a block. Each location had two treatment plots comparing mechanical thinning and manual thinning treatments. In each treatment, six to ten sub-plots were randomly chosen as sampling sites. Parameters measured for each treatment were thin timing, double/weed removal timing, spacing, doubles (two closely spaced plants), and weed stand counts. It was observed that the automated system was more efficient than the manual system in lettuce thinning ( $P < 0.05$ ), as the average thinning time for the two systems was 0.91 hours per acre and 6.56 hours per acre, respectively. Although the automated system left more ( $P = 0.058$ ) number of doubles, the time taken to remove the doubles was similar between the two systems. Spacing of plants, which is targeted to be 10 in., was more accurate ( $P < 0.05$ ) in the automated system as 71% of plants were between 9 and 11 in. compared to 57% in the manual system. However, the manual system resulted in higher ( $P < 0.05$ ) weed removal (73 vs. 68%, respectively) than the automated system. These results suggest that automated-thinning holds great potential to aid lettuce growers efficiently meet labor shortages in the Salinas Valley.

**Title: Seasonal Comparison of Pistachio Nut Development Influenced by Temperature**

**Authors: Nadia N. Juarez**

**Affiliation: California State University, Fresno**

**Contact info: 559-246-9649, nadiajuarez@mail.fresnostate.edu**

### **Seasonal Comparison of Pistachio Nut Development Influenced by Temperature**

Pistachio is one of the most important commodities in California. Research on how temperature variations affect tree development and nut quality are key to maintain a high quality product that is expected to keep growing in the market for the next decades. This study aims at graphically comparing phenological development of pistachio nuts from two different seasons in correlation to temperature. Our trial was located at the student farm of the California State University of Fresno pistachio orchard. Pictures were taken during the blooming and fruiting periods of 2013 and 2014. Observation of the seasons occurred from pollination through nut set, full development of pistachio nut and into harvest. Pictures were taken on a biweekly basis throughout the season. The progress in development of both seasons was compared to weather station data from CIMIS. We performed an analysis focused on winter chill hours as the potential driving factor for developmental differences. The orchard was submitted to the same irrigation, pest management and other cultural practices on both seasons.

**Title: Impact of Salinity on Biological Nitrogen Fixation in Alfalfa (*Medicago sativa*) and its Response to Applied Mineral Nitrogen**

**Authors:** Sangeeta Bansal<sup>1</sup>, Sharon E. Benes<sup>1</sup>, Daniel H. Putnam<sup>2</sup>, Stephen R. Grattan<sup>3</sup> and John T. Bushoven<sup>1</sup>

**Contact Name:** Sangeeta Bansal<sup>1</sup>, Sharon E. Benes<sup>1</sup>

**Affiliation:** <sup>1</sup>Dept. of Plant Science, California State University, Fresno;

<sup>2</sup>Dept. of Plant Sciences and <sup>3</sup>Dept. of Land, Air and Water Resources; University of California, Davis

**Address:** <sup>1</sup>Address: 2415 E San Ramon Ave. M/S AS72. Fresno, CA 93740

**Telephone, fax, and e-mail:** 559-278-2255, Fax: 559-278-7413

E-mail: sbansal88@mail.fresnostate.edu

**ABSTRACT:** As irrigation water supplies become scarce in California, more saline water will likely be used to irrigate field crops and forages such as alfalfa. A valid research question to ask is how salinity impacts biological nitrogen fixation (BNF) and its contribution toward fulfilling the nitrogen requirements of alfalfa. Our greenhouse study consisted of two experiments. The main experiment utilized inoculated seed (dusted with *Sinorhizobium meliloti* bacteria) of variety CUF101 sown into 40 cm deep pots containing washed sand and irrigated with water of either low salinity (LS = 1.5 dS/m EC<sub>w</sub>) or high salinity (HS = 6.4 dS/m EC<sub>w</sub>, emergence phase; 7.5dS/m EC<sub>w</sub>, mature plant phase) with three nitrogen levels, 0 ppm, 18.7 ppm (=1/12 Hoagland's N), and 112 ppm (=1/2 Hoagland's N) NO<sub>3</sub>-N. For Phase I (emergence), fifty seeds were sown in each pot, emergence percentages were determined and the plants were then thinned to 2 per pot. The adjusted emergence percentage at LS (1.5 dS/m) was 99%, while for HS (6.4 dS/m EC<sub>w</sub>), only 49% of the plants emerged within 30 days. Emergence difference at LS and HS salinity levels in both inoculated and non-inoculated treatments was statistically significant ( $P<0.05$ ). For Phase II, the alfalfa was harvested every three to four weeks to determine shoot dry weight, total N and Na<sup>+</sup> content. For inoculated treatments, shoot dry matter was significantly higher ( $P\leq0.05$ ) at the N3 level as compared to N1, but the effect of salinity was not statistically significant. Root dry matter was three times higher for the N3 plants as compared to N1 level, and salinity significantly decreased root growth ( $P<0.05$ ). The N3 level numerically reduced the number of root nodules and the N3 nodules appeared less active based on color, but these effects were not significant. Non-inoculated alfalfa had less response to N fertilizer application, particularly in the HS treatment. Tissue nitrogen data will also be discussed.

THE STUDY OF THE COURTSHIP BEHAVIOR OF A POLYPHAGOUS PARASITOID WASP

Sarah R. Parry<sup>1\*</sup>, Jun Abe<sup>2</sup> and Jorge M. Gonzalez<sup>1</sup>

<sup>1</sup>Department of Plant Science, California State University, Fresno, CA USA.

<sup>2</sup>Department of Biology, Kanagawa University, Kanagawa 259-1239, Japan.

\*Corresponding Author's Email: [sarahparry13@mail.fresnostate.edu](mailto:sarahparry13@mail.fresnostate.edu)

**Abstract:** The courtship behavior the polyphagous wasp *Melittobia australica* (Hymenoptera: Eulophidae) was observed, studied and compared with a similar species that appears to belong within its own “species-group.” *Melittobia* is a genus of ectoparasitoid wasps that commonly attacks pollinating bees, as well as other hymenopterans and even some dipterans. Scanning Electron Microscope pictures of both species under study were taken with the purpose of establishing possible morphological differences among them. Since both species are so similar morphologically, a study of their courtship was planned. All species in the genus exhibit a complex courtship. Each species displays unique behaviors during courtship in such a way that they can be used to separate cryptic species. Even though the courtship of *Melittobia australica* is known, not much detail is recognized for the morphologically similar species *M. hawaiiensis*. Cultures of *M. australica* and a similar species we suspect is *M. hawaiiensis* were kept in an incubator at 25°C. Female pupae were extracted from wasps cultures. Once emerged, virgin females between 24 to 48 hours old were coupled with experienced males (2-5 days old) extracted from cultures. Fifty courtships per species were recorded with a digital microscope-video camera. Results show that there are behavioral differences in the two species during courtship.

**Title: Potential threat of glyphosate-resistant palmer amaranth to perennial crop production and mitigation strategies**

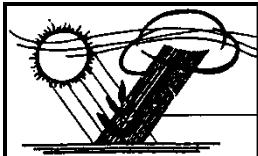
Authors: Sonia Rios<sup>1</sup>, Steve Wright<sup>2</sup>, and Anil Shrestha<sup>3</sup>

Affiliation: <sup>1</sup>UCCE Riverside/San Diego Co., <sup>2</sup>UCCE Tulare/Kings Co., <sup>3</sup>California State University Fresno

Address: 21150 Box Springs Road, Ste 202, Moreno Valley, CA 92557-8718

Phone and email: (951) 684-6491, sirios@ucanr.edu

**ABSTRACT:** Glyphosate is the most popular herbicide for weed management in perennial agriculture and non-crop areas globally. However, heavy dependence on glyphosate has led to the evolution of several glyphosate-resistant (GR) weed species worldwide. One such species of great concern in the U.S. is Palmer amaranth (*Amaranthus palmeri*). GR populations of this species have been confirmed throughout the southeast U.S. since 2005 causing massive economic losses. Currently, growers in the San Joaquin Valley (SJV) have witnessed reduced control of Palmer amaranth in perennial systems. It is not known if these are GR populations or application of glyphosate at more tolerant stages of the weed. This study evaluated Palmer amaranth populations from different locations of the SJV. Plants from two locations that showed some tolerance to glyphosate at the label rate (840 g ae ha<sup>-1</sup>) were further compared to a known GR population from New Mexico. Five- to 8-leaf stage plants were treated with glyphosate rates ranging from 0 to 3.36 kg ae ha<sup>-1</sup>. Most of the SJV plants died at the label rate. Hence, the presence of GR Palmer amaranth in the SJV could not be positively determined. Plant mortality was also evaluated at 3 different growth stages with several POST herbicides under greenhouse and field conditions. Tolerance to some herbicides including glyphosate was observed at more advanced growth stages. Several herbicides and herbicide mixtures were identified for control of Palmer amaranth should GR populations be definitively documented in the SJV in future.



California Chapter – American Society of Agronomy  
2015 Plant and Soil Conference Evaluation

Chapter web site: <http://calasa.ucdavis.edu>.

Please complete and return this form to the registration desk or drop it in the provided boxes. Thank you for your assistance in completing this survey. Your responses will help us improve future Chapter activities.

**1. Conference Evaluation**

	Agree	Disagree		
Conference fulfilled my expectations	1	2	3	4
Conference provided useful information	1	2	3	4
Conference provided good contacts	1	2	3	5

**2. What session topics do you recommend for future conferences?**

a. \_\_\_\_\_

b. \_\_\_\_\_

**3. Please suggest Chapter members who would be an asset to the Chapter as Board members.**

a. \_\_\_\_\_

b. \_\_\_\_\_

**4. Who would you suggest the Chapter honor in future years? The person should be nearing the end of their career. Please provide their name, a brief statement regarding their contribution to California agriculture, and the name of a person who could tell us more about your proposed honoree.**

\_\_\_\_\_  
\_\_\_\_\_

**5 Please rank your preference for the location of next year's conference. (Use 1 for first choice, 2 for second, etc.)**

Fresno  Visalia  Modesto  Sacramento  Bakersfield

Other (please provide) \_\_\_\_\_

**6. Would having the speakers' Powerpoint presentations, available on the CA ASA website after the Conference, be an acceptable alternative to the written Proceedings?**

Yes  No

**7. Additional comments:** \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_

## NOTES