American Society of Agronomy
California Chapter

Co-Sponsored by the California Plant Health Association

2016 Conference Proceedings

California Plant and Soil Conference

California Water – Value to Agriculture, Value to Society

February 2 & 3, 2016

Wyndham Hotel Visalia
9000 W. Airport Drive, Visalia CA

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California Plant and Soil Conference – February 2-3, 2016

California Water – Value to Agriculture, Value to Society

Location: Wyndham Hotel, Airport Drive, Visalia, CA

9:50 **General Session Introduction:** Chapter President – Richard Smith, Univ. California Coop. Extension, Monterey County

10:00 – 10:45 **Keynote Speaker**:- Richard Howitt, Professor (UC Davis Agricultural Economics Dept.) "Crop Production and the Economics of Water Scarcity"

DAY 1 (Tuesday, February 2) - CONCURRENT SESSIONS: 10:55AM – 12:15PM

Session 1 – Professional Development **Chair: Scott Stoddard**			**Session 2 –Site Specific Technologies for Managing Nutrients and Water** **Chairs: Andre Biscaro and Richard Smith**	
10:55	Introductory comments		10:55	Introductory comments
11:00	Toby O'Geen - UC Davis LAWR Dept.: Exploring Soil Survey Information with Interactive Web-Based Map Products		11:00	Michael Whiting – UC Davis Center for Spatial Tech. and Remote Sensing: Beyond NDVI with Airborne Imagery.
11:25	Scott Stoddard - UCCE Merced County: On-Farm Statistics and Ag Stats 02		11:25	Curran Hughes – The Wonderful Company, Strategy Group: Industry Perspective of Remote Sensing in Tree Crop Agriculture – Challenges and Opportunities.
11:50	Pam Krone-Davis - NOAA: AWQA Toolkits Provide Easy Access to Technical Information and Training		11:50	Shrinivasa Upadhyaya, UC Davis Biol. and Agric. Engr.: Precision Irrigation in Almonds and Grapes Based on Plant Water Status

LUNCH 12:15PM – 1:25PM

DAY 1 (Tuesday, February 2) - CONCURRENT SESSIONS: 1:30PM – 2:50PM

Session 3 – Nutrient management strategies **Chairs: Hossein Zakeri, Richard Smith**			**Session 4 – Land and water suitability** **Chairs: Anne Collins-Burkholder, Bob Hutmacher**	
1:30	Introductory comments		1:30	Introductory comments
1:35	Dan Putnam – UCCE and UC Davis Plant Sciences Dept.: Nitrogen Dynamics in Cropping Systems – Why Alfalfa Is Important		1:35	Joel Kimmelshue – Land IQ: Statewide Crop Mapping and Applications for Nutrient and Water Management
2:00	Patrick Brown – UC Davis Plant Sciences Dept.: Nitrogen management in Almond Orchards		2:00	Blake Sanden – UCCE Kern County: Soil and Water Considerations and Sampling for New Orchards
2:25	Tim Hartz – UCCE and UC Davis Plant Sciences Dept.: Nitrate leaching and mitigation methods in annual crops.		2:25	Keith Backman – Dellavalle Laboratories: Water Quality Considerations for Nut Crops

BREAK 2:50PM – 3:20PM

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Location: Wyndham Hotel, Airport Drive, Visalia, CA

DAY 1 (Tuesday, February 2) - CONCURRENT SESSIONS: 3:20PM – 4:40PM

Session 5 – Water Related Management Issues - Chairs: Steve Grattan, Dan Munk, Bob Hutmacher			**Session 6: Pest / Disease Management Chairs: Mark Sisterson and Margaret Ellis**	
3:20	Introductory comments		3:20	Introductory comments
3:25	Ken Shackel – UC Davis Plant Sciences Dept.: Water Management Under Drought Conditions: Strategies for Tree Crops		3:25	Brad Hanson - UCCE and UC Davis Plant Sci. Dept: Orchard and Vineyard Herbicide Performance Updates
3:50	Larry Williams – UC Davis Viticulture Dept. and UC Kearney REC: Strategies to Manage Grapes (table and wine) under Extreme, Long-Term Drought Conditions.		3:50	Kris Tollerup, UCCE and UC Kearney REC: Leaf-Footed Bug – What We Know and What We Need to Know
4:15	Danielle Zaccaria – UCCE and UC Davis LAWR Dept.: New Approaches to Refine Water Use Estimates for Permanent Crops		4:15	Allison Ferry-Abee, UCCE Tulare and Kings Counties: Impact of Canopy Management on Powdery Mildew in Table Grapes

EVENING SOCIAL – POSTER SESSION, WINE AND CHEESE RECEPTION, ETC. (5:00 pm)

California Plant and Soil Conference – February 2-3, 2016

California Water – Value to Agriculture, Value to Society

Location: Wyndham Hotel, Airport Drive, Visalia, CA

DAY 2 (Wednesday, February 3) - CONCURRENT SESSIONS: 8:30AM – 9:50AM

Session 7 – Manure and organic Amendments **Chairs: Richard Smith, Scott Stoddard**			**Session 8 – GHG and VOC's in Farming Systems -** **Chairs: Eric Ellison**	
8:30	Introductory comments		8:30	Introductory comments
8:35	Gene Miyao - UCCE - Yolo County: Compost for improving processing tomato yield		8:35	Robert Mikkelsen - IPNI: Greenhouse Gas Emissions – Does Agriculture Really Make a Difference?
9:00	Steve Zicari and Steve Kaffka - UCCE and UC Davis Plant Sci. Dept.: Fertilizers from anaerobic digester systems.		9:00	William Horwath - UC Davis LAWR Dept.: Sources and Mitigation Potential for Nitrous Oxide from Agricultural Activities in California
9:25	Daniel Geisseler - UCCE and UC Davis Dept of LAWR: Contribution of nitrogen mineralization to crop available nitrogen.		9:25	Frank Mitloehner - UCCE and UC Davis Animal Sci. Dept.: Dairy Sustainability and Carbon Footprint Implications

BREAK: 9:50AM – 10:20AM

DAY 2 (Wednesday, February 3) - CONCURRENT SESSIONS: 10:20AM – 11:40AM

Session 9 – Biologicals for enhancing crop growth **Chairs: Dave Holden, Eric Ellison, Karen Lowell**			**Session 10 – Salinity Management** **Chairs: Sharon Benes, Steve Grattan, Bob Hutmacher**	
10:20	Introductory comments		10:20	Introductory comments
10:25	Jocelyn Bridson - Rio Farms: How Can a Grower Make Informed Decisions for the Use of Bio-Stimulants?		10:25	Baris Kutman – UC Davis Plant Sciences Dept.: Physiology of Salinity Stress in almonds
10:50	David Holden, Holden Research and Consulting.: Results from Real World Replicated Testing of Several Biostimulants, Making Sense of the Data		10:50	Chris Linneman – Summers Engr.: Drainage Reuse by Grassland Area Farmers: The Road to Zero Discharge
11:15	Holly Little - Acadian Seaplants: A Review of Commercial Biostimulant Products		11:15	Jim Ayars - USDA-ARS, Parlier: Water Management practices/ leaching requirements under water-limited conditions

BUSINESS MEETING and LUNCH
12 Noon – 1:45PM

Table of Contents

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	2014	Steve Grattan
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	2015	Bob Beede
	Eduardo Apodaca		Jim Brownell		Carol Frate
1992	Robert S. Ayers		Fred Starrh		Allan Romander
	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				

2015-16 Executive and Governing Board Members
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Board Meeting Minutes
California Chapter of the American Society of Agronomy (ASA)

February 5, 2015
Radisson Hotel and Conference Center
Fresno, CA
12:40 PM – 1:55 PM

1. **Call to Order: Steve Grattan**, President, California Chapter ASA.
    a. Welcomed attendees to the 44th 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 Grattan 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) annual meetings.
    c. President Grattan emphasized 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 Fresno State and UC Davis. The assistance received from students from Fresno State in preparing nametags, manning the registration table, transporting and setting up/taking down the poster stands was acknowledged.
    e. The President acknowledged and thanked the sponsors (Valley Tech, Simplot Grower Solutions, Prime-Dirt, S&W Seed Company, Dellavalle Laboratory, Innovative Ag Services) for refreshments for the breaks and other conference events.
        i. He mentioned that the sponsors are listed on the inside page of 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 member donors to the Scholarship fund.
    f. President Grattan 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 volunteers. He

recognized the members, plus student help, particularly from Fresno State. The members included:

    i. Past President, Dave Goorahoo
    ii. 1st VP, Richard Smith (proceedings)
    iii. 2nd VP, Robert Hutmacher (conference site arrangements)
    iv. Secretary and Treasurer, Sharon Benes (registration and finances)
    v. Governing Board (Anil Shrestha, Rich Rosecrance, Warren Hutchings, Dan Munk, Karen Lowell, Mark Sisterson, Scott Stoddard, Anne Collins Burkholder, Eric Ellison).

g. Steve Grattan introduced and thanked Past Presidents of CA-ASA.

2. **Business meeting minutes from the 2014 ASA Plant and Soil Conference** (Grattan)
    a. Indicated that the minutes of the Feb. 5, 2014 conference was on page 4 of the proceedings
    b. Motion to approve the minutes was given (B. Roberts) and seconded (B. Taylor). Minutes for the 2014 business meeting passed as presented.

3. **Treasurer's Report** (Benes)
    a. Presented Treasurer's report for the 2014 meeting and activities. $34,413 was the current balance in the CA Chapter ASA account. Some charges and credits for this year's conference are pending.
    b. Approval of Treasurer's report was moved (Benes) and seconded (Grattan). Motion passed to approve Treasurer's report.

4. **Nomination and Election of persons to serve on the Governing Board** (Grattan)
    a. Brief overview of the Governing Board structure was provided: nine 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 (Goorahoo) 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):
        - Richard Smith as President
        - Bob Hutmacher as 1st V.P.
        - Sharon Benes as 2nd V.P.
        - Dan Munk as incoming Secretary/Treasurer

        Serving **3 year terms**
        - Andrea Biscaro, Farm Advisor, UCCE Ventura
        - Margaret Ellis, Asst. Professor, CSU Fresno
        - Dave Holden, Holden Research and Consulting

        Serving **2 year remaining terms**

- Eric Ellison, Agronomist, Koch Agronomic Services
- Anne Collins, Consultant, Dellavalle Laboratory
- Hosssein Zakeri, Asst. Professor, CSU Chico

Serving **1 year remaining terms**

- Mark Sisterson, Research Scientist, USDA-ARS, Parlier
- Karen Lowell, Agronomist, USDA-NRCS, Salinas
- Scott Stoddard, Farm Advisor, UCCE Merced

e. Motion was made (Grattan), seconded, and passed to approve the new members.

5. Presentation of awards to 2015 honorees. (Grattan, standing in for Goorahoo)

a. **Bob Beede**

Blake Sanden (UCCE Kern Co.) presented the award and described Bob's remarkable 34-year career as a farm adviser in King's County, working primarily on nut crops (walnut, pecans, pistachio, almond), with earlier work on hedging and trellising in Colombard grapes and dormant oil applications in kiwi. Bob is considered to be the "father" of *ReTain*®, a plant growth regulator that reduces pistillate flower abortion (PFA) in walnuts, which rescued the *Serr* variety, and he was the first to document navel orangeworm damage in pistachio and its effect on nut development. Irrigation Specialist, David Goldhamer and Bob developed the first documented irrigation crop coefficients and seasonal water use data for pistachios and walnuts and over the next 20 years, they examined the limits of deficit irrigation in these two crops and identified the crop development periods most susceptible to stress. There were numerous other contributions to improved production practices in California tree crop production, but above all, colleagues remember Bob's generosity and vitality of spirit

b. Carol Frate

Shannon Mueller (UCCE Fresno County) described Carol's productive career in UCCE, Tulare County, as a farm adviser for alfalfa, blackeye cowpeas, field corn and sugarbeets. This included variety evaluations, irrigation studies, pest management research and assessment of new production practices. In the 1980's, Carol was part of a team that evaluated the impacts of withholding summer irrigations on alfalfa, and later trials on *Sclerotinia* stem and crown rot of alfalfa contributed to the registration of a fungicide. Carol worked closely with UC blackeye cowpea breeders to test promising lines on-farm and she conducted corn and cowpea insecticide trials. Years before dairy nutrient management was regulated, Carol teamed with Farm Advisor Marsha Campbell Mathews to conduct workshops for consultants and producers to pro-actively manage lagoon water nutrients for crop production. Carol also coordinated workshops on farm management and introductory computer classes, specifically for farmers, and informational seminars on biosolids and proper tractor tire inflation. She was a Board member and President of the California Chapter of the American Society of Agronomy

c. **Allan Romander**

Rob Mikkelsen introduced Allan Romander. In 1994, Allan became one of the first Certified Crop Advisers (CCAs) in the state and he was instrumental to the success of the program, and continues to serve on the Executive Committee of the International Program. Initially, CCA numbers in California were small, but that began to change in 2004 when Allan joined the California CCA Board and chaired its marketing committee. Allan made presentations on the CCA program at extension meetings, CAPCA meetings, and for agencies such as the California Water Quality Control Board, which was looking at nitrates in groundwater. 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. The CCA program in California has been the fastest growing program in the world over the last eight years: in 2007 there were about 350 CCAs in the state and now there are more than 1000. The CCA program is managed by CAPCA now, which has stabilized its membership. California has the 3rd largest program in the U.S., behind Illinois and Iowa. As a representative of the California CCA Program and its success, Allan was elected to be an honoree of CA-ASA.

6. **Student Posters and Scholarships**
   a. Karen Lowell (Chair of student scholarship committee).
      i. Karen acknowledged the other committee members (Eric Ellison and Dan Munk) as well as the support of sponsors.
      ii. Karen briefly discussed the criteria used to judge the students, with applicants being asked to write an essay on a designated topic, summarize leadership/ scholarship/ personal development activities along with their work experience in agriculture and to provide two letters of recommendation.
   b. Winning essays were announced by Karen and Mary Junquiero from WPHA, and the awards were presented. The scholarship funds were provided by the Western Plant Health Association ($1500) and those members who donated to the student scholarship fund. Their essays are reproduced in the proceedings, and can be found on pages 12 and 13. The two winners, judged as being equal ($750 award to each), were:
      i. **Charlie Garcia, Fresno State** who was present to receive his certificate and check. Charlie's essay was entitled "What Can be Done to Feed a Population of 9 Billion". He wrote about new technologies in pest

management, including the potential for biotechnology to control huanglongbing (citrus greening disease) and pathogenic sequencing as a molecular tools to detect plant pathogens.

ii. **Lindee Mae Jones, Chico State**, was not able to attend. She wrote about the current water situation in California and new technology in the area of soil moisture sensors, as well as AB1739, California's new groundwater legislation and the importance of education efforts directed at water conservation.

c. Anne Collins Burkholder announced awards for student posters. Awards were made to graduate and undergraduate students. She thanked committee members Eric Ellison, Scott Stoddard and Rich Rosecrance who served with her on the evaluation committee.

Undergraduate winners included:
- **Mala To, Fresno State** ($500)

Graduate Student winners were:
- **Sangeeta Bansal** ($500)
- **Andrew Beebe, Fresno State** ($500)

7. Old business and New business
None was introduced.

8. President Grattan again requested attendees to fill out conference evaluation forms.

9. President Grattan passed the gavel (made special for the ASA California Chapter in 1978) over to Richard Smith, the incoming President.

10. Newly elected President Smith presented a plaque to President Grattan for his hard and excellent work over the years serving the Executive Board.

11. Steve Grattan adjourned the business meeting at 2:10 p.m.

American Society of Agronomy

California Chapter

2016 Honorees

Larry Schwankl

Joe Fabry

Scott Johnson

Joe Fabry
Consulting Agronomist

Honoree Recipient 2016
California Chapter of the American Society of Agronomy

Joe Fabry is a decedent of an early Kings County “Sand Dabber,” a term used to identify the first farmers to dry-land farm the margins of the old Tulare Lake bed. His grandfather arrived in Stratford, CA in 1906 from the Lockwood area where six German families had settled from the old country. Kings County offered the promise of “new ground” as the historical lake yielded tillable acreage. As the lake surface receded farmers were encouraged to turn this new ground into barley fields. Joe’s grandfather farmed this land until after World War II. During this period, returning water to this dry-land agricultural areas, through irrigation developments, opened the opportunity to expand plantings to wheat, cotton and alfalfa. Joe’s grandfather left the farm to his six children when he retired and moved to the Oakland hills.

Joe’s roots are deeply planted in Kings County. He grew up in Stratford and attended high school in Lemoore. He completed his Bachelors and Masters degrees from Fresno State in Plant Science. During this time, he enhanced his educational experience from working on the family farm to combining the practical aspects of farming with his formal education. In 1985, Joe undertook the entrepreneurial career path as an independent consulting agronomist. Over the 26 years until his retirement in 2011, Joe provided agronomic advice to his grower clientele. He worked closely with Stratford area farmers helping to improve production practices. His areas of emphasis were focused on improving irrigation practices, soil nutrition, soil chemistry, and plant pathology. He was an early adopter and advocate for monitoring plant-based stress levels for irrigation management. His irrigation management practices used pressure chamber measurements to determine plant-base recommendations for irrigation scheduling. Joe’s use of this new tool ushered in an innovative approach that changed the previously held philosophy on cotton irrigation practices. His work in soils focused on nutrition and soil amendments addressing soil chemistry and salinity management. Many of Joe’s clients were third generation “Sand Dabbers” too.

Joe served on the California Wheat Commission Board of Directors and was a member of the first Wheat Commission’s Research Committee. He also served on the Empire Irrigation District Board of Directors. Joe’s public service included being asked by the Kings County Board of Supervisors to serve on the Drug Advisory and the Alcohol Advisory Boards. He served as a Child Advocate for Fresno and Madera County Court Appointed Special Advocates. Joe has a long association with California Chapter of ASA. He served on the board for eight years and is a past president (2009). Joe has been married to Sandy for 28 years. Their daughter Melissa is a physical therapist in Tacoma Washington. Joe’s last “cotton crop” was in 2011 when he retired. He and Sandy rented an apartment in Stuttgart, Germany, before relocating to Olympia, Washington. Joe and Sandy’s world interests have taken them to Germany, Austria, France, Switzerland, Italy, Greece, the Netherlands, Belgium, Denmark, and the Czech Republic.

Joe’s career and travels have taken him a long way from the fields of the San Joaquin Valley but his roots are still firmly grounded in that Tulare Clay Loam first farmed by his grandfather.

R. Scott Johnson
University of CA Cooperative Extension Pomology Specialist

Honoree Recipient 2016
California Chapter of the American Society of Agronomy

R. Scott Johnson was born and raised in Utah. He received his BS in Biology from the University of Utah in 1977 and his PhD in Pomology from Cornell in 1982. From 1982 until his retirement in 2013, he was the University of California Extension Specialist for stone fruits, kiwifruit, apples and cherries. He spent his entire UC career in the Department of Pomology at UC Davis and was stationed at the Kearney Agricultural Center in Parlier where his research interests included field projects on irrigation, nutrition, thinning, rootstocks and training systems of peaches, plums, nectarines, apples and kiwifruit. His goal was to develop an extension / research program to improve the efficiency of a grower's operations by reducing labor, water application and fertilizer inputs without adversely affecting yield and fruit quality.

The overarching emphasis of his program was on developing cultural practices to improve fruit size and yield efficiency, enhance fruit quality, and which also promote environmental stewardship. Examples of his accomplishments include 1) the development of chemical and mechanical thinning/pruning strategies including the reduction of tree size with dwarfing rootstocks, 2) fertilization strategies (nitrogen, zinc and other nutrients) to optimize fruit size and quality and minimize environmental contamination and 3) irrigation management strategies to maximize productivity and fruit quality using as little water as possible. His work on refining peach tree water use, and on the long-term effects of soil applied nitrogen on peaches are considered throughout the world to be the seminal efforts in these areas.

Larry Schwankl
University of California Cooperative Extension Irrigation Specialist

Honoree Recipient 2016
California Chapter of the American Society of Agronomy

Larry, the son of two high school teachers, grew up in Mankato, Minnesota. From an early age he was fascinated by water. Lakes were great, but flowing water was even better. After a couple of years at Mankato State University, he transferred to Iowa State University where he received a BS degree in Civil Engineering. He then moved to California to work on a MS degree in Civil Engineering at UC Davis. While working on his MS degree, he worked for the USDA Soil Conservation Service as a Water Management Engineer. After finishing his Master's degree, he moved to Philadelphia where he spent 4 years working for the Federal Emergency Management Agency (FEMA) on floodplain management issues and disaster relief.

He returned to UC Davis in the early 1980's to work on a PhD degree in Civil Engineering. He also returned to working with the USDA Natural Resources Conservation Service as a Water Management Engineer in their State Office. In 1987, he finished his PhD and started working as a UC Cooperative Extension Irrigation Specialist in the Dept. of Land, Air, and Water Resources. He worked from the Davis campus until 2004 when he moved his office to the UC Kearney Ag Center. The move was precipitated by his marriage to Carol Frate, Tulare County Farm Advisor Emeritus and previous Honoree of the California Chapter of the American Society of Agronomy. He continued in that position until his retirement in 2014.

During his time with UC Cooperative Extension, Larry worked on a wide variety of projects in the agricultural and urban sectors, all with the common thread of improving irrigation water management. He worked with many cropping systems, including almonds, walnuts, pears, corn, alfalfa, sugar beets, cotton, blackeyes, and grapes. The projects included management of surface, sprinkler, and drip irrigation systems. He also worked extensively in nutrient management of agricultural crops, including dairy nutrient management. In addition to applied research activities, Larry was also very active in extension activities including many presentations, publication of numerous handbooks, and development of web sites. He received 3 Blue Ribbon Awards from the American Society of Agricultural and Biological Engineering for his handbooks and web sites. The Irrigation Association named him Irrigation Person of the Year in 2014. Larry served 2 terms on the Governing Board and is a Past President of the California Chapter of the American Society of Agronomy.

"It's hard to believe how lucky I've been. I had a great job and worked with wonderful colleagues. I got to work with CA growers and agricultural professionals who are some of the best people anywhere. To top it all off, I was blessed to have one of my UC Cooperative Extension colleagues become my wife. It just doesn't get any better than that."

American Society of Agronomy

California Chapter

2016 Scholarship Essay Contest Question and Scholarship Committee Members

Essay Question: *"Many new products, services and technologies are marketed to farmers and ranchers. Choose one and explain how you would evaluate it for use in California agriculture".*

General instructions given to participants: Include a discussion of how you would evaluate the product/service/technology for use in California agriculture settings, and state what setting you are considering (for example, a specific crop, orchards, vineyards, specialty crops, rangeland, etc.). Focus can be on products / services / technologies (examples: hardware or software to guide irrigation timing or amount, controlled release fertilizers, biological soil amendments, etc. or you may choose a specific product/service/technology).

Scholarship Committee:

Karen Lowell

Eric Ellison

Daniel Munk

American Society of Agronomy

California Chapter

General Session

California Water – Value to Agriculture, Value to Society

Richard Smith

CA-ASA President

Keynote Speaker

Richard Howitt, Professor

UC Davis, Dept. of Agricultural Economics

"*Crop Production and the Economics of Water Scarcity*"

American Society of Agronomy
California Chapter

Session 1

Professional Development

Session Chair:

Scott Stoddard

Exploring Soil Survey Information With Interactive Web-Based Map Products

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Introduction

Conveying information about soil survey to the public is challenging because of the complex architecture of soil survey data. Soil bodies are three dimensional and soil map units typically contain more than one soil. This issue can be a stumbling block for many users who are interested in understanding a specific soil property or a limiting condition for land use at a given location. Alternatively, many users want to compare soil properties or conditions across large areas where profile and map unit aggregation steps are necessary. Practically all soil survey users want this information to be easily and quickly obtained.

Online delivery of soil survey information is a tradeoff between the descriptive strengths of hard copy soil survey reports and the flexibility of using the Soil Survey Geographic Database (SSURGO) in a GIS. Hardcopy reports have a wealth of quantitative and qualitative information that can be easily accessed, but isn't designed for rapid synthesis of information, and are no longer in print. Using SSURGO in a GIS allows maximum flexibility in terms of making customized maps, but requires significant expertise to use the information correctly and lacks the qualitative information that provides information about morphologic characteristics of soils and context to map unit and legend designs.

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 is downloaded on user's smartphones in order to operate. Despite the popularity of the native app, the decision was made not to maintain the native app for the following reasons: 1. updates were difficult to deliver to users; 2. Costs associated with maintaining the apps in app stores; and, 3. The continual challenge of maintaining the app across all devices, smartphone models and operating systems. In response to these challenges associated with maintaining native the UC Davis Soil Resource Laboratory and USDA-NRCS has created a package of *web-based interactive maps* (Web-Apps) that attempt to cater to the diverse ways in which stakeholders use soil survey data. These Web-Apps are designed specifically to be fast, easy to use and educational. Here our goal is to introduce and communicate the design and operation of four soil survey apps developed by the CA Soil Resource lab: SoilWeb, CA Soil Properties, Soil Series Extent Explorer, and the Soil Data Explorer. All apps can be accessed at http://casoilresource.lawr.ucdavis.edu/soilweb-apps/ for free.

Interactive Soil Survey Apps

Functionality

Most of our apps have similar functionality featuring an interactive map. Users can navigate to an area of interest in a variety of ways. Manual navigation is accomplished using zoom buttons or directly on screen via touch/scroll and pan operations. All the apps have a "Use My Current Location" function that uses geolocating services that allows 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 (SoilWeb only). 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 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 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 apps have a variety of interchangeable basemaps that can be selected. The basemap choices vary slightly among apps. All apps have the option of some form of imagery (satellite or google maps), road maps, terrain, or a combination. Associated with the map view is an integrated data pane that allows users to explore content without leaving the map view.

SoilWeb

SoilWeb uses a nationwide snapshot of SSURGO data that is updated annually from USDA-NRCS around the beginning of the year. The newly revised SoilWeb builds on the functionality of the iphone app (Beaudette and O'Geen , 2010), now with onscreen interactive maps and integrated data displays depicting soil survey maps within Google Maps imagery http://casoilresource.lawr.ucdavis.edu/gmap/. The interactive web interface allows for more flexibility in data presentation, map browsing and has the added benefit of working across any device, smartphones, tablets and desktops.

Map unit composition information including the component name and percentage within the map unit is obtained by a touch or click of a map polygon. Data summaries are integrated into the map display instead of routing the user to a new webpage. The map unit summary page also provides aggregated map unit level information about drainage class for the dominant condition and wettest soil, area weighted average plant available water holding capacity, minimum water table depth and minimum soil depths, flooding frequency and prime farmland class among others. Selecting the series name retrieves component specific data organized under the following topics: Soil Profiles, Soil Taxonomy, Land classification, Hydraulic and erosion ratings, and Soil suitability ratings each of which can be expanded or minimized by selecting the arrows on the sidebar. Much of the content in these sections has largely remained the same (See Beaudette and O'Geen, 2009; 20010). Some highlights are discussed as follows.

The Soil Profiles section displays a soil profile with Munsell colors from the official series description that have been mapped to RGB color. The profiles contain horizon designations and associated thicknesses. Depth profiles of popular soil properties can be retrieved by selecting the corresponding soil property tab. Selecting view source data retrieves all soil property information by horizon in tabular format. The Soil Taxonomy section now provides access to the component and horizon SSURGO data tables. The Soil Suitability Ratings are now more fully populated and provide the limiting condition. Included in the component summary page are links to other apps including the Soil Data Explorer, Series Extent Explorer and a link to the official series description.

Data Visualization Tools

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 map the spatial extent of any soil series in the U.S. The acreage of up to five 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. 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, the reported total area for each series is a direct measure of the spatial extent of that series summed over each map unit scaled by its component percentage. Geographic extent and acreage estimates include soils similar to the queried series.

SEE has a link to SoilWeb. This linkage of apps allows users to 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 at the selected location. A link to the Soil Data Explorer is also provided.

Soil Data Explorer

The Soil Data Explorer was created to help visualize measured data and explore how series are related to other soils and to provide insight into the soil landscape model. To better understand the soil series properties, SDE has sections that portray the official series description (OSD tab) and soil properties (Lab Data tab). The Lab Data section summarizes physical and chemical properties from measured data from the Kellogg Soil Survey Lab database. Depth profiles are based on an aggregation of all measured pedons for a particular series. Profiles are discretized into 1-cm thick depth slices in order to account for differences in horizon depths and thicknesses. Within the graph, solid lines are the slice-wise median, bounded on either side by the interval defined by the slice-wise 5th and 95th percentiles. Values along the right-side y-axis describe the proportion of pedon data that contribute to aggregate values at this depth. For example, a value of "90%" at 25 cm means that 90% of the pedons correlated to the series were used in the calculation.

The Component Association tab is designed show the association of all other components that are mapped with the selected series when it is the major component. Component association is a function of how frequently components co-occur, weighted by component percentage. This summary generates structures from SSURGO to provide insight on how map units were constructed.

The Series Association tab is similar to the Component Association tab. It renders profile sketches of soils and displays relationships in a dendrogram based on the subgroup-level taxonomic structure. Series associations were constructed from the official series description records and the National Soil Information System (NASIS).

Another goal of SDE was to provide insight into the soil landscape model. To this end, we have uploaded and linked all digitized block diagrams that are available from USDA-NRCS. These diagrams depict soil landscape relationships and the conceptual model for a particular soil survey area. A Map Units tab summarizes all the map units that are named after the selected series. It links to information about each map unit including its extent in a soil survey area and information about the map unit. The Extent tab displays the approximate geographic extent of the selected series and provides a link to SEE.

California Soil Properties App

The CA Soil Properties App was developed 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. Map units were aggregated based on dominant condition in the case of classes and area weighted averaged for numerical values.

We created the Soil Properties App because using SSURGO in a GIS takes considerable time and effort, particularly when working at statewide scales. We perceived a growing demand for resources that deliver a broad-scale representation of soil properties. The app is organized to provide information on chemical and physical properties of soil and also includes some standard soil suitability ratings.

Each attribute has a color coded legend. The map is also interactive in that selecting a given location will retrieve the data value for the particular grid cell and its latitude and longitude. Help sections for each property are designated with a question mark and provide a link to the data aggregation technique.

Summary

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. These new apps have better functionality compared to the native apps, but are accessed via websites instead of being downloaded.

On-Farm Statistics and AGSTAT02

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Growers, industry reps, and consultants often set up a strip in commercial fields as a way of evaluating or comparing new pesticides, fertilizers, or production method products. These are typically demonstration trials, because they lack proper statistical design. A product that looks good on one side of a field may actually work – or it could just be that the field is more productive on that side. On-farm testing, on the other hand, has replicated, randomized treatments established in commercial fields that are managed with field-scale equipment. Properly designed, grower on-farm tests can determine if treatment effects are real or a result of random variation. Because of scale, on-farm testing typically has a smaller number of treatments than small plot trials – generally the number of treatments should be 5 or less.

On-farm testing is essentially an extension and application of small plot trial work done at University research farms. It allows for growers and consultants to test methods and/or products under the environmental and management conditions of a particular area. For example, a tomato herbicide that performs well on a Yolo clay loam with furrow irrigation in the Davis area may cause crop phytoxicity on a Hanford sandy loam with drip irrigation in Merced. Furthermore, on-farm testing has been shown to improve producer adoption of new farming technologies and methods (Veseth et al, 1999).

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. 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 completely randomized or randomized complete block (RCB) designs are 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). Three replications may provide enough resolution to compare some things, but the danger in having only 3 reps is that if one is lost, the trial is essentially ineffective. More than 6 replications is scarcely needed, as the gain in statistical power may not be worth the extra effort (Figure 2).

Statistical analysis is necessary to show whether treatment differences are truly significant or can be explained by chance. Least significant difference (LSD) is often used to show the minimum difference needed between treatment means to be considered real. If the difference between treatment means in a trial is equal to or larger than the LSD, the difference is statistically significant and believed to be due to the treatment effect and not natural field variability. 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 probability level assigned to the LSD (e.g. $LSD_{0.05}$) is frequently set to 0.05, but can be realistically set from 0.01 to 0.20. The smaller the probability level, the greater the confidence that treatments are significant different.

AGSTATS02 is an analysis of variance program available online at http://pnwsteep.wsu.edu/agstatsweb/. This free program (login name and password are required) is capable of doing simple stats for one trial at a time with up to 16 treatments. The output includes treatment means, coefficient of variation, LSD values, and an interpretation of the calculated p values (low p values = "significant"). Unfortunately, it is not possible to cut and paste data from Excel, and so plot data must be input one at a time, and it has no graphing capability nor a method to test the homogeneity of variance. Nonetheless, AGSTATS02 is fairly intuitive and easy to use, and offers a way to do some analysis of treatment results without the high cost and steep learning curve of most statistical software packages.

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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).

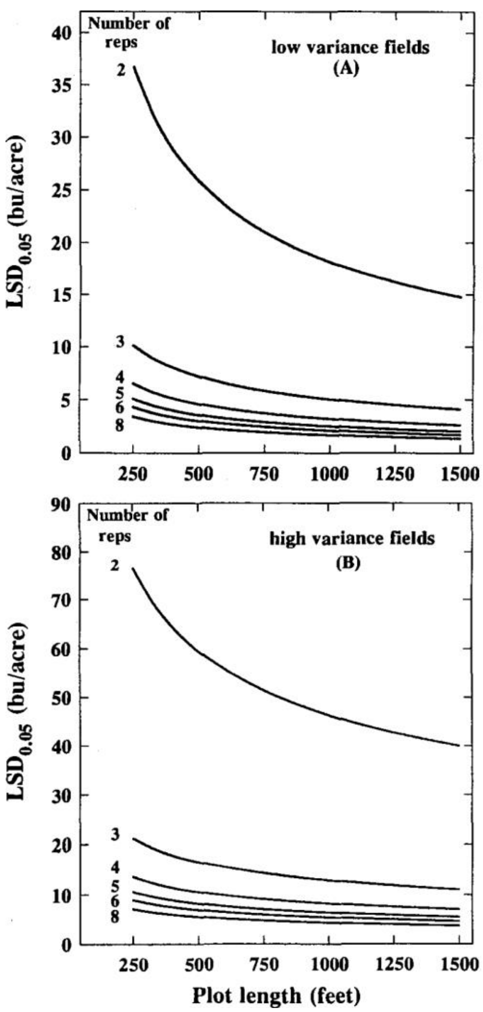

Figure 2. Effect of replication number and plot length on wheat LSD values at alpha = 0.05 based on field uniformity trials in Idaho, Oregon, and Washington (Wuerst et al, 1994). LSD values decrease (precision increases) as the number of replications increases, but the gain in statistical power with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

AWQA Toolkits Provide Easy Access to Technical Information and Training

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Summary:

The Agriculture Water Quality Alliance (AWQA) toolkits are a compilation of resources for use by CCAs, certified agronomists (CPAg), and other irrigation and nutrient management professionals to assist farming operations with water and nutrient equipment and management. These toolkits were compiled from numerous sources, including the USDA's National Resource Conservation Service, research universities, private consultants, and equipment manufacturers. Three AWQA toolkits provide pertinent information that directly targets CCAs and professional agronomists: Irrigation Systems and Scheduling, Irrigation Assessment, and Nutrient Management. The resources included in the AWQA toolkits are diverse, including links to online education and ongoing classes, research papers, fertilizer and water calculators or spreadsheets, vendor sites, and other websites with arrays of information on these topics. Those wishing to increase their knowledge in regard to a particular topic can use the AWQA toolkits to find relevant information. Information on the website can also assist CCAs with the design of reports, outreach materials, and with identifying online tools that they can recommend to growers and field managers. The toolkits can be found on-line at www.awqa.org/toolkits.

American Society of Agronomy
California Chapter

Session 2

Site-Specific Technologies for Managing Nutrients and Water

Session Chairs:

Andre Biscaro

Richard Smith

Beyond NDVI with Airborne Imagery

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Introduction

Basically this is a primer on how vegetative and water indices are used to judge water and nutrient stress in crops through specific light regions absorbed by plant pigments and water. The Normalized Difference Vegetation Index (NDVI) developed by Tucker (1979) during the early days of Landsat is now commonly used to transform broadband color infrared (CIR) images to enhance crop canopy variation. However, it is often not well understood and used to imply inappropriate conclusions.

To get started, let's define NDVI, then we can discuss the strengths and weaknesses. Many other spectral indices that have been spun-off the NDVI math formulation are described in the literature--each have had varied success in discriminating stress. We'll have a look at a few very different indices to highlight the regions of light related to the electronic bonds in plants and water in the visible near infrared region. Images in this light region are the most readily available and least expensive from un-occupied airborne vehicles (UAV), manned airborne, and satellite cameras and sensors. The light absorption by plant pigments in the visible region are well known, and used in designing sensor response to associate canopy density, chlorophyll, and water content. Access to hyperspectral sensor (having continuous narrow spectral bands) imagery over the past 20 years has opened the door to narrow band indices for greater spectral precision of these light regions. Further, hyperspectral data studies have led to developing narrow band sensors for specific light measurements to increase efficiencies by smaller instruments for lighter payload weights needed for UAVs. At present, inexpensive UAV cameras offer very high spatial resolutions with software to compensate for image distortion and geo-rectification, however, greater spectral resolution and selection is required for improved crop stress mapping.

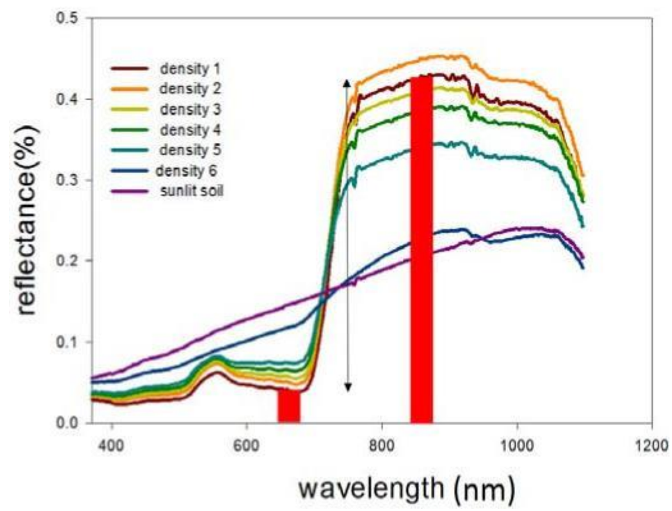
Nearly every crop manager and scientist has heard of NDVI, but we should define it here.

$$NDVI = (R_{nir} - R_{red}) / (R_{nir} + R_{red}) \qquad \text{(eq. 1)}$$

where R_{red} and R_{nir} are reflectance in the red and near infrared (NIR) regions. Originally published using broadband (80 to 100 nm) satellite sensor images. Simple enough, the normalized difference formulation, i.e., dividing the difference between reflectance values by their sum reduces the variation in ratio values, such as R_{red}/R_{nir}, due to differences in atmospheric or sun-angle effects. This normalized difference formulation can also be seen in a large number of indices in Zarco-Tejada et al. (2005).

The advantages of NDVI include being easily calculated from less expensive broadband imagery, strongly correlated to low levels of leaf area index (LAI), and within the same canopy density, correlated to chlorophyll. These advantages provide the ruggedness needed in sensors

Fig. 1. NDVI verses LAI LiCOR-2000 measurements. Circled area of high LAI and lack of NDVI prediction.



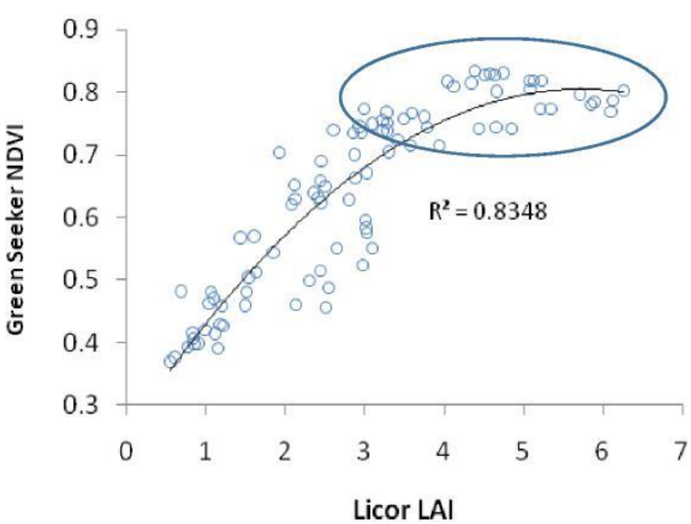


Fig. 2. Comparison of canopy densities (1 greatest to 6 least) with one nm spectra to 30 nm Landsat 8 OLI spectral resolution (red vertical bars on density 1) at 655 and 870 nm. With improved technology, broadband sensors come with narrower widths and greater ability to measure specific pigment light absorptions. Vertical arrow shows the distance calculated in red to NIR ratios by NDVI.

for the GreenSeeker canopy density meter (Trimble Inc.) and the handheld Minolta SPAD chlorophyll meter. However, NDVI disadvantages include a decrease in correlation at high levels of LAI and with variation in background soil and shadow tones, e.g., irrigated vs. non-irrigated soil. In Figure 1, our work in cotton trials at the West Side Research and Extension Center point out the saturation problem with NDVI at high LAI measured with the LiCOR-2000 (Ustin, 2010).

This is due to “bottoming out” of the red reflectance (very low values) while the NIR reflectance also decreases as leaf layers increase, seen in Figure 2. NDVI values increase by as the distance between R_{red} to R_{nir} values increase with light not absorbed or reflected but transmitted through the first layer of leaves to be absorbed, reflected upward or transmitted through to next layer of leaf, and on down through the canopy. However, above an LAI of 4, the red region reflectance by the canopy deceases non-linearly with increasing lower layers of leaves, as NIR reflectance decreases.

Background soil and shadow tones are troublesome because the pixel contains mixtures of reflected light from leaf, soil and shadow. Were it possible to be very selective of pixels from very high resolution images, it may improve the consistency in NDVI values for LAI.

While NDVI and other indices cannot discriminate nutrient stress directly, managers with access to multiple image dates with accompanying field inspections during the early stages (before NDVI saturates) will benefit by comparing field variation seen in the images to plant growth response seen in the same field locations. However, in many situations by the time NDVI differences are apparent in the images, it may be too late to adequately recover the delayed crop growth.

Over the years, remote sensing investigators have searched for the perfect index from both broadband and narrow band imagery. Looking for an existing index that correlated with cotton yield (variation evidently due to saline-sodic soil), Zarco-Tejada et al. (2005) evaluated 34 broad and narrow band indices. Satellite imagery is generally broadband. For example, Landsat 8 Operational Land Imager (OLI) has 5 refined bands in the visible near infrared (400 to 900 nm, 20 to 60 nm widths), and Worldview III has 8 bands (400 to 1040 nm, 40 to 125 nm widths). Some investigators have modified the NDVI formula--Huete (1988) was able to reduce the impact of soil background variation on NDVI by adding an adjustable parameter to NDVI formula, and Rondeaux et al. (1996) later added additional parameters to improve the correlation to LAI. These few bands in the VNIR regions do provide several indices that do better than red and NIR in some conditions. For examples, Kulkarni et al. (2008) demonstrated that nematode damage in soybean could be identified by replacing the red band with the green band in the NDVI equation.

In hyperspectral images, each pixel contains continuous bands of 10 to 15 nm widths, much like a lab bench spectrometer. From the same hyperspectral image and ground sampling data, various combinations of bands are possible for evaluating indices as predictors of plant pigments, water content and LAI. Zarco-Tejada et al. (2005) determined better combinations of narrow band indices for yield. We found in cotton more than one index that would not saturate in relation to LAI, e.g., a modification of Daughtry et al. (2000) Modification of Chlorophyll Absorption in Reflectance Index (MCARI), see Fig. 3.

$$mMCARI1 = 1.2[2.5(R_{880} - R_{674}) - 1.3(R_{880} - R_{555})] \qquad \text{(eq.2)}$$

where R_{880}, R_{674}, and R_{555} are the reflectance at these wavelengths.

To achieve an immediate marker of plant stress, the normalize difference formulation using narrow band reflectance values in the Photochemical Reflectance Index (PRI) was shown to significantly correlate to the radiation use efficiency and net CO_2 uptake at 531 nm (substituting 531 nm for red and 570 nm for NIR) (Gamon et al., 1997). This would not be possible with the older 80 nm band width of broadband images.

Hyperspectral sensors are rapidly downsizing and larger UAV platforms can hand these payload weights. After a specific index is found acceptable, optical filters can be used to narrow the light input to a three band camera or sensor. Now there are over a hundred broad and narrow band indices published. It's a bit of a research project in itself to identify the band combination that better identifies a condition at a given crop stage. In addition to the VNIR region, indices are

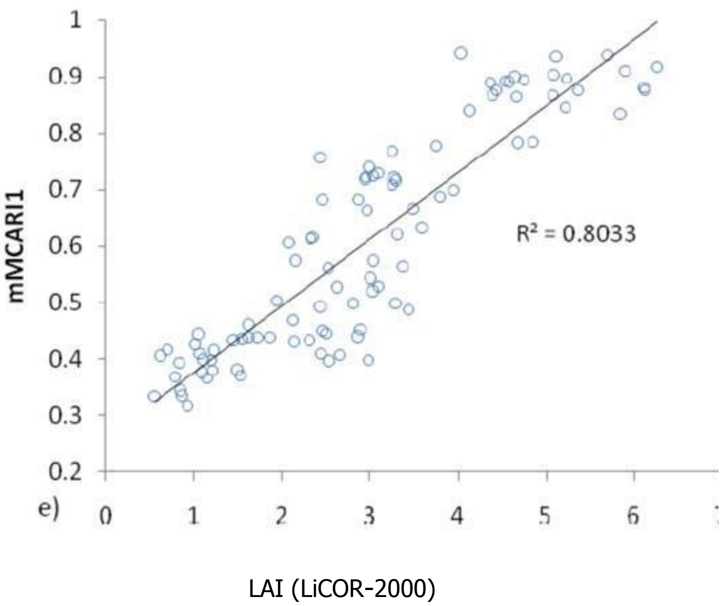


Fig. 3. Linear relationship between mMCAR1 and LAI.

also published for water content in the longer wavelengths in 1000 to 2500 nm shortwave infrared (SWIR) region, and in the thermal (10,000 to 13,000 nm). For example, the Normalize Difference Infrared Index (NDII) (Fensholt and Sandholt, 2003) was found by Cheng et al. (2013) sensitive enough to detect variation in canopy water content between morning and afternoon overflights using NASA's MASTER sensor bands 9 and 13 at 872 nm and 1667 nm. Further out in the thermal region, Gonzalez-Dugoa et al. (2012) established the intra canopy variation within almond canopy (an indication of varying water stress) using three UAV thermal flights within a single day.

Conclusion

Commercial UAV vendors will profit by using the proven strategies established with airborne remote sensing. Remote sensing may lessen the required number of ground samples, but these measurements remain critical for calibrating the spectral indices and models to known physiological conditions. To get the most of the additional resolution both in the spatial and spectral domains available in future, regardless of platform and sensor, we will require additional resolution and precision in the measurements of canopy conditions and ground control points used for geo-rectification.

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Industry Perspective of Remote Sensing in Tree Crop Agriculture – Challenges and Opportunities

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Introduction

Precision agriculture has evolved rapidly in recent decades with advances in sensor technology and data processing. However, many precision agriculture vendors focus on a single technology or a small portfolio of related technologies. Only a few commercial entities utilize both ground-based sensors and remote sensing in concert as a crop management decision-making tool. Nevertheless, novel remote sensing methods that provide actionable crop management information have yet to be widely adopted by the agriculture remote sensing community and growers alike. The Wonderful Orchards precision agriculture team provides an industry perspective on why current limitations of ground-based sensors have increased industry interest in remote sensing, and how data from new remote sensing techniques should be delivered to growers so as to foster data-driven crop management.

Ground and Plant Based Sensors

Ground and plant based sensors have served as the primary data source for crop water status for decades. Since the development of the pressure chamber technique in the mid-1960s, it has served as the most common tool for measuring plant water status in both industry and research settings (Cochard et al., 2001). Soil moisture sensors are perhaps more widely used than pressure chambers as an industry irrigation tool. However, soil moisture sensors are limited to measuring a small area. As variability in soil type and topography increases, more sensors are necessary thereby increasing costs.

Other crop data tools have begun to enter the commercial space including dendrometers, porometers, sap flow meters and chlorophyll meters. Vendors have developed complex platforms that selectively combine the aforementioned technologies. Field data is presented using online dashboards, which are often difficult to interpret. Often, data requires interpretation by the vendor’s agronomists who then provide summaries of recommendations to growers. These factors have hindered vendors from justifying the high cost of these technologies versus advertised gains in water use efficiency, yield or quality.

Ground and plant based sensors provide extraordinary value as tools for the development of precise crop models by observing tree behavior under stressed conditions at high accuracy and frequency. However, as tools in commercial operations, the Wonderful Orchards precision agriculture team has identified three key obstacles preventing widespread commercial adoption by tree crop growers in California:

1. **Cost:** Depending on implementation and the number of sample sites, the cost of ground sensors can be substantial. As demonstrated in Table 1, precision agriculture data collection cost is significantly more expensive per acre than conventional data collection and the total cost can increase based on type of implementation. The costs in Table 1 do not account for regular maintenance and repair required for ground-based sensors.
2. **Sample Size:** The cost and labor per sensor or sample limits a grower's ability to sample a significant portion of trees. Sample sites require stratification to better represent the spatial variability of stress induced by soil type, topography and microclimate. Often, growers are making a decision for their entire orchard based on an extremely small sample size.
3. **Crop Operations and Damage:** Ground sensors are highly subject to tree crop operations – sprays, harvest (especially in nut crops that shake trees for harvest), winter sanitation, pruning and/or hedging. This is especially true for on-tree sensors, like dendrometers or sap flow meters that could be damaged by machinery. Additional sources of damage include animals, severe weather events and theft. As orchards increase in commercial scale, the potential for operational damage increases due to communication difficulties between operational departments, e.g., irrigation and spray operations.

Table 1: Comparative costs and sample sizes between Conventional Data Collection (pressure chamber and soil moisture sensors), Precision Ag. Data Collection (an average cost of various commercial packages), and fixed wing Aerial Imagery Data Collection using novel methods.

	Ground-based Sensors		Remote Sensing
	Conventional Field Data Collection	Precision Ag. Field Data Collection	Advanced Aerial Imagery Data Collection
Cost per acre	$ 17	$ 26	$ 28
Number of trees sampled	10s to 100s	100s to 1,000s	Every Tree
Frequency of observation	Weekly & Daily	Hourly	Weekly

These three limitations present significant obstacles that have hindered broad adoption of ground-based precision agriculture practices in tree crops. One notable exception is wine grapes, where margins are high, close crop management has a dramatic impact on earnings, acreages are small with diverse soil types and micro climates, and operations are tightly managed by vineyard managers.

As tree crop operations increase in size and complexity, these three constraints are exacerbated. Furthermore, most ground sensors provide point measurements and do not provide sufficient information regarding the spatial variability of tree crop water or nutrition stress. Orchard spatial variability can be assessed with remote sensing, which has recently become a realistic alternative to strictly ground-based precision agriculture management of tree crops.

Remote Sensing Opportunities for Tree Crops

Remote sensing as a precision agriculture tool has seen widespread adoption in agronomic crops where it facilitates variable rate technologies that optimize irrigation, nutrition, seed density and soil amendments (Mulla, 2013). Despite its broader use in agronomic crops and recent technological improvements that decrease cost of implementation, remote sensing has seen limited adoption in tree crops as a precision agriculture tool. Many growers value remote sensing, but have struggled with its adoption due to the lack of actionable information provided by commercial vendors. Data delivery to growers has primarily focused on visual representations of field conditions with no actual data embedded in the map. These maps are semi-actionable at best, i.e. they identify and locate an issue without prescribing a solution. For example, vendors emphasize quick fixes like an irrigation leak. While a tangible benefit, this application of remote sensing rarely justifies the cost incurred from acquiring imagery. Leveraging imagery to improve water use, nutrition efficiency, and yield quality and quantity should be of greater focus.

Currently, only a few commercial vendors provide field maps that specifically address water and nutrition stress issues beyond true color imagery and normalized difference vegetation index (NDVI). However, these field maps are delivered in a visual form that requires training to interpret, and significant time to review regularly during the growing season when time is limited. Questions such as how many inches of water or how many pounds of nitrogen to apply are left for the grower to decide based on visual interpretation. These visual representations can be misleading depending on how they have been symbolized, and decisions made using these representations could therefore be misguided.

It is critical therefore that instead of visual field maps, vendors strive to deliver actionable data that provides prescriptive crop management solutions. NDVI for example, which continues to dominate the commercial agriculture remote sensing space, provides a grower relative values of crop vigor but does not directly translate into a crop management decision. Nevertheless, vendors often sell services based on NDVI collected at a high resolution or from a novel platform like an unmanned aerial vehicle (UAV), and claim yield improvements and cost savings.

Reflecting the desire for actionable information, the research community has increasingly dedicated attention to other remote sensing indices. TCARI/OSAVI, MCARI/OSAVI, and Red Edge have all demonstrated suitability in assessing crop nutrition status (Zarco-Tejada et al., 2004, Haboudane et al., 2008; Lin et al., 2012). Methods that leverage both remote sensing in conjunction with ground-based sensors, e.g., stomatal conductance, METRIC and CWSI, have demonstrated promise in assessing crop water demand (Jones, 1999; Allen et al., 2007; Bellvert et al., 2013).

With the ability to calculate actionable information from imagery, it must be delivered in a format familiar to crop managers as few will have the time, training and resources to analyze the raw data. To do this, remote sensing vendors will need to determine novel methods for translating aerially-obtained metrics into operational measures (e.g. stem water potential or evapotranspiration). In order to gain broader acceptance of remote sensing as a precision agriculture tool, imagery providers should shift their focus away from delivering data in map form to a format that enables growers to make timely field-level decisions.

Hybrid Remote Sensing and Ground Sensor Approach

An ideal remote sensing tree crop management solution is one that also involves ground-based sensor measurements. In this manner, a grower can have the coverage and spatial variability offered by remote sensing as well as continuous measurements from ground sensors strategically located throughout the orchard. Remotely sensed data can be used to identify systematic deficiencies in the orchard as imagery is collected throughout the season, while continuous ground-based sensor measurements can fill gaps between imagery acquisitions. Costs would be lowered by reducing the frequency of flights and the number of sensors in the field, given that they can provide complimentary data.

Ultimately, a successful remote sensing solution will benefit a grower the most if it is accurate and presented in a format that growers are familiar with and feel comfortable using as a decision making tool. While providing prescriptive crop management information presents risk to the vendor, it is this type of actionable information that has made technologies like CIMIS and pressure chambers so widely accepted.

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Precision Irrigation in Almonds and Grapes based on Plant Water Status

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Summary

The objective of this project was to irrigate orchard and vineyard crops based on plant water status as estimated by a real-time stress sensing system known as a continuous leaf monitor. To accomplish this objective, two management zones were created based on spatial variability in soil (texture, electrical conductivity (EC) at two different depths, and digital elevation) and plant (light interception, canopy temperature, stem water potential (SWP), normalized difference vegetation index (NDVI), and/or yield) characteristics in an almond orchard in Arbuckle, CA (Nickels Soil Lab) and in a vineyard in Galt, CA (E & J Gallo Wineries). Within each management zone, both conventional grower treatment and plant water status based precision irrigation management were investigated. The continuous leaf monitor measured the leaf temperature, ambient temperature and relative humidity, incident solar radiation, and wind speed to estimate plant water status. The continuous leaf monitor, soil moisture sensor, pressure sensors (to detect the pressure in irrigation lines), and latching solenoid valves (to turn on and off irrigation lines) were all connected to nodes which formed a wireless network. The sensor information was accessed remotely through PCs or mobile devices. Plant water status of selected trees were estimated by comparing the performance of those trees with respect to a well-watered tree and a simulated dry tree. The results were presented as daily crop water stress index (CWSI) valves that were then used to implement management zone based precision irrigation.

Introduction

California's large agriculture industry depends heavily on irrigation water, which amounts to more than one-fourth of the total irrigation water withdrawn in the whole nation (USGS, 2005). Increasing urban demand, limited availability of water, and recent severe drought conditions are forcing growers to implement better irrigation practices that increase water use efficiency. Irrigation scheduling techniques have been developed mostly based on soil moisture monitoring in the past. However, soil moisture measurements may not represent water availability to plants in the whole root zone, especially in the case of orchard trees and grape vines that have a vast root structure. Therefore, a plant's response to water stress is considered as a better indicator of plant water stress (PWS), as it responds to the integrated soil moisture status of the whole root zone (Jones, 2004). Furthermore, irrigation scheduling techniques based on PWS are ideally suited for regulated deficit irrigation management that aim to improve the quality of fruits (Leeuwen et. al., 2009).

Studies have shown that measurement of PWS provides the key information necessary to implement efficient irrigation management schemes in orchards (Dhillon et. al., 2014a). A pressure chamber is often used to measure stem water potential (SWP) which is considered as the standard method to measure PWS. However, this technique is labor intensive, tedious and time-consuming, which makes it impossible to obtain the large number of samples necessary to develop precision irrigation scheduling techniques. Dhillon et al. (2014a) developed a sensor suite consisting of a thermal IR sensor and other relevant microclimatic variables (i.e., air temperature, relative humidity, wind speed, and incident radiation) and demonstrated that leaf temperature (particularly shaded leaf temperature), correlated with plant water status and microclimatic variables very well for almond, walnut, and grape crops with coefficient of multiple determination values of 0.90, 0.86, and 0.86, respectively. However, they noted a calibration drift in the sensor suite predictions as the season progressed. Moreover, this system required frequent visits to the orchard/vineyard to obtain sensor data to predict PWS and manage irrigation. To address these issues, Dhillon et al. (2014b) developed a continuous leaf monitoring system which included same sensors as the sensor suite (i.e. leaf and air temperatures, relative humidity, photosynthetically active radiation (PAR) and wind speed) to determine PWS, but was capable of acquiring and communicating the data in real-time using a wireless network. They analyzed the leaf monitor data and showed that it can provide daily PWS values for almond and walnut crops successfully. The objectives of this project were: (i) to evaluate the suitability of the leaf monitor to determine PWS in grape crop, and (ii) to utilize the leaf monitor to implement management zone based precision irrigation in almond crop.

Materials and methods

Creation of management zones and testing of the suitability of leaf monitors for detecting stress in both almond and grape crops were performed during the 2015 growing season. Management zones were created based on soil and plant characteristics using unsupervised Fuzzy classification. The soil characteristics considered were digital elevation (obtained using RTK GPS units), soil texture, and surface (shallow depth) and subsurface (deep layer) electrical conductivities. Plant characteristics considered were NDVI (Landsat image) and yield maps from the 2014 growing season for grapes, and canopy cover (as measured by an UAV) and leaf temperature for almond crops. This information was used to create maps using a kriging technique. After maps were created, samples were obtained using an inverse distance technique at locations that represent a tree (almond crop) or blocks of five vines (grape crop). The idea behind these zones was that they represent relatively homogeneous management units. Based on these management zones, we made modifications to irrigation water supply systems, selected optimal locations to install leaf monitors, soil moisture sensors, pressure sensors, hubs or nodes and latching solenoid valves.

In each location, a wireless data acquisition and communication system was installed. The system consisted of soil moisture and plant water status sensors (leaf monitors) to monitor soil, plant, and ambient conditions continuously. Moreover, the systems were capable of actuating latching solenoid valves for a desired duration to implement site-specific water management. Plant water status was monitored by comparing the performance of selected vines/trees with respect to a well-watered vine/tree and a simulated dry vine/tree. The well-watered leaf corresponded to a tree with an extra dripline and the simulated dry condition corresponded to a leaf for which the stem had been detached from the branch. In order to perform this comparison, leaf temperature and air temperature sensors in each of the leaf monitor were calibrated with respect to the saturated and dry leaf monitors, respectively. A day when the selected trees were saturated (i.e. one day after irrigation) was chosen to calibrate each of the leaf temperature sensors (i.e. IR temperature sensor). Calibration was needed to account for any discrepancy in the slope and intercept values between the leaf monitor that was mounted on the fully saturated tree and a leaf monitor mounted on a tree in one of the treatments.

Between September 18^{th} and 27^{th}, leaf monitors were tested in grapes by measuring PWS in eight vines, where four vines corresponded to vines that were not being watered following full irrigation in order to experience increasing amount of stress; and four other vines corresponded to vines that were watered daily after a long period of stress to recover from stress. In the case of almond, attempts were made to manage irrigation in such a way that the level of plant water stress, represented as daily CWSI values, remained within a reasonable range between July 25^{th} and August 6^{th}.

Results and discussion

The krigged maps developed using plant and soil characteristics, and the management zones created from those maps are shown in Figures 1 and 2, for almond and grape crops, respectively. In the almond plot, the soil characteristics had a greater contribution in the classification than plant characteristics. Among the soil characteristics considered, digital elevation was the feature that contributed the most. In the case of grapes, two patterns emerged; these were combined to develop two management zones. Even though we did not install leaf monitors in the regions located at the edges, they were management in the same way as the respective neighboring regions.

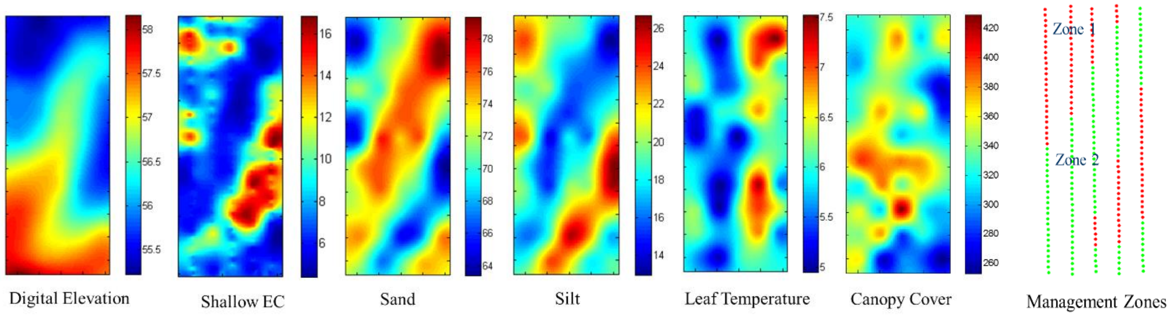

Figure 1. From left to right: krigged maps of (a) digital elevation, (b) shallow EC, (c) sand, (d) silt, (e) leaf temperature and (f) canopy cover, and (g) classification result for five rows of almond trees.

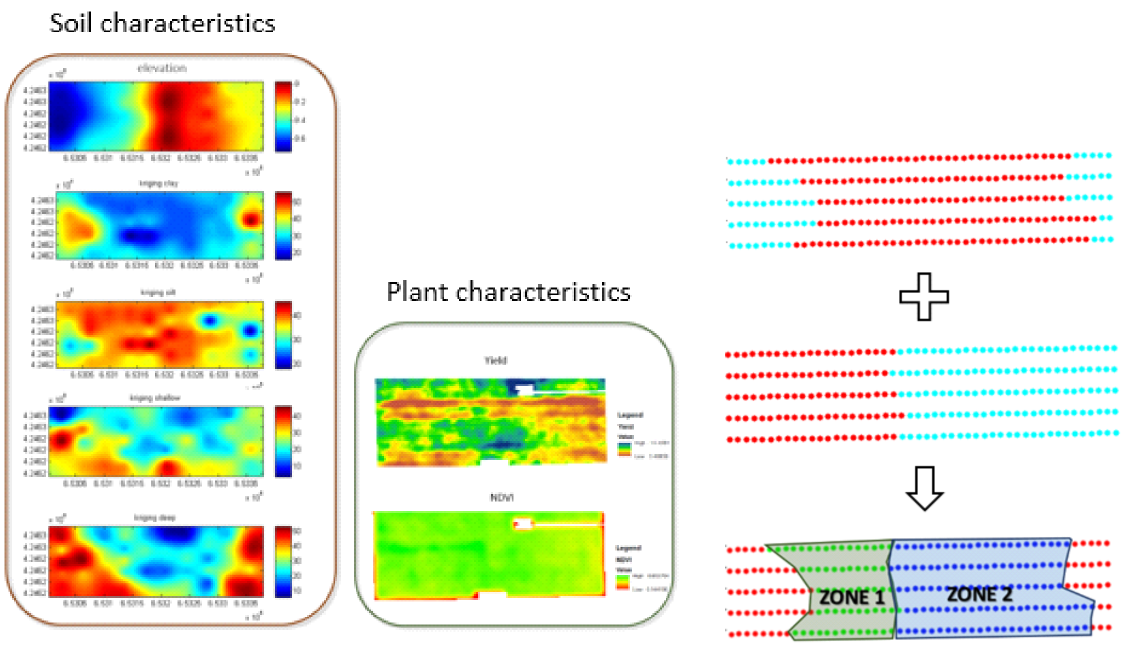

Figure 2. From left to right: (a) Soil characteristics from top to bottom: Elevation, clay, silt, shallow and deep EC. (b) Plant characteristics are Yield (Top) and NDVI values (bottom). (c) Management zones based on: elevation and texture (top); elevation, texture, EC, and yield (center); and final classification in which edge regions have been excluded (bottom).

An example, of the behavior of temperature difference (i.e., Air temperature – Leaf temperature) for the period of July 25th to August 4th for three almond trees, and for the period of September 18th to 27th for three vines are shown in Figures 3a and Figure 3c, respectively, where the curves corresponding to the dry (red) and well-watered (green) conditions are displayed together with the curves of each selected leaf monitor (blue); the horizontal axis represents time in Julian days. In the case of almond crop, attempts were made to manage irrigation in such a way that the level of plant water stress represented by daily crop water stress index values remained within a reasonable range. In the case of grapes, data were used only to analyze the behavior of PWS and compare the Deficit Stem Water Potential (DSWP) values with the values of CWSI (an index obtained using the difference between the air temperature and leaf temperature) or modified crop water stress index (MCWSI – an index obtained using leaf temperature only). Further details regarding these indices can be found in Dhillon (2014b). The implementation of the precision irrigation based on PWS was left for the next season. Note that temporal variability in PWS was different for different management zones in both crops, indicating that management zone based precision irrigation management that utilizes plant water status as a stress indicator could be a useful tool. The estimated CWSI or MCWSI values are shown in Figures 3b and 3d for almond and grape crops, respectively. In these plots a value of 1 corresponds to the dry or highly stressed condition and 0 corresponds to the saturated or well-watered condition. Figure 3d shows how the vines that were not receiving water started developing stress after a few days. These indices quantify the water status of the plants and can be used for decision making. In the case of almond trees, when the average CWSI values for a zone exceeded the maximum allowable stress (i.e. CWSI value of 0.3), zone based precision irrigation management was implemented to maintain the stress level within a desired range.

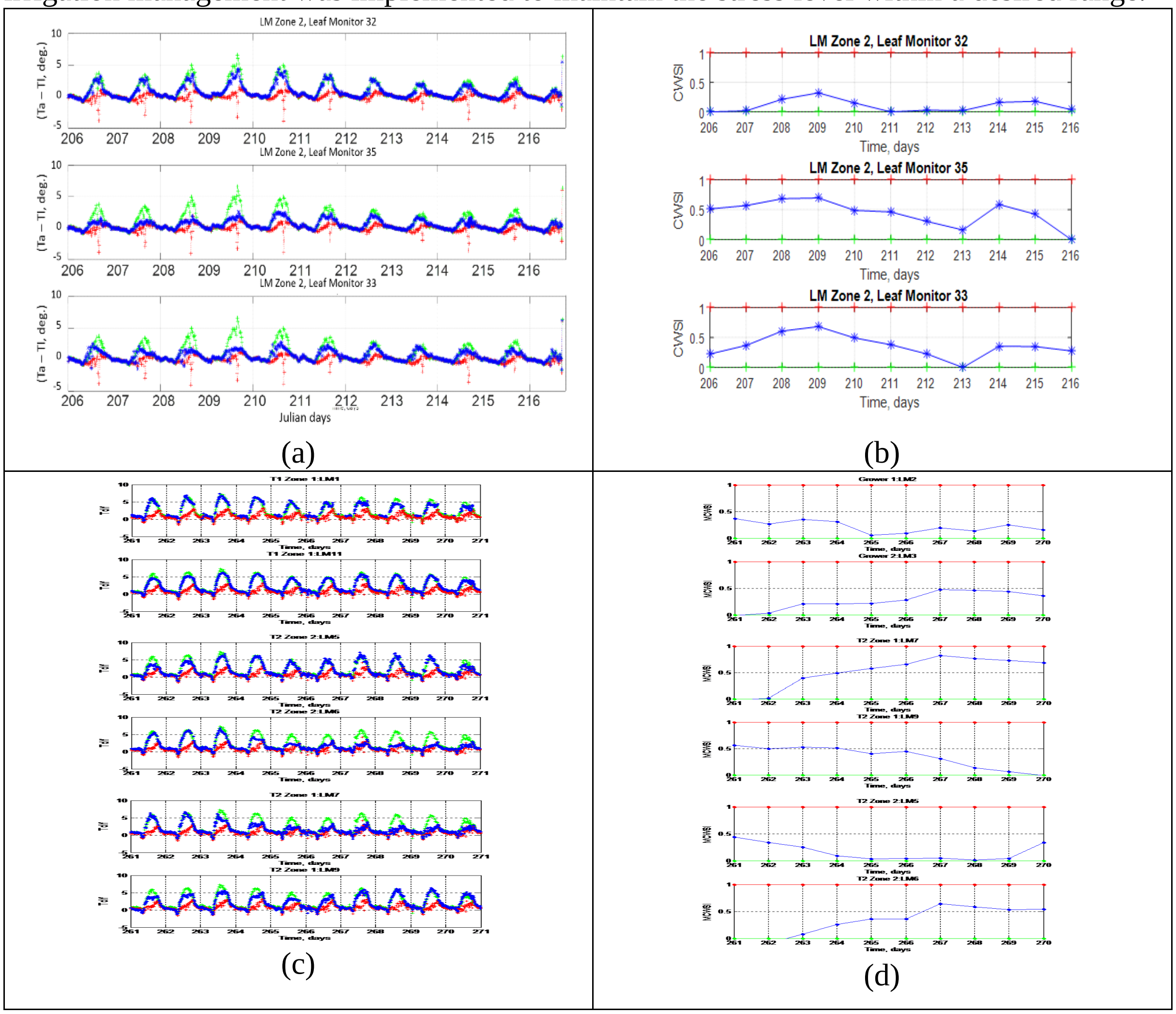

Figure 3. Continuous leaf monitor data for: almond crop – (a) Display of temperature difference between the ambient and the leaf for a well-watered (green), simulated dry (red), and monitored tree (blue), (b) Computed daily CWSI values; and grape crop – (c) Display of temperature difference between the ambient and the leaf for a well-watered (green), simulated dry (red), and monitored vine (blue), (d) Computed daily MCWSI values.

Midday DSWP data were compared with their corresponding values of CWSI (almonds) or MCWSI (grapes). In almond, each treatment was represented by three leaf monitors in each zone. CWSI and DSWP values were found to be strongly correlated, with a second order relationship (Figure 4a). The coefficient of multiple determination evaluated from the average values for each treatment of each management zone was 0.75. In grapes, a linear relationship between MCWSI and DSWP was found with a coefficient of determination value of 0.70 (Figure 4b). Note that in figure 4a there are two points that appear to be outliers.
In the case of almond crops, zone based precision irrigation management was performed according to the stress level of the trees. Preliminary results indicated that stress based irrigation management required about 70% water compared to grower treatment in zone #1 while zone #2 required about 90% water compared to the grower treatment.

Conclusions

Two management zones were successfully developed based on soil and plant characteristics in both almond and grape crops. Temperature difference (i.e. air temperature minus leaf temperature) responses to plant water stress were compared to a well-watered vine/tree and a simulated dry leaf in both crops. The CWSI and MCWSI indices were estimated and found to be capable of representing the stress level of the grape and almond crops. Comparison between the stress indices and DSWP values yielded a coefficient of determination of 0.70 for grape crop, and a multiple coefficient of determination of 0.75 for almond crop. By monitoring leaf temperature and microclimatic variables with leaf monitors, variable rate irrigation was implemented, in the almond plot, according to the crop stress level observed in each management zone. Preliminary results indicated that zone #1 required about 70% water compared to the grower treatment and zone #2 required about 90% water compared to the grower treatment.

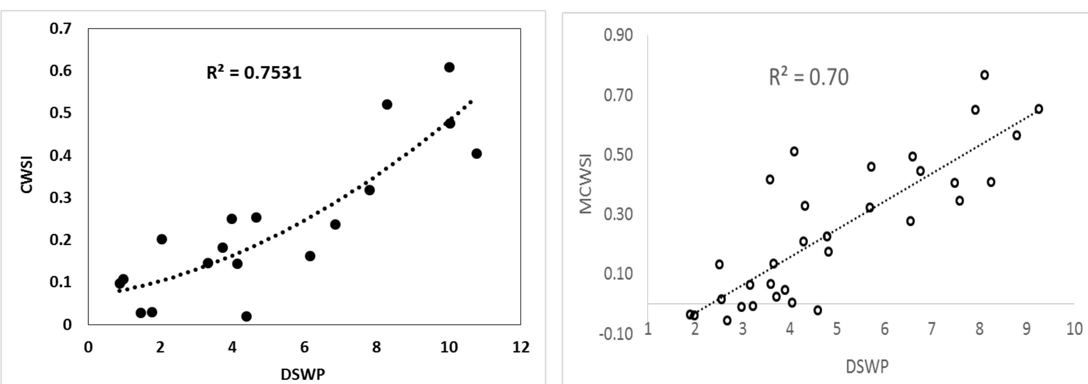

Figure 4. Comparison between (a) CWSI versus DSWP in almond crop, and (b) MCWSI versus DSWP for grape crop.

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California Chapter

Session 3

Nutrient Management Strategies

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Nitrogen Dynamics in Cropping Systems
-- Why Alfalfa is Important

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ABSTRACT

Alfalfa (*Medicago sativa* L.) as the most important agricultural legume in California cropping systems, has an important role to play in N cycles and mitigation of N risk to the environment. These include 1) it's ability to take up considerable quantities of excess N from soil, and act as a 'buffer' under high N conditions, 2) the production of protein without subsidy from N from fertilizer sources in food-producing systems, and 3) contribution of N to non-legumes in rotation. Based on the wheat N response data, we estimated the legume N credit at the three sites to range from 50 to 125 lbs. N ac^{-1}, which was higher than previous estimates in California of 40 to 80 lbs. N ac^{-1}. The crop's deep-rooted attributes, it's high uptake of water (and thereby soil N), and high N content in the crop indicate that alfalfa is capable of mitigating excess N as well as contribute considerable N to subsequent crops in a rotation, indicate alfalfa's valuable contribution to N management in cropping systems.

INTRODUCTION

Nitrogen is frequently the most limiting plant nutrient for crop growth in cropping systems, critical for the formation of plant proteins as crop products, as well as a potential pollutant in ground and surface waters when applied as fertilizers. Nitrogen is most commonly applied to non-leguminous crops in the form of N fertilizers which mostly originate from the Haber-Bosch process which converts N_2 from the air into ammonia utilizing fossil fuels. Manures are also used to satisfy the N needs of crops, but a portion of manure N similarly originates from crops fertilized with N fertilizer. It is well known that excess N from agricultural sources can result in nitrate contamination of groundwater.

N_2-fixing plants (alfalfa, clovers, beans, vetch, peas, etc.) conduct the same process as Haber-Bosch through biological enzymatic symbiosis with *Rhizobia* spp., providing essentially 'free' N for protein production originating from atmospheric N_2 gas, not fossil fuels. Alfalfa (*Medicago sativa L.*) as California's most important leguminous crop, plays several roles in N management, including:

- The ability to substitute for N fertilizers for protein production in food systems.
- The ability to absorb high quantities of nitrate from the soil or water.
- The ability to contribute biologically-fixed N to subsequent crops in rotation.

The first point is often not appreciated, and not considered in depth here—but (for example), if corn were used to produce the protein currently produced in California's alfalfa crop, nearly 5 million additional acreage of corn grain would be required (as well as the fertilizers and water needed for protein production). The second two points are important in mitigating impacts of N in groundwater, and for N management in general in cropping systems and are considered here.

Does Alfalfa Require N Fertilizers?

Generally the answer to this question is 'no' under most conditions, at least from an economic perspective. While some legumes (e.g. some Phaseolus spp.) respond to exogenous N fertilizers, alfalfa generally does not. An extensive review of this issue for either early establishment phase or established phase indicated that when plants are well nodulated and nitrate was above 15 ppm and neutral soil pH (6.2-7.5), seedling alfalfa did not benefit from applications of N fertilizers (Hannaway and Shuler, 1993). In established alfalfa, most studies indicate no positive response to N fertilizers in alfalfa when crops are well-nodulated. Exceptions to this include situations where biological N_2 fixation may be compromised, such as cold temperatures, since nodule formation, root growth and biological N_2 fixation are all affected by temperature (Sprent and Sprent, 1990). Alfalfa under desert conditions may be highly stressed due to moisture limitations or salinity. Shuler and Hannaway (1993) suggested moderate rates of fertilizer only benefits alfalfa growth and yield under low-N, cool conditions.

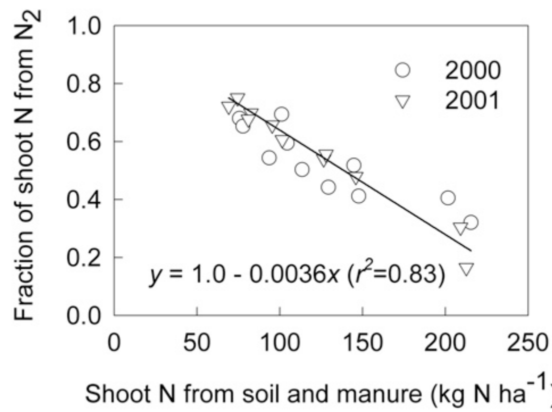

Figure 1. Fraction of N in alfalfa provided by atmospheric N2 at various soil N contributions (M. Russelle, unpublished data).

Alfalfa acts as a 'buffer' with soil N uptake .

Most of the N required for alfalfa crop production is provided by N_2 fixation (estimated to be 60-80% under most conditions), with the rest supplied from soil sources. However, when nitrate concentration in the soil is higher, N_2 fixation is reduced, and the crop preferentially takes up N from soil sources (Figure 1). Thus the high uptake of N for protein production is generally satisfied through contributions from biological N_2 fixation, but the crop will preferentially take up soil N when available from the soil. This is unlike high N-requiring crops (like corn) which must satisfy their N requirement from soil residual or exogenous N from fertilizers or manures, and when that supply is depleted, yields are reduced. In the case of alfalfa, yields are rarely reduced under low N soil conditions, but N uptake remains high.

Alfalfa Can Mitigate Excess Nitrogen in Cropping Systems

Alfalfa is a crop which has been shown to mitigate excess N in cropping systems, whether applied as manures, nitrates in water, or from municipal wastes. This is due to several attributes:

- Perenniality and long-season growth--Established alfalfa will remain from 3-7 years, and remains active nearly year-round in warmer climates like the Low Deserts and Southern San Joaquin Valley.
- Deep-Rootedness—Alfalfa Roots commonly reach 4-7 feet and can take up water and nitrates from depth.
- High yields, and high protein content and thereby high N content of the crop, resulting in

high uptake levels.

- Frequent harvest which allow removal of N throughout season, not just one time.
- High seasonal water demand which allows uptake of nitrate if present in water.

Alfalfa produces more harvestable protein per unit area than any other crop plant. This is particularly true in high-yielding environments like California, Arizona and Mexico, where yields can exceed 10 tons/acre.

Quantification of N uptake with alfalfa is a function of two attributes: 1) yield and 2) N concentration in the foliage (which is directly related to Crude Protein concentration). Typical per-year N uptake levels for alfalfa in California's Central Valley are illustrated in Table 1. Average yields in the non-Intermountain regions are about 8 tons/acre and percent nitrogen ranges from about 3.2% to 3.5% (protein can range from about 16% to 26 percent and yields from 5 to 13 tons/acre as shown here). Realistic averages for the CV and desert regions of California are likely to be about 8 tons/acre at about 21% CP, or about 500-600 lbs. N/acre per year in 6-8 cuttings, but can be as much as 700 to nearly 1000 lbs N/acre/year .

Table 1. Annual Estimated Crop removal of Nitrogen at different alfalfa yield and protein levels. Shaded area indicates most likely range for California Central Valley locations.

	Crude Protein of Alfalfa Forage					
	16	18	20	22	24	26
	%Nitrogen in Forage					
Tonnage	2.56%	2.88%	3.20%	3.52%	3.84%	4.16%
(t/a)	Crop Removal of N					
	lbs N/acre					
5	256	288	320	352	384	416
6	307	346	384	422	461	499
7	358	403	448	493	538	582
8	410	461	512	563	614	666
9	461	518	576	634	691	749
10	512	576	640	704	768	832
11	563	634	704	774	845	915
12	614	691	768	845	922	998
13	666	749	832	915	998	1082

Table 2. Estimated per-cut crop removal of Nitrogen at different alfalfa yield and protein levels. Shaded area indicates most likely range for California Central Valley locations.

	Crude Protein of Alfalfa Forage					
	16	18	20	22	24	26
	%Nitrogen in Forage					
Tonnage	2.56%	2.88%	3.20%	3.52%	3.84%	4.16%
(t/a)	Crop Removal of N					
	lbs N/acre					
0.5	26	29	32	35	38	42
0.75	38	43	48	53	58	62
1	51	58	64	70	77	83
1.25	64	72	80	88	96	104
1.5	77	86	96	106	115	125
1.75	90	101	112	123	134	146
2	102	115	128	141	154	166
2.25	115	130	144	158	173	187
2.5	128	144	160	176	192	208
2.75	141	158	176	194	211	229

However, per-cutting yields and uptake differ significantly over the year, so there is likely to be a seasonality to N uptake in alfalfa. Yields are highest in the first 3-4 cuttings of the year and then decline significantly, in a phenomenon known as 'summer slump'. Protein percentages tend to be highest in the early harvests, decline during summer, and go back up during fall harvests. In most environments, late summer and fall harvests are significantly lower than early spring and early summer harvest (April through June), so crop uptake of N is likely to be highest in the spring and decline throughout the summer. Adjustments for stand health and other stresses should be made. Generally, alfalfa has low N uptake rates during cold winter months.

Alfalfa Provides Nitrogen Benefits to Subsequent Crops

In order to manage N in a cropping system, the contribution of the legume to a subsequent crop in rotation is important. This is known as the legume N credit. Such N credit values help growers estimate the amount of N fertilizer they can withhold for crops following the legume compared to following a non-legume (Bundy et al., 1997; Kaiser et al., 2011; Leikam et al., 2007). Legume species, stand vigor, soil, climate, and other location-related factors can affect N contributions to a subsequent crop.

The majority of research on the legume N credit for crops following alfalfa has been conducted under rainfed conditions, where hundreds of site-years of data (Yost et al., 2014) have indicated that N contributions can range from 30 to 75 lb ac^{-1} for seeding year stands (Hesterman et al., 1986; Kelner et al., 1997), up to 175 lb ac^{-1} for older stands (Harris and Hesterman, 1990; Hesterman et al., 1987). The majority of studies reviewed by Yost et al. (2014) have indicated that all to partial N needs of corn are satisfied by the rotational contribution of alfalfa (Figure 2). It's striking that in this meta analysis, 10 of 19 studies showed a benefit in year 2 after rotation with alfalfa (data not shown).

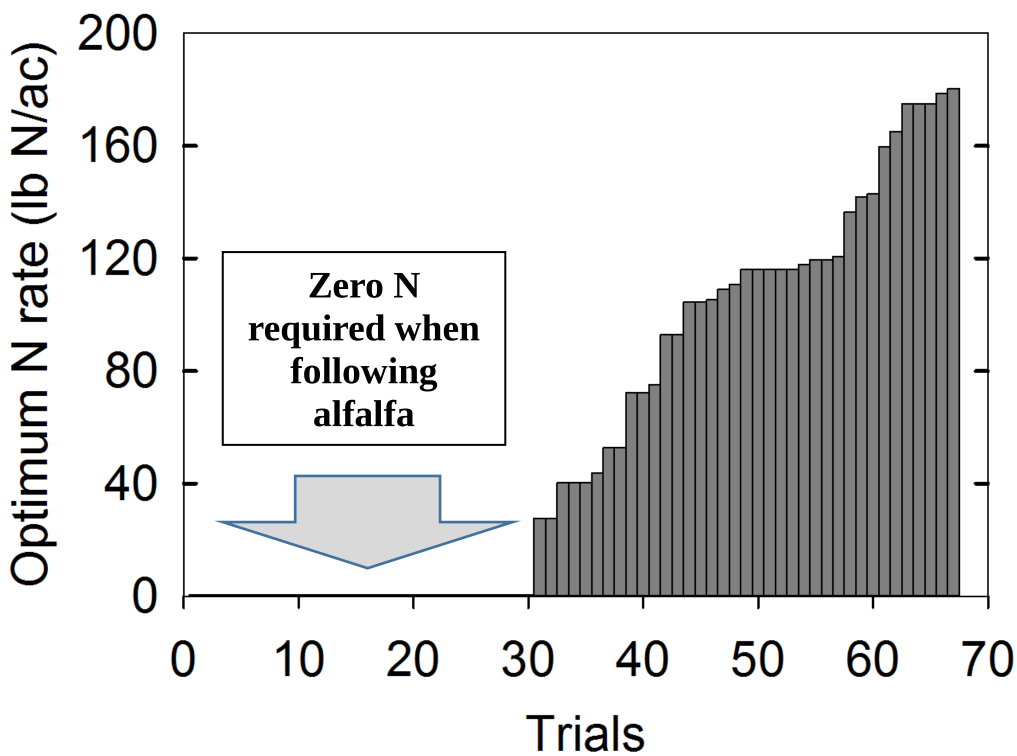

Figure 2. Response of corn to N fertilizers when following alfalfa in rotation – from a meta-analysis of multiple trials, mostly in Midwest, USA. In many of the studies, little or zero N was required and in 10 of 19 studies, zero N was required for two years following alfalfa. (Yost et al., 2014). While it is clear that alfalfa rotation N can supply a majority of the N to a following crop, such benefit is likely to be soil type specific.

In irrigated semiarid and arid regions, however, experimental evidence has been comparatively lacking. Some recent work in semiarid Spain has produced estimates of approximately 140 lb ac^{-1} (Ballesta and Lloveras, 2010; Cela et al., 2011). In Idaho, crop rotation research conducted under irrigation found that alfalfa could often supply all the N needs of subsequent crops (Carter et al., 1991). Compared to rainfed regions, high yielding irrigated regions could have higher N credits due to higher total N_2 fixation, higher yields, and longer growing seasons. Alternatively, they could have lower N credits due to greater N removal or higher temperatures promoting mineralization and losses.

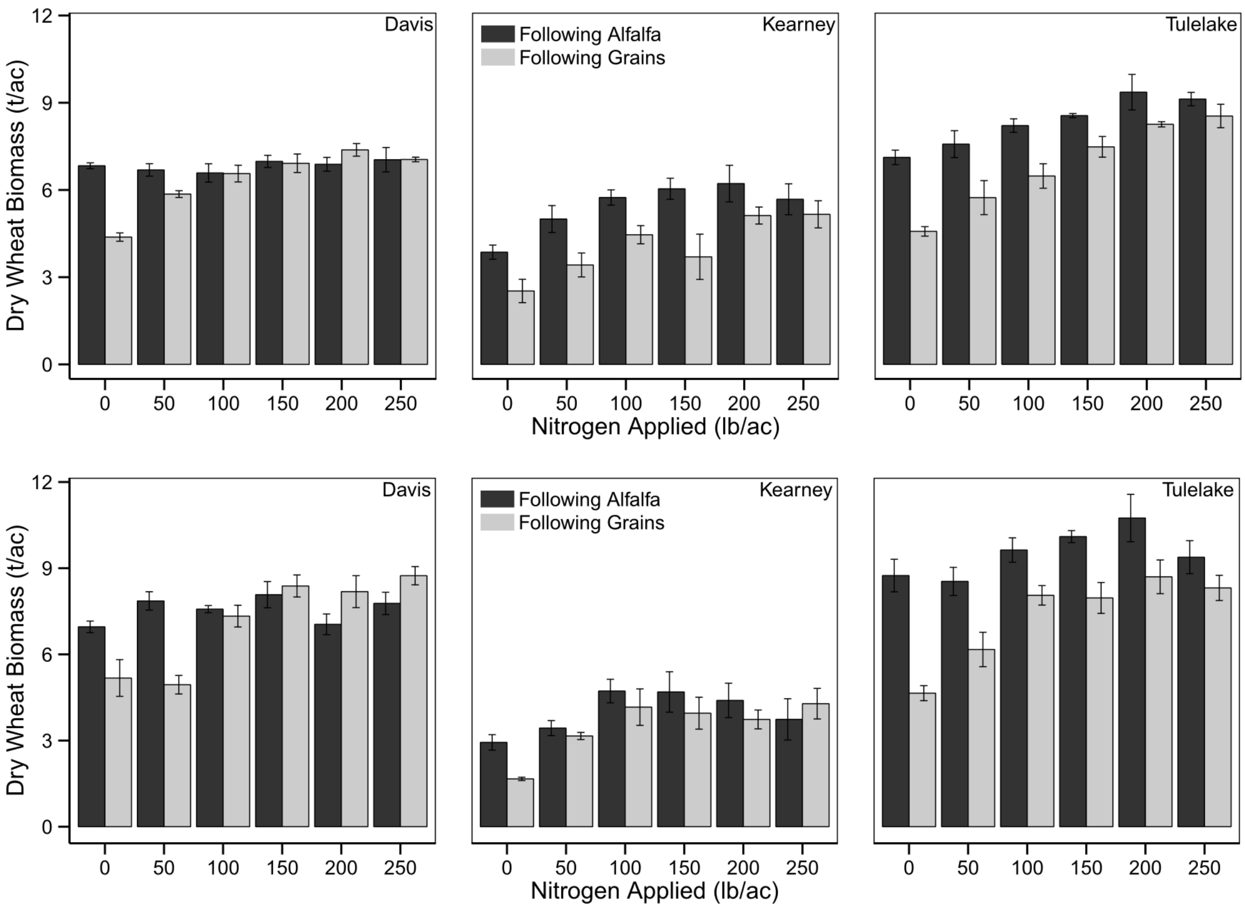

Figure 3. Response of wheat to N rate as affected by previous crop in rotation. Data from fields planted to wheat in 2013 (top) and 2014 (bottom). Wheat yield expressed as above-ground plant biomass (dry weight) at soft dough stage. Error bars represent standard errors of the mean.

Field Studies in California

To determine the alfalfa N credit, we conducted field trials at UC field stations in three locations: Tulelake near the California-Oregon border, Davis in the southern Sacramento Valley, and Kearney in the San Joaquin Valley. At each location, we grew irrigated wheat in small plots within larger replicated strips that previously had either (1) alfalfa for 2.5+ years or (2)

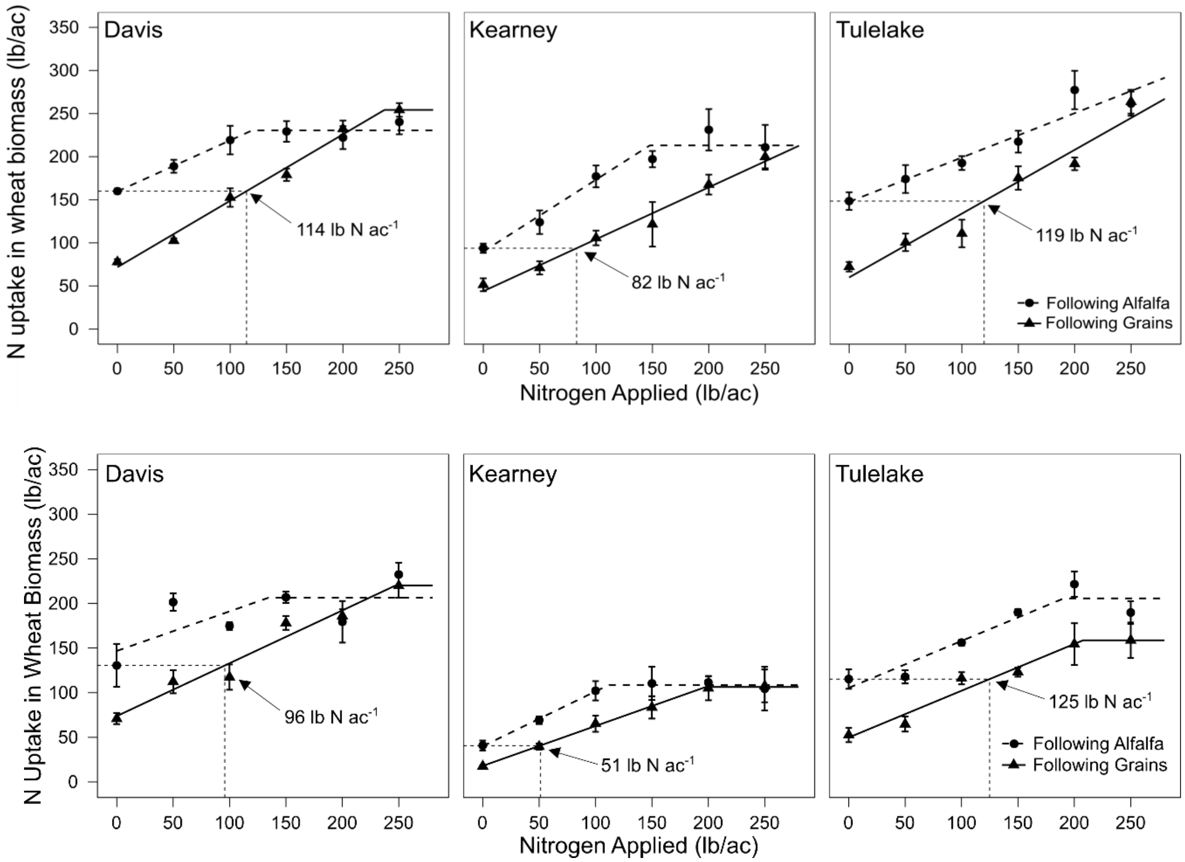

Figure 4. Total nitrogen uptake of wheat grown with 6 N rates after alfalfa and following sudangrass-wheat (grains) at the three locations from fields planted to wheat in 2013 (top) and 2014 (bottom). Error bars represent standard errors of the mean. Regression curves (dashed and solid lines) represent linear-plateau models. Dotted lines and arrows indicate the amount of fertilizer N required for wheat following sudangrass-wheat to take up the same amount of N as unfertilized wheat following alfalfa.

sudangrass-wheat rotation for 1.5+ years before being terminated in the fall and planted to wheat shortly after. Neither the alfalfa nor the sudangrass-wheat strips received N fertilizer, but were otherwise grown using standard farming practices. At Kearney and Tulelake, strips of alfalfa were removed from existing stands and planted to sudangrass to establish sudangrass-wheat rotations. Remaining strips of alfalfa were used for plots of alfalfa for 2.5+ years. At Davis, the sudangrass-wheat rotation was established in a separate field. Alfalfa and sudangrass were both terminated by tillage before establishment of wheat. To determine the effect of the preceding crop (alfalfa vs. sudangrass/wheat) on wheat N requirement, we applied N fertilizer rates to the wheat ranging from 0 to 250 lb N ac^{-1}. Besides N fertilization, the wheat was grown using standard farming practices for the region. When the wheat reached the soft dough stage, plots were harvested to determine aboveground biomass. Subsamples were taken for determination of plant moisture and N content. At maturity, wheat was harvested, and grain yields, grain moisture content, and grain protein content were determined. The experiment was repeated in 2014 in different plots at the same locations.

Soil nitrate-N levels (0-12 inch depth) in the fall of 2013 were 5-7 ppm NO_3-N in plots that had just been in alfalfa and 0.5-4 ppm in plots following the sudangrass-wheat rotation. Similar levels were observed in 2014. This soil nitrate difference between the two rotations was consistent across the three locations.

Wheat aboveground whole plant biomass and N Uptake

In plots receiving no N fertilizer, wheat whole-plant above-ground biomass was higher following alfalfa than following sudangrass-wheat for all location-years (Figure 3), indicating that, as expected, the alfalfa contributed more plant-available soil N than did the sudangrass-wheat rotation. At Davis, Tulelake, and Kearney, wheat following sudangrass-wheat required 100-150 lb N ac^{-1}, 100-150 lb N ac^{-1}, and 50-100 lb N ac^{-1}, respectively, to produce the same amount of biomass as wheat grown without N fertilizer following alfalfa. Additionally, at Davis, wheat biomass following alfalfa was the same regardless of N fertilization levels for both years, indicating that alfalfa likely satisfied a high proportion of the wheat's N needs there.

Indeed, nitrogen uptake data from the wheat biomass suggest that, in plots at Davis receiving no N fertilizer, wheat following alfalfa assimilated 80-100 lb ac^{-1} more N than wheat following sudangrass-wheat (Figure 4). In order to sequester this additional 80-100 lb N ac^{-1}, the wheat following sudangrass-wheat needed about 114 lb N ac^{-1} and 96 lb N ac^{-1} fertilizer in plots planted to wheat in 2013 (Figure 3, top) and 2014 (Figure 3, bottom), respectively. Similarly, for 0 N plots following alfalfa in plots planted to wheat in 2013 and 2014, 119 lb N ac^{-1} and 125 lb N ac^{-1}, respectively, were required for wheat following sudangrass-wheat at Tulelake to achieve similar levels of N uptake, and at Kearney, 82 lb N ac^{-1} and 51 lb N ac^{-1} were required.

From these N uptake data, alfalfa's N contribution to irrigated wheat in a semiarid climate might range from 50 lb N ac^{-1}, as observed at Kearney, up to 125 lb N ac^{-1}, as observed at Tulelake.

CONCLUSIONS

Alfalfa's N contribution ranged from about 50 lb N ac^{-1} at Kearney to about 125 lb N ac^{-1} at Davis and Tulelake, but there was evidence of contributions above 120 lb N ac^{-1} at Tulelake. Calculations using different metrics or different methods could yield slightly different results. These results were higher than expected, but correspond well with results from research in Spain for irrigated plots in a climate similar to California's (Ballesta and Lloveras, 2010; Cela et al., 2011). Wheat grain protein was also significantly improved in rotation with alfalfa at most location/years, indicating a benefit for quality as well as yield.

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Nitrogen Management in Almond Orchards

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Abstract

Historically, N management in almond orchards has been based on leaf sampling in late summer and comparison with established critical values. While this approach is a valuable tool for diagnosing deficiencies it is inadequate as an N management strategy since samples are collected too late in the season and this method is not sensitive to over fertilization. Importantly, leaf sampling and analysis does not provide specific N fertilization guidelines. To provide an alternate approach to N management and sampling for almond a long term experiment was conducted from 2008 to 2014 to determine the rate and time of N demand of almond crop and to develop support tools for N management in almond. In almond, fruits are the greatest sink for N representing over 90% of the total N demand. N export in 1000 lbs kernel yield (including all fruit parts) varied from 53 to 74 lbs depending upon the N status of the trees and yield with an average of 68 lbs N exported in every 1000 lbs kernel yield for trees with optimum N status and yield. The pattern of root growth and N demand during the season and strategies for early season leaf sampling were also developed and an integrated approach to N management will be discussed.

Introduction

Application of nitrogenous fertilizers to tree crops at time when not needed or in excess of crop demand results in leaching of nitrate below root zone if followed by heavy rainfall and irrigation. In many parts of California, nitrate levels in ground waters exceed the EPA standard of 45 ppm nitrate in drinking water due to over fertilization (Burow et al., 2008; Viers et al., 2012). Historically, nutrient management in the majority of crops has been based on monitoring of tissue Critical Values (CVs). Critical Value is defined as the nutrient concentrations in a standard leaf sample at which yield is ninety percent of maximum yield (Ulrich and Hills, 1990). As a standard, leaf samples in almond are collected in mid-July, analyzed and the values are compared with the established CVs. CVs were developed for July due to the fact that nutrient concentrations are least variable at this stage. However, when samples are collected in July and the analyses are performed, it is too late to respond if there is nutrient deficiency. Also this method does not provide specific guidelines on how to respond to deficiencies. Further, leaf nitrogen status in almond is not sensitive to over fertilization and consequently has resulted in over application of N fertilizers. In a survey of almond growers to access their plant mineral nutrition practices (Lopus et al., 2010), over 70% of respondents regarded leaf sampling and critical value analysis to be inadequate to ensure maximum productivity. This is consistent with the knowledge that CVs were originally developed only as a tool to diagnose deficiencies and their use as a primary means of nutrient management was never explicitly recommended.

In many annual and high value crops, application of fertilizers is based on demand estimation and nutrient uptake dynamics and model of plant growth, however these protocols had not been developed for almond. The objectives of this experiment were to develop protocol for N management in almond based on whole tree N demand and uptake pattern to guide the right rate, right time and right placement of N fertilizers and to develop in-season N monitoring tools that could be used by growers to optimize production, reduce nitrate movement to ground waters and increase N use efficiency.

Materials and Methods

To estimate the demand and seasonal pattern of N in almond, to study the nutrient uptake dynamics, root growth pattern, and to develop in-season N monitoring protocol, a long-term field experiment was conducted in a mature (8-13 years old) almond orchard from 2008 to 2014. The development of an early leaf sampling protocol was conducted in an additional 5 orchards across California during this same period (for details see Saa et al, 2014 and Muhammad et al, 2014)

The quantity and time of N accumulation in fruits and whole trees was studied in mature Nonpareil trees under four nitrogen rates (125 lbs., 200 lbs., 275lbs. and 350 lbs. per acre) from 2008 to 2012. Fruit samples were collected five times during the season and biomass and N concentration in the fruits was determined. Trees from N rates were excavated at the beginning and end of two seasons to determine changes in tree perennial biomass. Samples from all perennial organs were collected throughout the season by coring and subsampling from sixteen trees and N concentrations was determined to derive the seasonal total tree N accumulation in perennial biomass. The seasonal patterns and depth of root growth were investigated over a 2-year period utilizing soil excavation and mini-rhizotrons and taking photograph of root growth at biweekly intervals. To predict July leaf nitrogen from early season samples, leaf samples from individual trees in four mature commercial orchards was collected (n =1148) for three consecutive seasons and analyzed for macro and micronutrients to develop nitrogen prediction models and to estimate the distribution of N values in orchards in July. Spatial variance analysis was used to determine optimal sampling strategies.

Results

The results showed that over 90% of the N was accumulated in the fruits (Figure 1) whereas a small portion of the annual N was partitioned to leaves and the perennial organs. N in the perennial biomass declined from dormancy to March 12 and then increased whereas fruit N accumulation progressed at high rate early in the season and then at lower rate. By March 12, N accumulation in fruits was equal to N decline in perennial biomass. Thus flowering, fruit set and early leaf and fruit growth were entirely dependent upon the stored N in perennial organs.

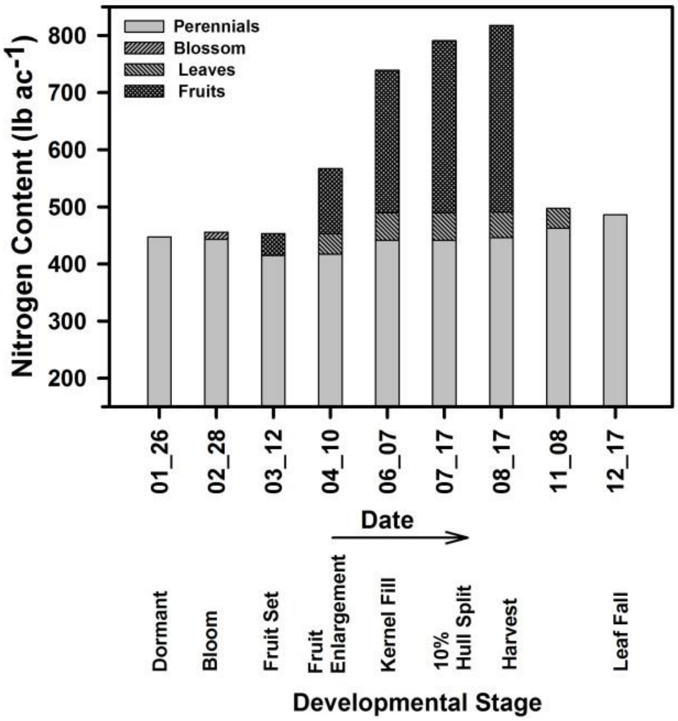

Figure 1. N partitioning in the perennial and annual organs during the season.

N accumulation in fruit varied from 53 lbs to 75 lbs N in fruit per 1000 lbs kernel yield between N rate treatments and between years depending upon the N status of the trees (Table 1). The lowest N export in fruit per 1000 lbs kernel yield was observed for 125 lbs per acre N rate in all years of the experiment. The 275 lbs per acre N rate that produced highest yield in this experiment and had optimum leaf N status, exported 61 lbs, 59 lbs, 73 lbs and 74 lbs N per 1000 lbs kernel in 2008, 2009, 2010 and 2011respectively.

Of particular significance is the observation that the increase in N application from the N rate associated with optimal yield (275 lbs.) to the higher rate (350 lbs.) resulted in no increase in yield and no increase in N removal from the orchard and no significant increase in tree N storage. The implication of these results is that N application in excess of tree need is not taken up by the tree and will remain in the soil where it will build up and potentially be lost from the soil if a leaching event occurred.

Table 1. Nitrogen export (lbs) in fruit per 1000 lbs kernel yield in almond from 2008-2011. Letters indicate significant differences within the same year at < 0.05 level of significance.

N rate (lbs ac^{-1})	2008		2009		2010		2011	
125	56	c	53	b	55	c	54	c
200	59	bc	56	ab	61	b	65	b
275	61	ab	59	a	73	a	74	a
350	62	a	60	a	70	a	75	a

The pattern of N accumulation in fruits varied slightly between years (Figure 2) depending upon climatic conditions. Overall, thirty percent of the total N in fruits was accumulated by 43±3 days after full bloom which coincided with full expansion of spur leaves. 60% N accumulated in fruits by 86±3 DAFB (between full leaf expansion and kernel fill) and 88% by 123±3 DAFB (10 % hull split) and 12% between 123±3 DAFB and harvest. The majority of nutrient accumulation in fruit coincided with kernel filling.

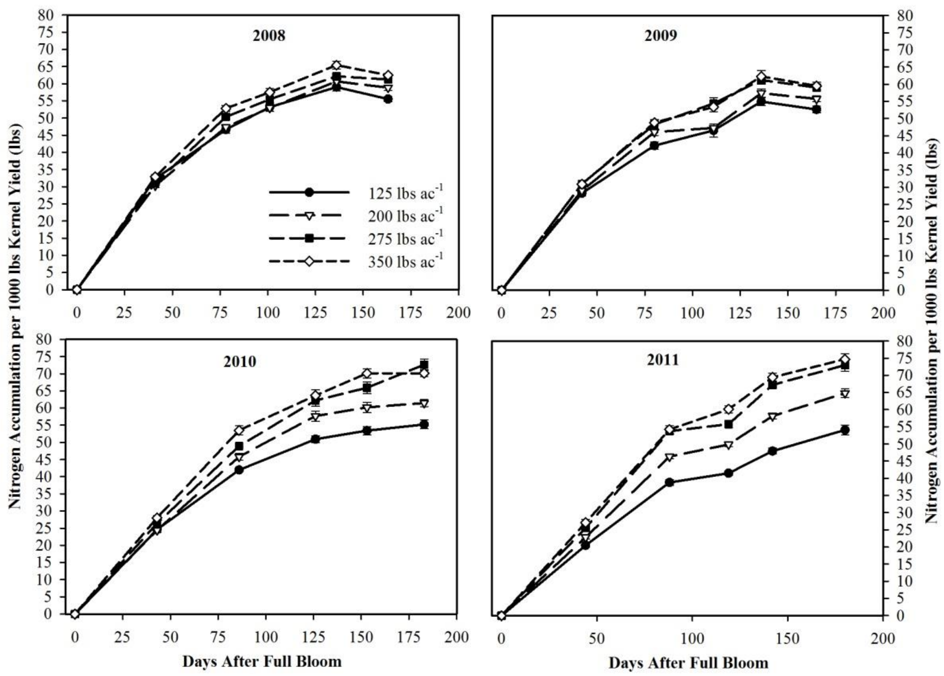

Figure 2. Nitrogen accumulation in fruit over the season per 1000 lbs kernel yield, 2008-2011. Each point represents the mean and bars show standard error of the mean.

Patterns of root growth over the season derived from the minirhizotron tubes showed a consistent dual cycle growth pattern, irrespective of year and N treatments (Figure 3). The majority of new roots were produced at two growth phases during the year (spring and fall). Spring root growth, occurring from mid-March to June was significantly higher than the fall growth, mainly occurring from mid-September to December. New root growth was very limited from June through September. There was very little root growth prior to leaf out with the predominant root growth period occurring after 70% leaf out. The difference in root growth between the two years is unexplained.

Patterns of root growth distribution by soil depth were studied by determining the number of new roots produced per 0.2 m interval (figure 4). There was no significant difference in root distribution or density between treatments. Despite, the wide variation in the amount of roots between years (figure 4, top graph), the percentage of roots per depth interval was similar. Virtually all the root growth was observed within 1.4 m depth, and 60-65% of the new roots were produced in between 0.2 and 0.6 m.

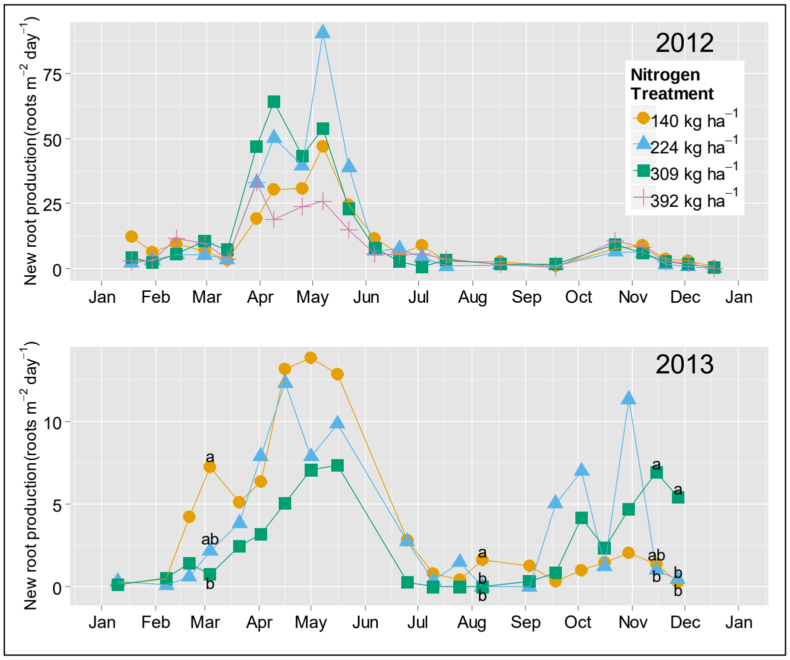

Figure 3. Number of new roots produced during the growing season in Experiment 1: N rate experiment. Note differences in scale used in these figures.

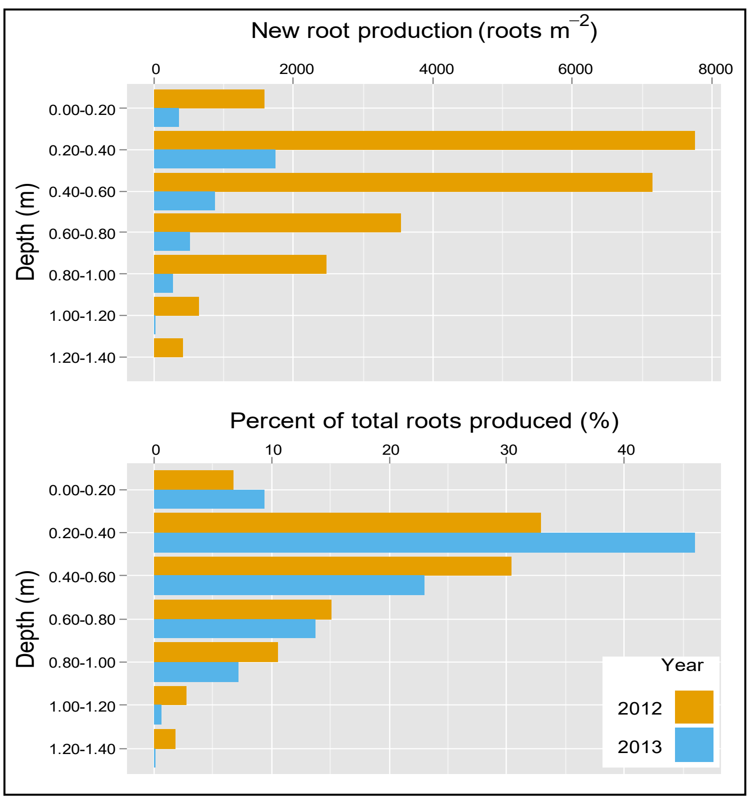

Figure 4**:** Root production with depth over two years expressed as total new root length per meter square of soil surface (top) and as percent of total root length (bottom).

Use of early spring leaf analysis to predict leaf N in July showed that leaf nitrogen concentration in summer can be predicted (r^2=0.9) from the leaf N and B concentration in spring with the sum of K, Ca, and Mg equivalents. Mean field leaf nutrient concentrations can be obtained by collecting one pooled sample per management zone composed of 30 trees each of which are at least 30 m apart. Using these methods the percentage of trees with leaf N above the recommended July critical value can be predicted accurately.

Discussion

The results of the experiment showed that fruits are the major sink for N in mature almond with over 90% of N accumulating in fruits. Mature almond tree has limited vegetative re-growth and majority of the tree N is partitioned to fruits. Small quantities of N are also partitioned to leaves and some is used for perennial growth, however the N in leaves is either remobilized during leaf senescence or recycled in soil with leaf fall. On average, 68 lbs N per 1000 lbs kernel yield was exported in fruits in trees with high yield and optimum N status. N requirements of the flowers, fruit set and initial leaf growth is fulfilled by N stored in the perennial organs and 30-35 lbs per acre N was stored in the perennial organs. N uptake from soil did not start until 70% leaf out (two week post bloom) which coincided with the commencement of root growth. This suggests that almond trees cannot up take N from the soil unless root become active and any fertilizer N applied before this time has the potential to leach below root zone, especially in areas with heavy early spring rain fall.

N fertilizer decisions in almond orchards should be based on N export in expected yield with applications matching the seasonal demand of the trees. Based on the seasonal N partitioning in fruits, we suggest applying 30% of the annual N demand from two weeks after full bloom until full leaf expansion, 30% of the total annual demand from full expansion of spur leaves until shell hardening, 28% of the total N demand during nut fill (May to July) and 12% of the demand soon after harvest. If postharvest N is applied late in the season there may not be enough root uptake and any nitrate remaining in soil has the potential to leach below root zone with rainfall during winter. In areas with high early spring rainfall N fertilizer applications can be delayed to avoid nitrate leaching or can be applied in split to increase uptake.

Early spring leaf samples can be collected to accurately predict the N status of the trees in July. Based on the information of this experiment, a leaf N prediction model has been developed (http://ucanr.edu/sites/scri/Crop_Nutrient_Status_and_Demand__Patrick_Brown/). The experiment improved leaf sampling technique for almond growers by providing the means to sample early in the season, to use that data to estimate July N and to predict the percentage of trees that will be above certain critical value in July. Once N is applied according to estimated crop demand, leaves can be sampled at 70% leaf out (about 43 days after full bloom) and the N status of the trees in July can be predicted and the N fertilization program can be adjusted accordingly. A model that integrates the findings of this research and interpret early leaf N samples is available for free public use at http://www.almonds.com/nutrients.

Conclusions

N in almond should be applied according to estimated yield with time matching crop demand. N uptake from soil is limited until active root growth start which coincides with 15 days post full bloom and any fertilizer applied earlier has the potential to leach below root zone if followed by irrigation or heavy rainfall. Fertilizer should be applied in many fertigation events to avoid leaching of nitrate. Leaf samples collected at full expansion of spur leaves can be used to predict N status of trees in July and N management program can be altered accordingly if July N status is predicted to be excessive or deficient. A model that integrates the findings of this research and interpret early leaf N samples is available for free public use at http://www.almonds.com/nutrients.

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Nitrate leaching and mitigation methods in annual crops

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Nitrate leaching from irrigated agriculture has been an environmental concern in California for decades. However, serious regulatory pressure on growers to limit nitrogen losses from their field operations has only recently been imposed. Both the Central Valley (Region 5) and the Central Coast (Region 3) Water Quality Control Boards have adopted regulatory programs that require growers to track and report nitrogen inputs. This information will be used to estimate a *nitrogen balance*, comparing the amount of N applied to fields with the amount of N estimated to have been removed from fields in harvested products. The greater the imbalance between applied N and N removed in harvested products, the greater the potential for N loss to the environment. Growers who consistently show a large imbalance between N application and harvest N removal are likely to come under increased regulatory scrutiny. Although there are a number of ways in which agricultural N can be released to the environment [release of N_2, nitrous oxide (N_2O) and ammonia (NH_3) gases to the atmosphere, nitrate movement into surface water, etc.], the current regulatory focus is on nitrate-nitrogen (NO_3-N) leaching to groundwater.

There are several lines of evidence suggesting that leaching is a primary N loss mechanism in many annual cropping systems in California. Direct measurements of nitrate leaching have been made in coastal lettuce and strawberry fields (Cahn, 2010, 2013). Significant seasonal nitrate losses were observed, with both irrigation and nitrogen fertilizer management having major effects. Nitrate concentration of tile drainage provides a surrogate estimate of potential N leaching, since water reaching tile drains has moved below the crop rooting zone. Letey et al. (1977) measured tile drainage from a number of vegetable and row crop fields in the Central Valley, the Salinas Valley and the Ventura-Oxnard area. They found that NO_3-N concentration often exceeded the Federal 10 PPM drinking water standard, and sometimes exceeded 100 PPM; combined with estimated tile drainage volume, they calculated that annual N leaching losses exceeded 100 lb/acre at a number of sites. Los Huertos et al. (2001) found that the nitrate concentration of drainage ditches in the Pajaro Valley receiving substantial inflows of tile drainage often exceeded 50 PPM NO_3-N. Hartz et al. (2012) reported that tile drainage from two Salinas Valley vegetable farms ranged from approximately 60-180 PPM NO_3-N across 2 years of monitoring.

That leachate concentrations are often in the range of 50-100 PPM NO_3-N is not surprising. Fertilized root zones of annual crops are often 10-30 PPM NO_3-N on a soil dry weight basis. However, all soil nitrate is in the soil solution, which in a mid-textured soil weighs only about 25% as much as the dry soil. This means that the NO_3-N concentration in the soil solution is about 4 times higher than if expressed on the basis of dry soil weight; in this example, the soil solution would be in the range of 40-120 PPM NO_3-N. Even when diluted by irrigation water, leachate will usually be substantially above the 10 PPM NO_3-N environmental target for groundwater.

Of course, NO_3-N concentration is only half the story. Leachate volume is also important; a very low volume of high nitrate concentration may represent a smaller environmental N load than a high volume of lower nitrate concentration. However, even where irrigation is managed efficiently, leachate volume will often be at least 10% of applied water, and high nitrate concentration usually represents a significant environmental N load.

In minimizing the potential for nitrate loading to groundwater a strategic approach similar to the Hazard Analysis Critical Control Point (HACCP) system widely used in the food industry to improve microbial food safety can be useful. In this approach the characteristics of a particular cropping system are carefully evaluated to identify practices that may cause undesirable effects, in this case leaching of soil nitrate. Annual cropping systems in California are very diverse, and therefore the important 'control points' may differ among cropping systems. The following examples illustrate some of these differences.

Leafy greens production

In coastal districts leafy greens (lettuce, celery and *Brassica* crops) are intensively farmed, with fields typically producing 2-3 crops per year. Historically, production was accomplished with sprinkler and furrow irrigation, with calendar schedules for N sidedressing timed around cultural requirements (thinning, cultivation, spraying, etc.). The widespread adoption of drip irrigation has opened opportunities for improving N efficiency, both by freeing N application from cultural constraints, and by improving water management. An analysis of current conditions reveals several features of this production system that offer opportunities for improvement. First, these crops leave from 30% (celery) to 70% (broccoli and cauliflower) of crop N in the field as residue. This residue is high in N, and readily breaks down following soil incorporation, providing plant-available N to the following crop. Second, irrigation wells in this region often contain significant NO_3-N concentration (10-20 PPM is common); this can represent 40-100 lb N/acre/year in irrigation, occasionally more. Not surprisingly, in fields where irrigation is well managed, significant amounts of soil NO_3-N may carry over from previous crops.

These facts suggest three practices that could improve N efficiency. Careful control of sprinkler irrigation to germinate a crop is crucial to avoid leaching soil NO_3-N carried over from the previous crop. Post-establishment soil sampling before N application can identify fields in which N fertilization can be delayed or reduced. Crediting the NO_3-N content of irrigation water against the assumed N fertilizer requirement can reduce overall N input. Field trials demonstrating these three practices have shown that typical N fertilization programs can be reduced substantially in many fields.

Strawberry production

The majority of California strawberry fields receive a preplant application of control release fertilizer (CRF), which can represent 50% or more of seasonal N application. While the use of CRF may appear to be a 'best management practice', an analysis of this cropping system suggested otherwise. Strawberry planting occurs in the fall in the Santa Maria and Salinas districts, but rapid growth of the transplants does not occur until February-March. Furthermore, most strawberry fields are coming out vegetable rotations, and there is typically high residual soil NO_3-N at planting. The most common CRF products used have a 6-8 month release rating, meaning that the majority of the N is released before the crop can take it up. Not surprisingly, studies have shown that the majority of the annual nitrate leaching loss from strawberry fields occurred during the winter, and that reduction or elimination of preplant CRF had minimal effect on crop productivity (Cahn, 2013; Bottoms et al., 2013, 2014).

Wheat production

A common feature of wheat production north of the Delta is relatively high preplant N application. This practice is attractive to growers because relatively low cost N sources can be used, and application is easy. However, applying high rates of N pre-plant can result in reduced grain protein content because soil NO_3-N availability becomes limiting before the crop reaches the grain filling stage, which is the critical time in determining grain protein. Additionally, high early rates of N fertilization may cause excessive vegetative growth and lodging. While it may be counterintuitive in an area in which winter rain can be substantial, the need for preplant N is actually quite modest. Recent research has demonstrated that reducing preplant N in favor of N application at tillering or beyond can both improve yield as well as increase grain protein content.

As growers confront more aggressive regulation of nitrogen management, critical analysis of their current irrigation and fertilization practices can help identify modifications that will improve N efficiency, and reduce the potential for nitrate leaching loss.

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American Society of Agronomy
California Chapter

Session 4

Land and Water Suitability

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Statewide Crop Mapping and Applications For Nutrient and Water Management

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Introduction

As part of a joint project by the Almond Board of California (ABC), the California Walnut Board (CWB), the California Pistachio Research Board (CPRB), and the California Dried Plum Board (CDPB), Land IQ was contracted to map the four respective tree crops on an orchard by orchard basis. Subsequently, Land IQ has added in other crops in an effort to cover large areas of the Central Valley with comprehensive crop mapping. This work established an cropping year. Accuracies are in excess of 95 percent for all tree crops. Young orchards (<3-4 years depending on tree type) are classified separately and acreages estimated based on distribution determined through ground truthing efforts.

This report demonstrates the almond, walnut, pistachio, and dried plum results for the state of California. Age estimation on an orchard by orchard basis was determined for almonds, walnuts, and pistachios through additional remote sensing analysis. Dried plum age analysis was not a part of this initial effort. Applications of these base layer mapping results are numerous. Examples include: nutrient management, water management, biomass estimations, regulatory support including Irrigated Lands Regulatory Program (ILRP) and Sustainable Groundwater Management Act (SGMA), crop production estimates, market analyses, crop forecasts, various spatial analyses, environmental impacts, etc.

Objective

The primary objective of this project was to produce a statewide spatial database of specific crop mapping with accuracies exceeding 95% (on an acreage basis) using remote sensing, statistical, and temporal analysis methods. This database provides timely, consistent, and comprehensive information on the location, extent, and acreage of specific crops throughout the state of California for a baseline year of 2014. The approach utilized to produce this baseline database lays the groundwork for less intensive updating of the spatial database in subsequent years.

Summary

Accurate and current information on constantly changing acreage and location of crops is critical for environmental, market, and production applications. Growers and commodity groups need to understand the impacts of land use, crop location, crop change, acreage, tree age and best management practices on environmental attributes and impacts such as water quality, air quality, disease, and/or pest vectors. Conversely, environmental factors, such as climate change and sensitive habitats, increasingly influence how much and where these crops are grown. For these purposes, as well as many others, a spatial mapping base layer is integral for effective decision-making and other applications.

In response to this need for information, this project was undertaken to initially develop an accurate spatial database of almonds, walnuts, pistachios, and dried plums (amongst other crops) for the 2014 growing season throughout the state of California. Results indicate that accuracies exceeding 95% have been achieved in a timely and cost-effective manner using our remote sensing crop mapping methodology in combination with agronomic knowledge, ground truth data, and an overall comprehensive field-by-field approach. Significantly, this project paves the way for cost-effective updates of the inventory over time using focused remote sensing change analysis methods. Recommendations are that a now more simplistic update of the database occur on an annual or every 1-2 year basis. Updates will identify changes in crop acreages and locations.

Approach

Data specifically developed, enhanced, or used by Land IQ for the mapping project included:

- Integration of agronomic/crop production knowledge
- Detailed ground truth information
- Analysis of multiple image resources

This analysis was conducted at the field scale (Figure 1). Individual fields (not parcels, but rather homogeneous crop types representing true irrigated area) for permanent crops statewide (Figure 2) were used so that each independent management unit could be analyzed independently and assigned to a crop class. The result represents the true irrigated area and not legal or other, less detailed boundaries that may be available elsewhere.

Ground truth data was collected during the 2014 growing season in the field for use in the mapping analysis and also to provide an independent dataset for accuracy comparisons (Figure 3). Approximately 8-12% of all irrigated land in the state was collected. Ground truth data collected during 2012 and 2015 were also integrated into the analysis and accuracy assessments.

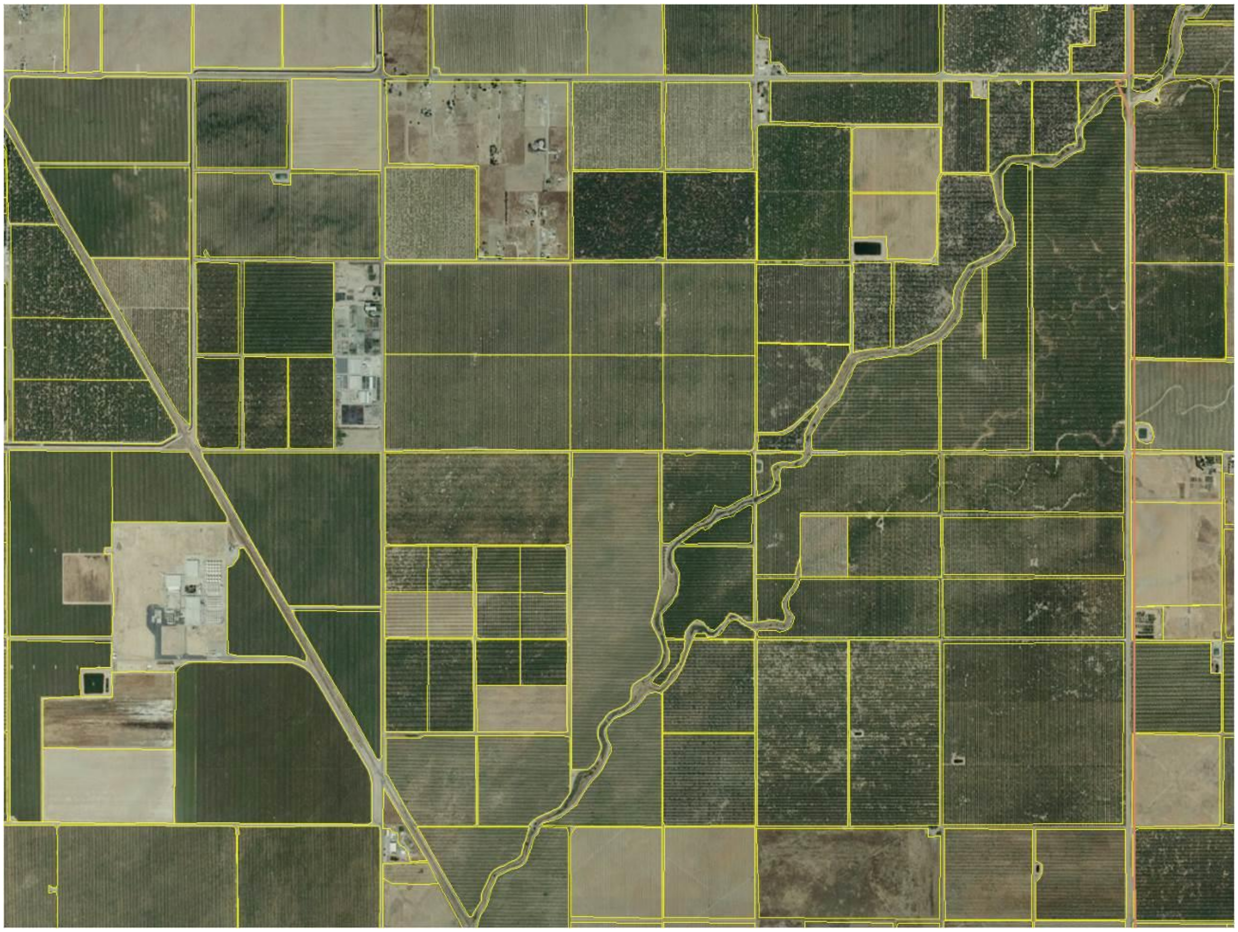

Figure 1. Example of field boundaries.

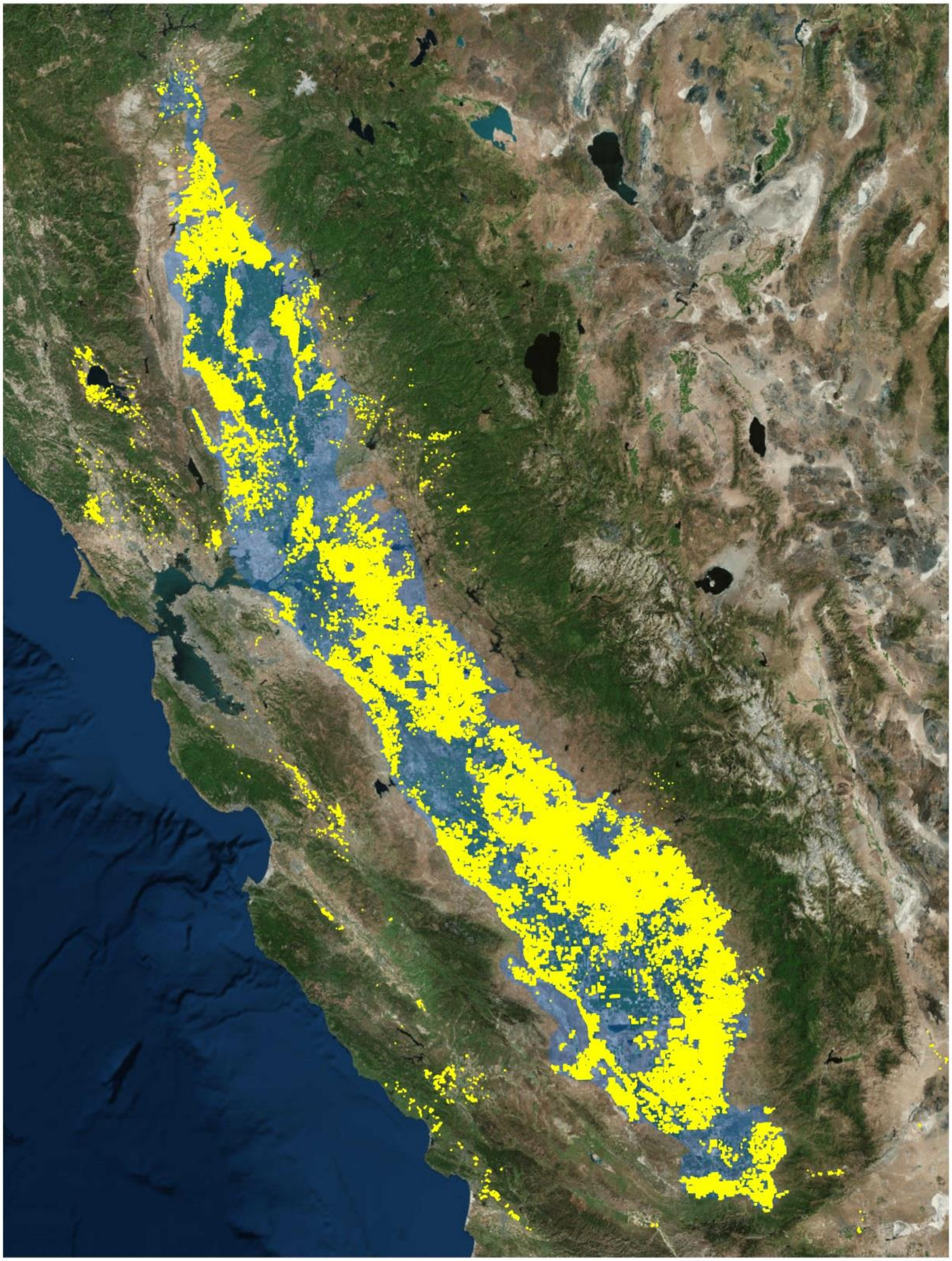

Figure 2. Example of permanent crop fields for the entire state.

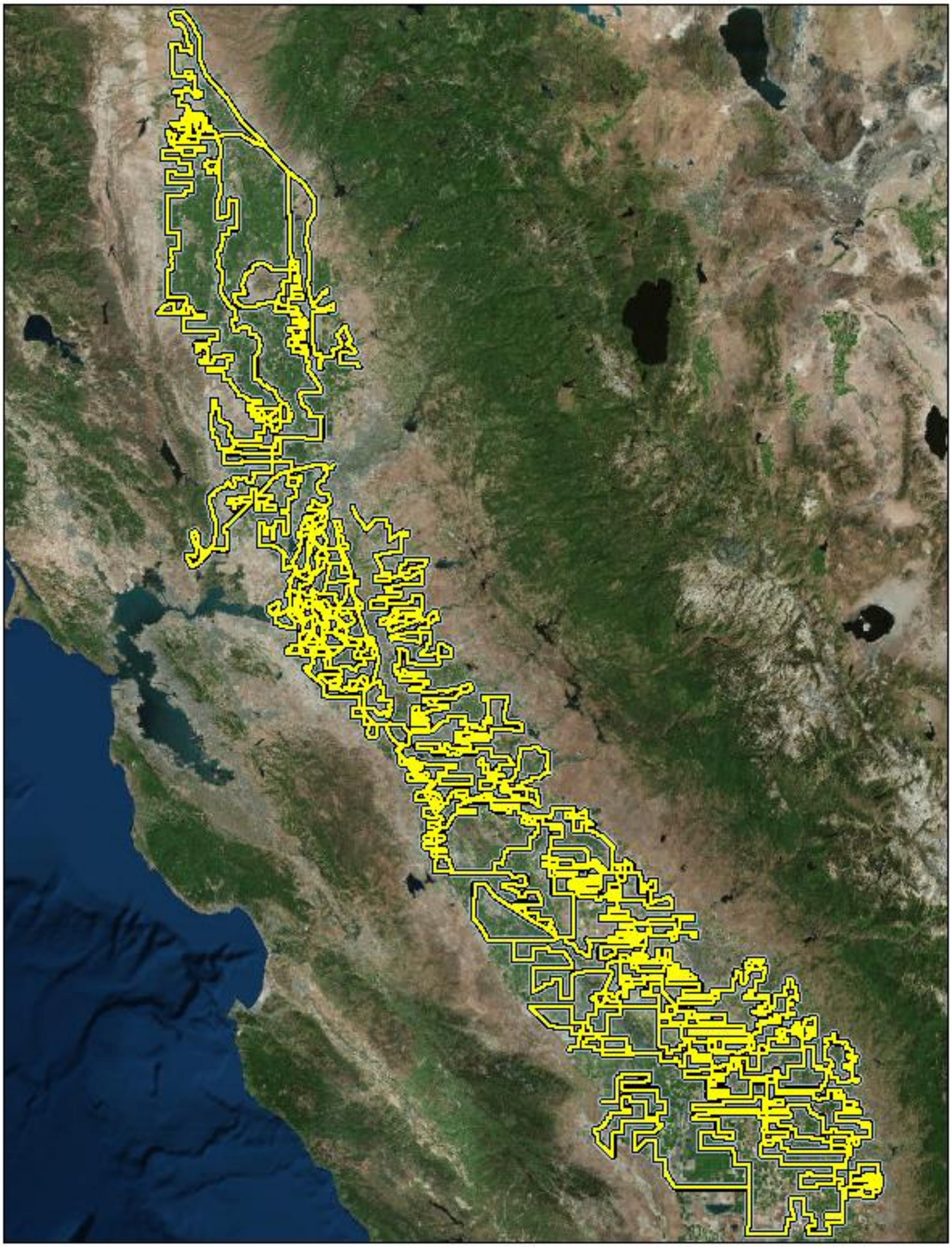

Figure 3. Example of Central Valley ground truth data collection route map.

Counties mapped include the following:

- Butte
- Calaveras
- Colusa
- Contra Costa
- Fresno
- Glenn
- Kern
- Kings
- Lake
- Madera
- Merced
- Placer
- Sacramento
- San Joaquin
- San Luis Obispo
- Shasta
- Solano
- Stanislaus
- Sutter
- Tehama
- Tulare
- Yolo
- Yuba

The remotely sensed crop mapping methodology utilized for this project involved analysis of multiple image sources that encompass a range of spectral characteristics, spatial resolutions, and temporal representation of the crops of interest. These methods were derived from and guided by our understanding of agricultural systems, landscape processes, production systems, and crop phenology.

Results and Applications

Classification of almonds, walnuts, pistachios, and dried plums (in addition to other crops) was conducted jointly and has been completed for the 2014 growing year. Completion of this dataset occurred during the third quarter of 2015. It is expected that updates to this dataset for future years can be completed within the same growing year or early during the first quarter of the following year. For example, 2016 update mapping results should be expected by around December of 2016.

Now that the statewide mapping is complete, spatial results (e.g. almonds, walnuts, pistachios, and dried plums) can be developed and shown in a variety of different ways (Figures 4 and 5) through either GIS or web mapping applications. Applications of these base layer mapping results are numerous. Examples include:

- Water use estimations and analyses – Understanding true irrigated acreage removes or greatly reduces variability of erroneous estimates. When acreage is accurately known, including location and age, estimating crop consumptive use with both empirical and remotely sensed methods can be conducted with more certainty and less error.

- Regulatory support including Irrigated Lands Regulatory Program (ILRP) and Sustainable Groundwater Management Act (SGMA) – It is critical that common base data are used during regulatory compliance and monitoring. These base layer data offer an opportunity for unification of land use classification throughout the Central Valley.
- Biomass estimations – Although age analysis for dried plums was not conducted, it can be completed fairly easily. The resultant data classifies each individual orchard into an age category and a correlation to biomass accumulation can be conducted.
- Proximity analyses – A variety of proximity analyses can be conducted comparing the base layer crop distribution to other publically available data resources. These may include other crop types, hydrologic systems, watersheds, sensitive environments, etc.
- Crop production estimates – Different regions of the state are known to have different yield potentials. With a unique base layer dataset comprised over the entire Central Valley for one year, a more accurate crop production estimate can be forecasted.
- Market analyses – Age determination, location, crop density, and comparison to soil type, available water resources, etc. are all key information that can be used to better determine potential crop volume as well as
- Other spatial and trend analyses – These analyses could include location change evaluations, tree density analysis, vegetative cover analysis, irrigation method relationships, etc.
- Environmental impact analyses – These analyses could include impacts of climate change, chilling hour analyses, pest infestations/management, etc.

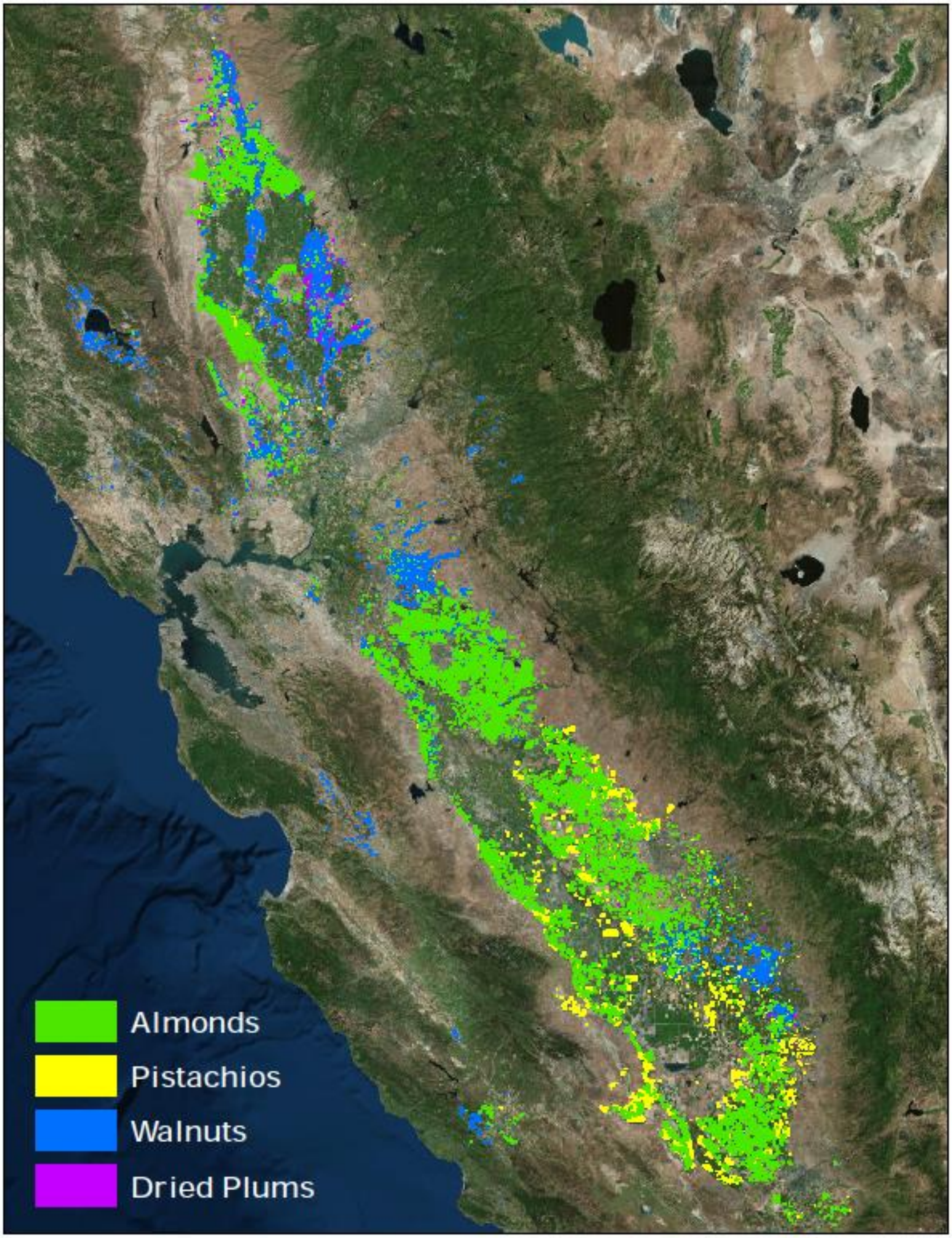

Figure 4. Statewide spatial distribution of almonds, walnuts, pistachios, and dried plums.

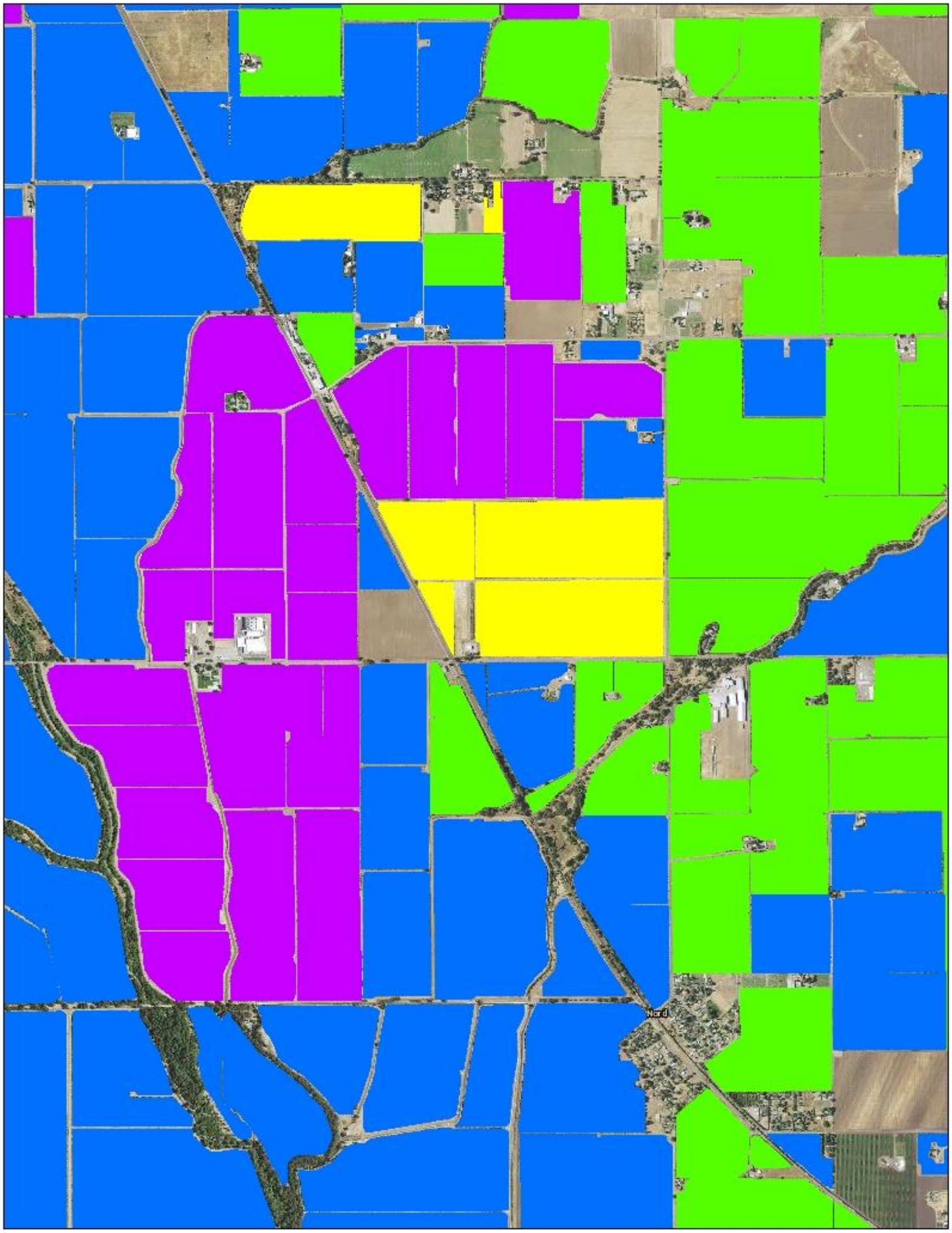

Figure 5. Example of individual mapped orchards for all four tree crops (almonds=green, walnuts=blue, pistachios=yellow, dried plums=purple)

Soil and Water Considerations and Sampling for New Orchards

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Given the history of available canal water over the last 10 years I figure I will have to rely on groundwater for at least 50% of the irrigation water for my new orchard. How do I assess the factors and management strategy necessary for a successful development?

The manager of a well producing orchard has one of the most difficult engineering jobs on the planet. Figure 1 below describes the interaction of the natural to engineering factors a grower must deal with to achieve this level of optimal production. This paper will deal only with the assessment of the natural factors and general salinity tolerance of the proposed crop.

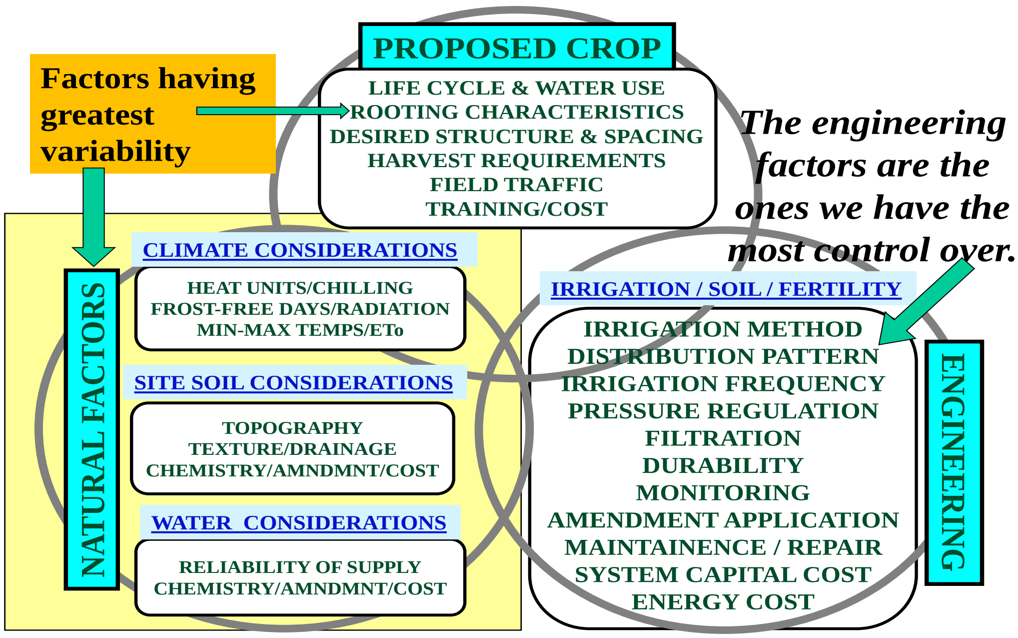

Fig. 1. Schematic of interacting factors affecting irrigated crop development.

<u>Strategy 1:</u> 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) 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. Wells should be run for at least 2 hours if possible before taking a water sample. The local water district should have running canal water quality records.

Table 1. Guidelines for water quality for irrigation[1] (Adapted from FAO Irrigation and Drainage Paper 29)

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

[1] Adapted from University of California Committee of Consultants 1974.

[2] 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.

Strategy 2.a.: 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:

Relative yield (%) = 100 – 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 calculation. 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 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.

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_{thresh} (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

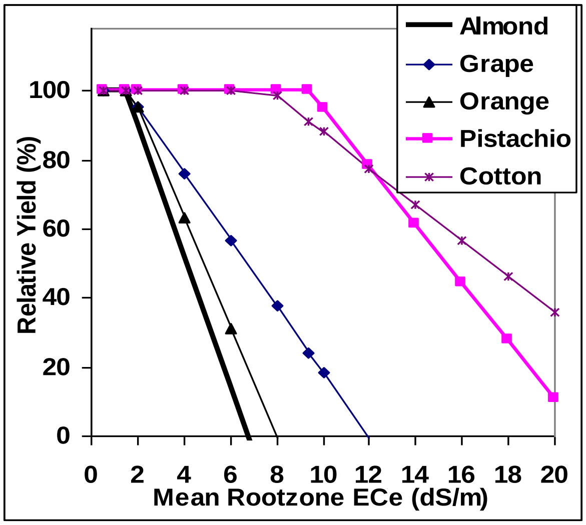

Fig. 2.a. Relative yield (RY) of various crops as a function of soil EC_e . (Symbols on lines are for legend identification and do not represent specific data points. Sanden, et.al., 2004)

Figure 1 shows various permanent crop relative yield as a function of soil salinity ($EC_{extract}$) 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.

__Strategy 2.b.:__ **Take all tolerance curves and thresholds with a grain of salt!** The reduced pistachio tolerance shown in Table 2 compared to Figure 1 is recent data resulting from a more extensive 10 year trial (Figure 2.b.) and similar to the 2014 yield decline measured in saline areas of 9 other Kern County fields.

Figures 3.a. and b. illustrate individual tree almond yields for Nonpareil on Nemagard rootstock for a uniform 10th-13th leaf orchard in western Kern County irrigated with

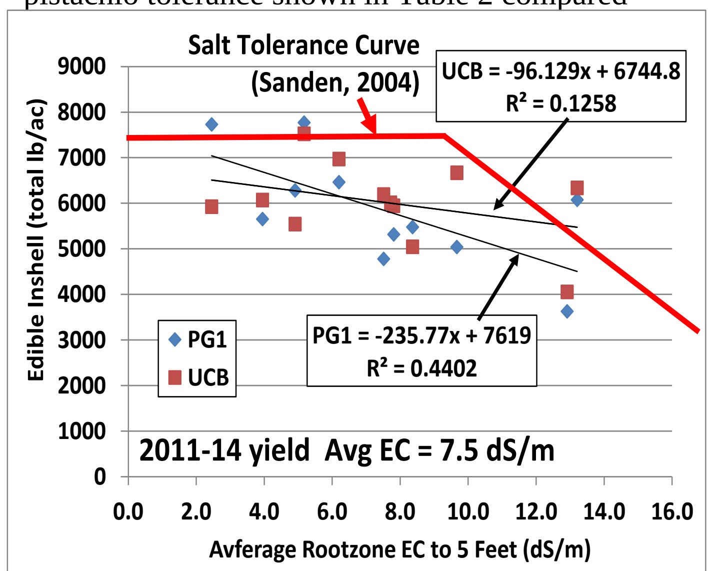

Fig. 2.b. Starrn trial 2011-14 combined pistachio yield by salinity for PG1 and UCB rootstocks (For PG1 $P<0.01$)

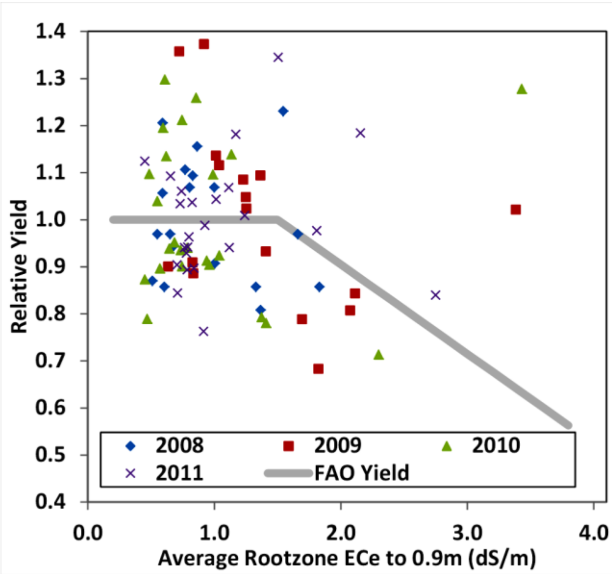

Fig. 3.a. Relative kernel yield as a function of average rootzone salinity (0-0.9 m) for all years and the “classic” almond salt tolerance curve (Ayers and Westcott, 1985).

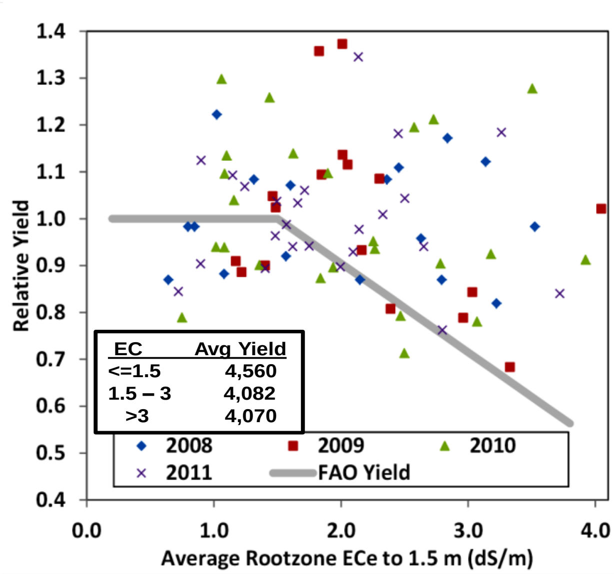

Fig. 3.b. Relative kernel yield as a function of average rootzone salinity to 1.5 m for all years and the “classic” almond salt tolerance curve (Ayers and Westcott, 1985).

California Aqueduct water under extremely efficient irrigation with minimal rainfall and consequent salt accumulation over time – especially in the 4 to 5 foot depths. You can see that the 1.5 dS/m EC threshold (FAO yield) isn’t too bad if you only use a 3 foot rootzone. But this orchard pulled about 30% of its water over the season from the 3 to 5 foot depth so it is appropriate to use soil samples all the way to a 5 foot depth to obtain the average rootzone EC. Doing this we now have a rootzone salinity over 3 dS/m, twice the FAO tolerance threshold, with no yield decline. **POINT:** Continue to search out the most recent salt tolerance data for new varieties and revisions of field research before making a final decision!

<u>Strategy 3:</u> Use soil surveys, Google Earth images and backhoe pits to assess different soil textures and layers across the field

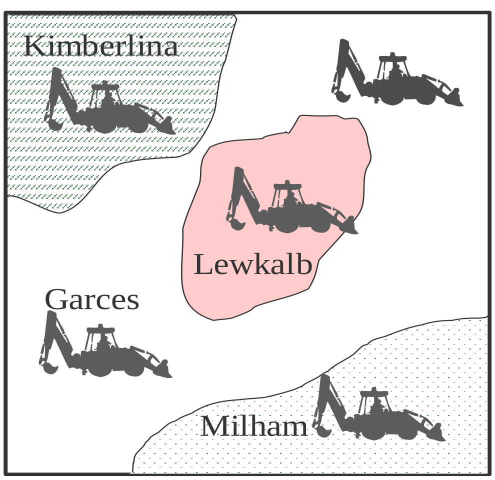

Fig. 4. Soil variability and required sampling areas for a new 160 acre orchard development.

A thorough site evaluation uses a series of backhoe pits in the different zones. Observation pits clearly show the number and types of soil layers, the depth of the layers, and the variability of the subsoil throughout the orchard site. This information can help determine the most economical method of soil modification, how to properly set up and use deep-tillage equipment, and when to what depth tillage is required. One alternative to backhoe pits is the use of a soil probe or auger to pull soil cores for evaluation. Special equipment is required for undisturbed cores (the preferred method), but a common bucket auger can be used by an experienced agronomist/soil scientist who knows what to look for. Using your farm backhoe or even renting one may be cheaper in the end and will be more revealing as the entire profile can be viewed at once. As a rule of thumb, it is advisable to dig at least one backhoe pit per 20 acres. Where possible, locate backhoe pits in areas of the prospective orchard site that have a history of desirable as well as poor growth, for comparison. Samples can be scraped from the sides of backhoe pits by depth and/or extracted with an auger if a backhoe is unavailable or to provide addition coverage for other areas. Bucket augers and various soil sampling probes that enable you to sample down to at least 5 feet are not options – they are necessities. I will do a composite sample in a representative area for each different soil type/area in the field (as shown in Figure 4) 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/reclamation needed (if any) to avoid excessive salt accumulation in the upper 40 inches prior to planting. Soil samples can be stored in paper or plastic bags and should be submitted to a lab that participates in an outside certification program. Several days' storage will not affect the sample analyses as the salt content (except for high nitrate levels) will not change.

Strategy 4: Monitor in-season soil water content, collect & analyze soil and water samples

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 – especially to insure optimal growth in young trees. If marginal or tip salt burn on the crop appears, I will sample two locations doing mid-season composite samples under emitters of the affected trees for the 0-15 and 15-30 depths for a young orchard. One location: (for the two sample depths) in the "average" wetted area (say 1 foot away from the dripper) and the second near the edge of the wetted subbing zone (maybe 3 foot from the dripper) that represents the higher salt accumulation. 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 5: 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 the divide the numbers into 4 ranked groups.

DU = 100% * Average Low Application Quarter / 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** (LF = 1- 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.

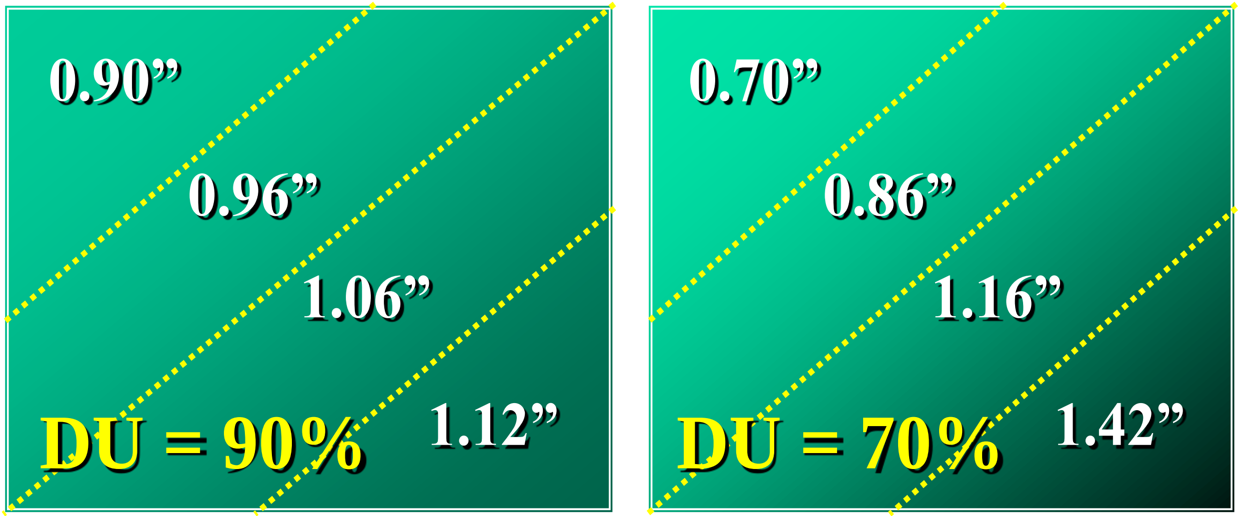

Fig. 5. Conceptual illustration of total applied water for the "wet (high) quarter" compared to the "dry (low) quarter" for a 1 inch/day microsystem design operating at a 90% and 70% DU.

Table 3 below gives the expected long-term rootzone ECe for different irrigation 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:

LF = 0.3086(Desired ECe/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*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 then many Westside growers.

Strategy 6: 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:

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):

Required Leaching Ratio (depth water/depth soil) = K / (Desired EC/Original EC)

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

Required Leaching Ratio (depth water/depth soil) = 0.15/(1.5/4.05) = 0.405

Actual depth of leaching water needed = 0.4055 * 4 feet = 1.62 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 7: Search out information on soils, sampling, soil amendments and infiltration

http://casoilresource.lawr.ucdavis.edu/gmap/
http://fruitsandnuts.ucdavis.edu/photogallery/Soil_Sampling_Video_Series/
http://cekern.ucanr.edu/Irrigation_Management/ANALYTICAL_CONVERSIONS_AND_LEACHING_CALCULATIONS/

The following web links can be helpful for understanding the use of acid, sulfur and gypsum.
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/IMPROVING_WATER_PENETRATION/

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Water Quality Considerations for Nut Crops

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Background

It is no secret that agriculture depends on the availability of adequate, good quality water. Challenges during the California drought of 2014 & 2015 have affected the availability and quality of irrigation water. In many areas the lack of the traditional river water sources forced growers, primarily food producers, to switch to well water to continue their production. The result was to deal with water that is often laden with varying levels of problematic salts. This situation began to degrade the soil and reduce crop quality & yield.

Situation

The Central Valley and Central Coast growing areas of California have many wells providing problematic sodium, chloride, boron, and total salts at detrimental levels. As if this were not enough, dealing with these components is often aggravated by complicating levels of pH, carbonates, bicarbonates, calcium, magnesium, and nitrate. During the recent drought the effect of these levels and complications began to deteriorate the suitability of the farm fields to grow their intended crop.

Growers that identified this situation early were often able to mitigate the accumulation of salts in the soil and maintain the quality of the soil in the root zone. Those who did not monitor their water quality or changing salt loads in their soil now need to identify what corrections are needed. These decisions will vary depending on availability of adequate volumes of well and river water (if available) to improve the situation.

Problematic Levels

Ideally, when salts are applied to the soil, they continue to travel thru the root zone. Growers who systematically controlled the leaching in their soil generally survived well with no significant deterioration of their soil. With poor leaching moderate salt levels in the water will eventually reach problematic levels. With a good, systematic leaching program even relatively high levels of salts can be present without harmful accumulation of salts in the crop.

Controlling Salts

To keep salt accumulation under control in the root zone, timing of "leaching" irrigations is important. Soil preparation and treatment also come into play to keep the salt situation under control. In this presentation I will address the options that may be available.

American Society of Agronomy

California Chapter

Session 5

Water-Related
Management Issues

Session Chairs:

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Dan Munk

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Water Management under Drought Conditions: Strategies for Tree Crops

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Introduction

In recent years, many tree and vine growers have been faced with cutbacks from water districts, and recent studies of weather patterns for the state have also shown that above-average rainfall has occurred over the last 20-30 years. Hence, even a return to normal rainfall may pose a problem of water availability to many growers and water districts. In the event of a severe drought, when the emphasis may be on tree survival rather than on production, growers need information on what options are available in order to plan their strategy. Proebsting and Middleton (1980) reported a 100% survival rate of severely pruned (dehorned) peach trees in WA, compared to some tree death, in a year with 3.4" of rainfall. Goldhamer et al, (1995) evaluated a 16" in-season (+ 4.2" pre-season) irrigation regime on almonds near Fresno, CA, and found the best results with a gradual cutback to 40% ETc by harvest, but a resumption to 60% ETc post harvest. Goldhamer also performed dehorning in almonds as part of another study and found that tree water stress, as measured by predawn water potential, was substantially improved by this practice, and he has proposed that almonds may only require a total of 8-12" ETc in order to survive (Goldhamer, personal communication), but to our knowledge there has been little research into the question of the minimum quantity of water required for tree survival. Goldhamer et al (2006) also compared a number of deficit irrigation levels and deficit timings in almonds, in order to identify stress-sensitive periods in crop development, but found that the highest yields were obtained using a fixed deficit level of irrigation throughout the season. It is likely that grower decisions about the best course of action to take for any particular orchard and soil condition will depend on the level of stress being experienced by the trees, particularly for trees on shallow or variable soils. Some trees may require severe pruning in order to assure survival, but whether or not this would be justified economically will depend on the cost of pruning and the speed of recovery of production from both the pruning effects as well as the drought effects. Clearly, any test of drought survival strategies must consider both in-season effects on yield as well as carryover effects on bloom and yield for an additional 2-4 years.

Materials and Methods

A drought/pruning study was performed in 2009 at the Nickels estate (Arbuckle, CA), on mature almonds under single line drip irrigation. Previous research at this site showed that the active root-zone of these trees was limited to about 3', and the soil had a low water holding capacity, both factors contributing to a potentially lethal level of drought stress. A total of 5 replicate plots consisting of 6 rows by 11 trees were established, with 2 of the rows being Nonpareil, bordered on each side by one of three other varieties (Butte, Carmel, Monterey), serving as guards. Each plot consisted of 8 irrigation/pruning treatments as described in Table 1. The pruning and kaolin spraying treatments were designed to reduce canopy water demand and increase the chance of tree survival, particularly under the non-irrigated treatment. Based on work by Goldhamer et al (2006), target irrigation deficits were spread evenly throughout the growing season. The 5" and 10" irrigation targets were established by replacing drippers in the existing system, but using the same schedule of irrigation timing as used in the control. Applied water was measured with water meters and direct flow measurements on each dripper, as well as automated sensors for determining the timing of irrigation system operation. Grids of 9 neutron access tubes were installed in a single quadrant of one tree in each drought treatment in 4 of the 5 plots. Measurements of midday stem water potential (SWP) were taken approximately weekly, and soil moisture with neutron probes monthly. SWP was measured on one central tree in each rep of each treatment (total of 40 trees). Individual tree yield was measured, as well as dieback and bloom status

Table1. Combination of irrigation and pruning treatments imposed in year 1 (2009), followed by normal irrigation and cultural practices in subsequent years.

Irrigation Treatment target	In-season rain+irrigation	Pruning treatment
0 (rainfed)	2.1”	None
		50% canopy reduction
		50% canopy reduction + Kaolin spray
5" in-season	5.7”	None
		Kaolin spray
10" in-season	9.3”	None
		Kaolin spray
Control	32.9”	None

A randomized complete block water production function (WPF) experiment was set up in commercial almond orchards in three counties (Tehama, Merced, and Kern) in 2013. At each site, 4 to 5 irrigation treatments, with target levels ranging from 70% - 110% ETc (Table 2), in 3 to 6 blocks, depending on the site, were established by modifying the

Table 2. Irrigation treatments imposed in three commercial almond orchards, representative of different almond growing regions in CA.

location	Treatment targets (% ET)
Kern Co.	70, 80, 90, 100, 110
Merced Co.	70, 80, 90, 100, 110
Tehama Co.	74, 86, 100, 116

existing irrigation system. Applied irrigation amounts were measured approximately weekly in at least half of the experimental plots using water meters, and periodic measurements of soil water to 9' were made with a neutron probe throughout the season in order to estimate soil water use in each plot. Periodic measurements of SWP were made on individual monitoring trees in each plot. Mid-season canopy cover (% PAR Interception) as well as yield have been measured annually.

Results and Discussion

The deficit and the non-irrigated trees of the 2009 drought study showed clear symptoms of water stress, with the severity of the symptoms related to the degree of stress experienced by each individual tree (Fig. 1). Early symptoms of moderate stress included interior canopy defoliation, with complete defoliation observed once trees reached extreme stress (on the order of -60 bars, Fig. 1). Because these trees were growing on a relatively shallow and low water holding capacity soil, and had been irrigated with a single line drip system, it was expected that the active root system would be restricted to the upper 3' of the soil profile, and that stress under non-irrigated conditions would be lethal, but none of the Nonpareil trees of the study died. Also, only the most extremely stressed trees showed any dieback, restricted to relatively small portions of the exterior canopy. Hence, it is clear that

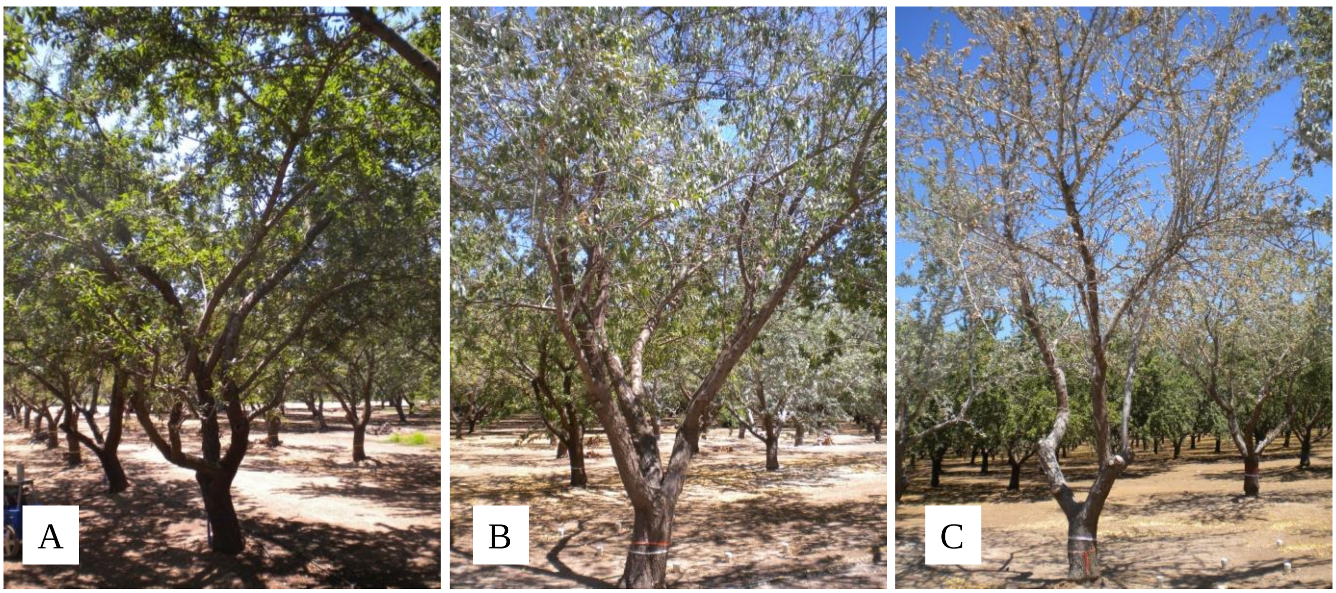

Figure 1. Example tree appearance on June 29, 2009, in the control (A, SWP = -9 bars), 10" (B, -25 bars), and 0" (C, -40 bars) treatments. By July 14, 2009, the tree pictured in C had reached -63 bars, and by July 28 was completely defoliated.

almonds are relatively tolerant of water stress in terms of survival. Because of the small impact of drought on canopy dieback, we also conclude that the yield loss due to canopy reduction (data not shown) as well as the labor required for any meaningful canopy reduction for the purpose of improving tree survival, would not be economically justified.

While these almonds were surprisingly tolerant of water stress, it is important to note that irrigation at any level was effective in moderating the degree of tree water stress. Also, as found in previous studies, the level of stress experienced by any particular tree was strongly influenced by factors (i.e., available soil moisture) beyond just the amount of irrigation water applied. Neutron probe as well as soil moisture sensor data showed water uptake at the deepest depths measured (10' in the case of some neutron probe sites), indicating that while both the soil and the root system at this study site were considered 'shallow,' under drought conditions these trees were able to mine deep soil moisture. This indicates that almonds may establish and maintain deep roots, even when drip irrigated on a relatively frequent basis (twice per week was the typical irrigation schedule for these trees). Neutron probe data showed that the non-irrigated as well as deficit irrigated trees were able to acquire a minimum of 5.5 – 6.7" of water from the soil (uptake below 10' may have occurred, but this was outside of monitored range), depending on the treatment (Table 3). Interestingly, the use of soil water was as high, or higher, in the deficit irrigated treatments than it was in the non-irrigated treatment, indicating that low levels of supplemental irrigation can improve the ability of almonds to access deep stored soil moisture, rather than inhibit it. Based on the applied irrigation water and the measured soil water depletion, the treatments tested in this study ranged from about 20 to 100% of crop demand, with on the order of about 7.6" of total ET required for almond tree survival (Table 3), again, indicating that almond is a very drought tolerant crop.

Table 3. Water budget analysis for the drought experiment based on neutron measured soil water uptake from the each treatment.

Treatment	Irrigation applied	Rain	Soil uptake	Total	%ETc
0"	0"	2.1"	5.5"	7.6"	21%
5"	3.6"	2.1"	6.7"	12.4"	35%
10"	7.2"	2.1"	5.9"	15.2"	42%
Control	30.8"	2.1"	(?)	(32.9")	(92%)

Current season yield as well as carryover effects on yield depended on the level of water stress experienced by the tree. When trees were grouped based on the level of stress experienced, rather than the irrigation treatment, the pattern in yield over the 4 years of the study was very clear, with greater levels of stress being associated with progressively lower yields, both in the drought year, as well as the year following the drought (Fig. 2). Yields were more reduced by water stress in the year following drought (2010), than in the year of the drought (2009) and it appears that by 2011, the recovery in yield was largely complete (Fig. 2). Since the yield effects of stress were consistent over years, and increasing stress was associated with decreasing yields, we

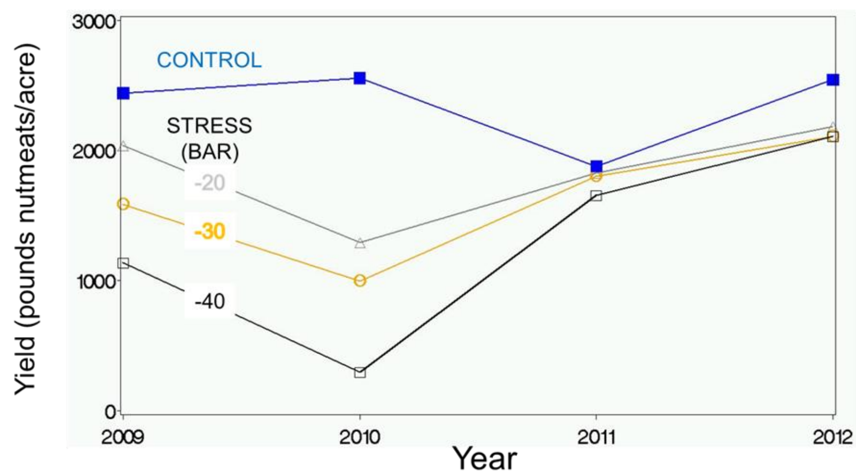

Figure 2. Drought year (2009) and carryover yield responses in almonds, grouped based on the level of stress experienced in the drought year.

conclude that application of even relatively modest amounts of water will increase tree health/yield, and presumably increase tree survival during a drought. Carryover effects of water stress were apparent in 2010 for both flowering (return bloom) as well as % set (data not shown), both contributing to the low yields observed in the year after the drought treatment (Fig. 2).

Thus far, a three year study in which differential irrigation has been applied to large plots of commercial almonds has not detected a clear relation between water application and yield, at least for the range of applied water from about 25" to 45" (Fig. 3). Year to year variation in yield has been more pronounced at the Kern and Merced sites than the Tehama site, and there was some indication of a yield response to applied water at the Kern site in the first year of the study (2013, Fig. 3). However this trend was primarily due to the 70% treatment being substantially lower in yield and applied water than the other treatments, and the same trend was not apparent in 2014 or 2015. This lack of a yield response to applied water been surprising, but the midsummer levels of stress in these commercial orchards has only been in the range of -15 to -20 bars for the lowest irrigation amounts (70% ET target, Table 2), and hence this level of tree stress may not be sufficient to have a detectable effect on yield, given the variation inherent in commercial almond orchards. Additional years of data will be required to determine if a yield trend will be apparent over time.

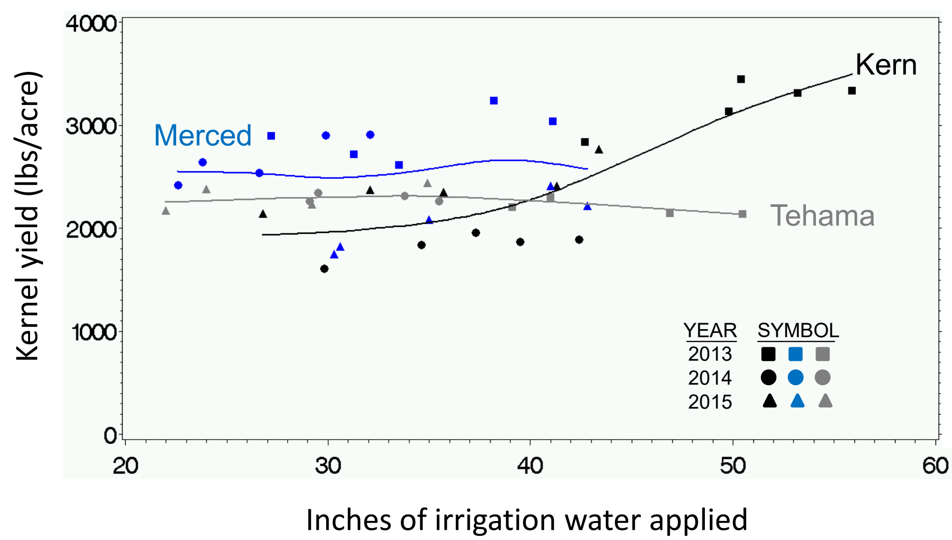

Figure 3. Treatment average yields over 3 years as a function of treatment average applied water at each of the three commercial almond orchards in the WPF study. Lines represent a smoothed curve (spline) fit to the data.

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Strategies to Manage Grapes (Table and Wine) under Extreme, Long-Term Drought Conditions

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Introduction

The majority of grapevines (*Vitis vinifera* L.) worldwide are cultivated in Mediterranean type climates having warm to hot temperatures and little rainfall during the summer. The cultivation of grapevines in arid and semi-arid regions of high evaporative demand would indicate that water stored in the soil profile from winter rainfall would be insufficient to meet a vineyard's consumptive water use. Therefore, supplemental irrigation is necessary if one is to produce a harvestable crop of high quality even during years with average to above average rainfall (Williams and Matthews, 1990).

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. 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 $1.7 billion (California Table Grape Commission).

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 utilizing various forms of overhead trellis systems.

Water Use of grapevines in the San Joaquin Valley

Numerous factors should be considered when devising an irrigation strategy for the production of wine and table grapes. To assist in implementing such a plan one needs to know how much water non-stressed vines use. 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 (vines trunk girdled and sprayed with gibberellic acid (GA_3)) used a mean of 773 mm (30 inches) across two years (Williams and Ayars, 2005a). Girdling to increase the size of seedless grapes 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) 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 (also called fraction of ground cover by others) measured at the soil surface beneath the canopy at solar noon. Shaded area was measured beneath the canopy of Merlot grapevines grown in Madera County across five seasons and a seasonal K_c determined from the following equation: K_c = 0.017*percent shaded area (equation reported by Williams and Ayars, 2005b). The maximum K_c in that study was approximately 0.7. 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 (Williams, 2012a). 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 spacings would be greater. The above examples indicate that estimated vineyard ET_c could be calculated by knowing the percentage or fraction of ground cover and using the equation in Williams and Ayars (2005) to calculate the K_c. The calculation of the seasonal K_c using this method has been used successfully by the author at other locations in California (Williams, 2010; Williams, 2014a). Recently, the use of surface renewal to measure actual ET_c (Shapland et al., 2013) may also aid in determining vineyard water use and schedule irrigation amounts during the growing season.

Efficient Use of Soil Water Reserves

The amount of water in the soil profile at budbreak (approximately 15 March in the San Joaquin Valley and 1 April in the coastal vineyards of California) should be taken into consideration as to when the first irrigation of the season takes place to conserve water. Even when rainfall during the period from 1 November to budbreak the following year is greater than normal in the San Joaquin Valley those amounts may not be enough to refill the soil profile to field capacity, especially if the vineyard had been deficit irrigated the prior growing season (Williams, 2012a). Soil water content (SWC) was measured at the end of October each year and at budbreak the following year in the study by Williams et al. (2010a). Rainfall during the period from 1 November to budbreak ranged from 162 mm (6.4 in.) to 447 mm (17.6 in.) across years in that study, however, the increase in SWC ranged from 37 to 57% the amount of rain that fell. Therefore, the ability to predict effective rainfall received during the winter months may be difficult. One can measure SWC in the soil profile using various means but a single access tube or tensiometer placed in the vine row, as done by some growers or consultants, may not provide a reliable estimate of total available water in the soil profile a vine has access to.

Alternatively, one can use a measure of vine water status to determine when the first irrigation should take place. Midday leaf water potential (Ψ_l) has long been used in viticulture and highly correlated with other measures of vine water status, grapevine water use, soil water content and vegetative and reproductive growth of grapevines (Zarco-Tejada et al., 2013; Williams, 2010; 2012b; 2014a; Williams and Araujo, 2002; Williams et al., 2010a, 2010b, 2011; Williams and Trout, 2005). The data indicate midday Ψ_l greater (less negative) than -1.0 MPa (equivalent to -10 bars) would indicate that the vines are not stressed for water and transpiring at close to maximum amounts. If irrigation does not commence until this water potential value is reached then water could be conserved early in the growing season. Most wine grape growers in the North Coast viticulture region may not irrigate until midday Ψ_l is from -1.2 to -1.4 MPa.

Knowledge of seasonal vineyard ET_c may also be used early in the growing season to determine when to start irrigating. The author has determined that the amount of water used by grapevines from budbreak to anthesis (bloom) is approximately 10% of the seasonal consumptive water use (Williams et al., 2003; Williams, 2012a; 2014a). For example, seasonal water use of Merlot grapevines (California Sprawl canopy and 12 ft. row spacing) has been estimated to be 700 mm (28 in.). Therefore, maximum water use of those vines between budbreak and anthesis would amount to 70 mm (2.8 in.). If the amount of water in the soil profile or precipitation after budbreak is able to meet this demand, then an irrigation event could be delayed and minimize water leaching below the root zone. The author has also determined that the percentage of seasonal vineyard ET_c between budbreak and veraison (phenological stage where berries soften, turn color and start to accumulate sugars) is 40% for white wine or raisin cultivars and 50% for red wine grapes.

Vineyard water savings during the growing season

Most studies conducted on grapevines have demonstrated 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 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 and the rate of shoot growth is reduced. This would be appropriate for all grape types.

The degree to which berry growth is affected by water deficits is dependent upon the stage of berry development that the stress occurs. Berry growth is most susceptible to water stress during Stage I of berry growth (between bloom and ~4 weeks later) when growth occurs via cell division and elongation. The ultimate size of a berry is determined in part by the number of cells, a function of cell division. Extra water applied later on will not overcome a stress imposed during this stage. Berry growth during Stage III (subsequent to veraison) is only via cell elongation. Growth during Stage III is less susceptible to water deficits than during Stage I primarily due to the fact that 65 to 75% of final berry weight is determined 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 berry set or a little later.

Based upon the above, moderate deficits may be imposed during the growing season to conserve water. A study conducted by the author on table grapes in the Coachella Valley where deficits (applied water at 50 to 75% of estimated ET_c) imposed from berry set to veraison had no significant effect on berry weight and/or yield. It was found that sustained deficit irrigation (SDI) at values from 60 to 80% of measured ET_c maximized Thompson Seedless berry weight and yields (Williams et al., 2010a; 2010b). The application of water at 68% of estimated ET_c in a Merlot vineyard had no significant effect on berry weight but did reduce yields by 12% over the course of the five year study (Williams, 2012a). However, applied water amounts at less than estimated ET_c linearly reduced Cabernet Sauvignon yields (Williams, 2010) but had no significant effect on Chardonnay yield (Williams, 2014b). The difference between the two wine grape studies may be more of where the vineyards were located; Cabernet Sauvignon in Paso Robles, Chardonnay in the Carneros District of Napa Valley. One may be able to apply less water in a cooler location with fewer detrimental effects on yield than at a much warmer location.

Vineyard water savings post-harvest

It is thought that a post-harvest irrigation is beneficial to grapevines in order to retain leaves and replenish carbohydrates that may have been depleted in the permanent structures of the vine. Harvest of table grapes in the Coachella Valley begins in April and finishes by the first of June. Thus vines will keep their leaves if irrigated until a freeze occurs (if such an event takes place) or the vines are pruned. A study was conducted to determine the effects of irrigation cutoff timing (15 September vs. 1 December) on date of budbreak the following year (Williams et al., 1991). Vines in which the water was cutoff in September lost all leaves shortly thereafter. Vines in the early cutoff treatment had significantly earlier dates of budbreak compared to the later cutoff date. No detrimental effects on yield were observed resulting from the early cutoff date. It was estimated the early cutoff treatment saved 125 mm (5 in.) of water.

Table grapes are bred for differing characteristics to include date of harvest. Harvest of Flame Seedless grown in the San Joaquin Valley begins in July. Conversely, Crimson Seedless harvest may not begin until late September with the last pick taking place in November. While irrigation management in the Crimson vineyard must be concerned with fruit quality late into the growing season, irrigation management in the Flame Seedless vineyard is not. During the 2014 growing season the author was conducting a N fertilization trial in a Flame Seedless vineyard where the last harvest of the season took place on July 15. While the cooperator continued to irrigate the vineyard, applied water amounts were much less that ET_c with considerable leaf abscission and midday Ψ_l ranging from -1.3 to -1.5 MPa into September and October. Flame Seedless yields in 2015 averaged 24.1 tons per acre (2,536 19 lb. boxes per acre). These yields were similar to those in a Scarlet Royal and Crimson Seedless vineyard where vines were irrigated later into the season. It would appear that early maturing table grape vineyards could be deficit irrigated subsequent to fruit harvest with minimal detrimental carry-over effects.

Effects of water deficits on the perennial nature of grapevines

Roots, the trunk and cordons (horizontal extensions of the trunk) comprise the perennial organs of the grapevine. In addition to taking up water from the soil, grapevine roots will serve as a reservoir of N and non-structural carbohydrates (NSC) for possible remobilization and use by the current season's growth. While the trunk and cordons physically support the current season's shoots they may also serve to store N and NSC in the vine. It has been demonstrated that the dry biomass of the roots, trunk and cordons of Chenin blanc grapevines irrigated at 52% of estimated ET_c across four years was reduced by 20 to 30% compared to vines irrigated at 100% of estimated ET_c (Mullins et al., 1992). Similar reductions were found in the amounts of NSC. This would indicate that water deficits will also depress growth of the permanent structures and that the lowered amounts of NSCs in those organs may be one reason current season's growth is diminished early on due to water stress.

Yield components of grapevines develop over the course of two growing seasons with cluster primordia developing in the compound buds the year previous to harvest. (Mullins et al., 1992). Studies with vines grown in controlled environments have shown that the number and size of inflorescence primordia is reduced by water stress (Mullins et al., 1992). Cluster primordia begin differentiating in the compound buds around anthesis (bloom) in the current year and those in the basal three nodes of spur pruned cultivars are fully developed by veraison. The number of clusters per vine were significantly reduced when Merlot grapevines were irrigated at 38% of estimated ET_c season long compared to those irrigated at 68 and 100% of ET_c (Williams, 2012a). However, moderate water stress could actually improve the differentiation of cluster primordia as light is an important environmental factor affecting cluster differentiation. Moderate water stress may increase light into the canopy due to reduced vegetative growth.

Conclusions:

While it has been demonstrated in numerous studies (Williams, 2012a; 2014b; Williams et al., 2010b are examples), 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 SDI or 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, 2012a) 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 yields (albeit less than the fully irrigated vines) in the San Joaquin Valley.

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 differ from wine grape vineyards. 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. In addition, deficit irrigation subsequent to harvest may be a viable option to conserve water in early maturing table grape vineyards.

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New Approaches to Refine Water Use Estimates of Permanent Crops

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Introduction

In the face of the increasingly limited and impaired water supplies resulting from the severe drought facing California over the past few years, growers need updated information on actual crop water use to optimize irrigation management under the prevailing growing conditions of California. Our UC Davis team has been investigating the actual evapotranspiration (ET) of some perennial crops in growers-managed commercial fields, as related to field topography in vineyards, canopy size and orientation in citrus orchards, and to canopy features and soil-water salinity in pistachio orchards. We have been using a suite of ground measurements, spatially-distributed field evaluations, and remotely-sensed estimations with the aim of capturing the site-specific complexity and variability of crop water use over commercial orchards and vineyards.

Methodological approach and components

Our goal is to develop, validate and make available to growers simplified information and tools to support improved irrigation management decisions under limited and impaired water supply. Within the different research projects, we aim at developing a hybrid approach to up-scale point-based crop ET obtained from ground-measurements to orchard-wide spatially-distributed ET estimates, accounting for planting density, canopy size and its spatial distribution, and row orientation, field topography, and soil water salinity. Such a hybrid approach entails the use of point/areal-based ground measurements of micro-meteorological and crop parameters in combination with field assessments and remotely-sensed estimations to better understand the spatially-distributed dynamics of crop water use over the cropping season. We will also conduct a cross validation between the hybrid-based and ground-based ET estimations to find out whether high-resolution remotely-sensed data alone or in combination with ground measurements can provide spatially-distributed ET information with good accuracy and thus benefit growers, orchard managers and farming operations.

Studies conducted in the last decade by researchers at UC Davis led to the development and validation of more accurate, dependable and less expensive methods to measure actual crop ET under commercial field conditions. In particular, estimating actual crop ET by the residual of energy balance using the surface renewal (SR) method to determine sensible heat flux has proven reliable, considerably less expensive, and more easily applicable than other methods such as the eddy covariance (EC), weighing lysimeters and Bowen ratio. These recent research findings have enabled surface renewal to become commercially available for growers to use as a field tool to measure site-specific ET and enable them making irrigation decisions based on real-time ET information resulting from site attributes. However, inferring the orchard-wide water use from point-based ET estimates by SR requires to account for the spatial variability of canopy and radiation parameters throughout the orchards, and their effects on the orchard water use. These aspects are the main objectives of our on-going research.

We are using the residual of energy balance method through a combination of eddy covariance (EC) and surface renewal (SR) equipment to estimate the actual crop evapotranspiration (ETa) based on ground measurements of different components of the surface energy balance under grower-managed field conditions. The simplified surface energy balance can be written as in the Equation 1 below:

$$\mathrm{Rn} = \mathrm{G} + \mathrm{H} + \mathrm{LE} \qquad [1]$$

where Rn is the net radiation (Wm^{-2}), G is the soil heat flux (Wm^{-2}), H is the sensible heat flux (Wm^{-2}) and LE (Wm^{-2}) is the latent heat flux.

LE can be calculated as residual by difference between Rn, G and H as shown in Equation 2:

$$\mathrm{LE} = \mathrm{Rn} - \mathrm{G} - \mathrm{H} \qquad [2]$$

Latent heat flux density can then be divided by the latent heat of evaporation (λ) to obtain the mass flux density of water vapor (Equation 3), which can be finally converted to hourly and daily ETa (inches or mm).

$$ETa = \frac{LE}{\lambda} \qquad [3]$$

Using ETa estimated from the residual of energy balance to schedule irrigation has the advantage of avoiding the risk of over- or under-estimation of crop ET that may occur if the usual reference ET and crop coefficient approach ($\mathrm{ETc} = \mathrm{ET}_0 \times \mathrm{Kc}$) is used, given that site-specific conditions, as well as crop and irrigation management practices followed by growers may be quite different than those of research fields where crop water use information were obtained, thus leading ETa to be lower than ETc (potential evapotranspiration).

Once information on actual crop water use is obtained, the availability of ET_0 data with the same time-steps, both from conventional and Spatial CIMIS, enables to estimate the actual crop coefficients (Ka) over the cropping season through Equation 4:

$$Ka = \frac{ETa}{ET_0} \qquad [4]$$

Complementary field evaluations are necessary to better understand the dynamics and main drivers of actual crop evapotranspiration occurring over the footprint area around the ground measurement devices, and throughout the orchards. Below is a brief description of how each of those complimentary evaluations can potentially contribute additional information to our understanding of processes related to actual crop water use.

- A spatially-distributed in-field soil mapping (zoning) can be conducted to investigate the functional relationships between soil-related parameters and the crop water-related processes. Soil zoning aims at characterizing the soil hydraulic properties by means of EM-surveying technology, followed by soil sampling, analytical determination of soil properties (lab analyses) and the final mapping of soil types, according to the ESAP Model and Survey Protocol developed and validated by the US Salinity Laboratory (Corwin and Lesh, 2005). This soil zoning allows understanding relationships between the spatial variation of canopy with that of soil texture, water holding capacity, as well as the impact of soil-water salinity and grower-managed irrigation practices on ETa and Ka.
- An irrigation system evaluation enables to appraise how evenly water is delivered throughout the orchard (irrigation distribution uniformity, DU), the average application rate and efficiency, which in turn can help understanding whether irrigations are adequately managed by growers to refill the soil water depletion, thus matching the actual crop water use.
- The light intercepted by the plant canopy, the fractional canopy cover (Fc), and their spatial variability throughout the orchard can be assessed by surveying the orchards on a few clear-sky days during the crop season with a mobile platform fitted with a Photosynthetic Active Radiation (PAR) measurement system. Fc and light interception by the canopy can be then correlated with ETa and Ka data obtained from SR and EC systems to investigate and define their functional relationships.
- Airborne orchard surveys allow estimating the canopy reflectance in the visible, near infrared and short-wave infrared regions of the electromagnetic (EM) spectrum through high-resolution multispectral and thermal remotely-sensed imagery. These data can be used to derive the spatially distributed fractional canopy cover (Fc), canopy and soil temperature, which in turn can be used to estimate some terms of the surface energy balance, i.e. net radiation (Rn), sensible heat flux (H) and ground heat flux (G) over the study orchards. This will also enable to derive a crop-specific spatially-distributed vegetation index (VI) that is highly correlated with the ground-estimated ETa and Ka. Our plan is to develop and test vegetation index-based crop coefficients as indirect way to estimate ETa of orchards through a modeling equation like $ETa = ETo \times VI^n$ where VI^n is a vegetation index to the power "n", according to the work conducted by Choudhury et al. (1994), Neale et al. (2005) and Glenn et al. (2011)
- The plant water status can be assessed over the crop season through periodic ground measurements of midday stem water potential (SWP) using pressure chambers, and/or by estimating the stomatal conductance of trees and vines through high-resolution remote

sensing techniques using data from canopy reflectance in the thermal bands. The remotely-sensed values can be compared with in-situ ground measurements for cross validation.

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Session 6

Pest and Disease Management

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Orchard and Vineyard Herbicide Performance Update

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Managing weeds in orchard and vineyards presents several interesting challenges. While established crops are generally pretty tolerant of weed competition for resources due to size, stature, and rooting depth, new plantings can be dramatically impacted by competition in the short and long term. However, even in established orchard or vineyards, weeds can interfere with harvest, irrigation and other cultural practices and use water and nutrients intended for the crop. Most growers utilize different intensities of weed management in different parts of the orchard with more intense (and expensive) practices used under tree or vine row while less intense management is conducted in the middles. Additionally, in the case of both mechanical and chemical weed control, different management tactics may employed over the life of the planting.

Weed control in most orchards and vineyards in the California utilize herbicides as part of an integrated approach to managing weeds. Preemergence (PRE) or postemergence (POST) herbicides can provide cost effective and efficient weed control in many cases but also can have negative consequences in some situations. Much of our current weed science research work focuses on three general areas related to herbicides in orchard and vineyard crops.

Herbicide resistant weeds: Herbicides are highly efficient weed management tools and, consequently, impose high selection pressure for weed shifts to tolerant species or selection of resistant individuals within a population. In California tree and vine production systems, we continue to exert considerable weed management effort on weeds resistant to the POST herbicide glyphosate. For many years, glyphosate resistance was primarily an issue with winter weeds such as hairy fleabane, horseweed, and ryegrass and these continue to be challenging in much of the Central Valley. Recently, we've also been seeing new problems with summer annual weeds such as junglerice and other grasses. Because these weeds germinate and emerge during the summer, long after the dormant-season preemergence herbicide program are applied, this will require substantially different management approaches such as different POST modes of action or sequential applications of PRE herbicides late in the spring to carry residual control longer into the summer season.

Herbicide injury and drift: Most herbicides used in orchards and vineyards <u>can</u> injure the crop to some degree. Crop safety usually is a function of placement below the canopy but above the root zone. Crop exposure and injury from herbicides can occur from a number of routes: drift from off-site, drift from within the orchard, vapor movement, and movement on dust. Of these, we often tend to think that crop injury from off-site movement of herbicides is the largest problem. While these major drift cases can be dramatic (and expensive), the most common cases of injury are "self-inflicted" from applications within the field. Fortunately, the causes of self-inflicted drift injury are the easiest to mitigate with proper equipment setup, calibration, and operator training. Another primary route of herbicide exposure to tree and vine crops is via root uptake from applications made within the orchard. In some cases unusual soil or weather conditions can be major factors (e.g. very coarse soils, very low CEC, large rainfall or irrigation events right after application). In other cases, overdoses due to poor sprayer calibration, miscalculations, or too slow speed (such as when turning) can be contributing factors. The best way to avoid major crop injury from this route is calibration and training combined with a cautious approach when using new herbicides. When troubleshooting known or suspected cases of herbicide injury, the new UC-IPM "Herbicide Symptoms" website is a useful tool http://herbicidesymptoms.ipm.ucanr.edu/

Herbicide registration and performance: No "one size fits all" herbicide program for orchards and vineyards exists; however, there are a number of good herbicides available for this agricultural sector (see attached T&V Herbicide Registration Chart). Growers and Pest Control Advisors should use field scouting and good field records to base herbicide recommendations on known weed problems to avoid wasting time and money and needlessly over treating a field.

A few new herbicides have been registered in California and several important label changes have been made in recent years. A few highlights include: **Alion** – in tree nut crops, maximum use rate reduced to 5 fl oz/A in soils with greater than 1% organic matter or 3.5 fl oz/A in soils with less than 1% OM; also cannot currently be used in flood-irrigated orchards. **Prowl H2O** preharvest interval shortened to 60 d PHI for tree fruits and nuts. **Broadworks**, with a new mode of action for this sector, was recently registered in tree nuts, citrus, and some stonefruit crops. **Zeus** was registered on grape, walnut, and pistachio. **Glufosinate** – this active ingredient is now off-patent and several manufactures have brought herbicides into the California market that compete directly with Rely 280; these include Refer, Lifeline, Cheetah, Glufosinate 280, Reckon, and others. Many of these glufosinate herbicides were recently registered on olive, pear, citrus, and other crops. For additional herbicide registration updates and other products with the same active ingredients refer to your preferred pesticide label source such as Agrian or CDMS.

A few key points about herbicides in orchard and vineyard systems always bear repeating.

- First, proper weed ID, calibration and maintenance of spray equipment, operator training, and selection of appropriate herbicide rates and mixtures can greatly reduce the likelihood of poor performance or crop safety issues with herbicides.
- Applying preemergence herbicide to clean strips will greatly increase the performance as will timely incorporation via rainfall or irrigation.
- For POST herbicides, add water conditioners to the spray tank before the herbicide, use appropriate adjuvants for the herbicide mixture, and carefully consult the label for weed size and application requirements.
- Nozzle technology has really advanced in recent years and the newer nozzles can greatly reduce the fine droplets that are more prone to drift while maintaining good coverage.
- For contact materials, good coverage is critical so using appropriate nozzles, GPA, and boom orientation is important.
- Rotate and combine herbicide modes of action to minimize selection pressure for herbicide resistant weeds.

Weed management in orchards in vineyards may not seem terribly complicated but it is an annual and costly part of the production system. Growers and advisors should invest the time and energy into developing purposeful, integrated and sustainable weed management programs based on a reasonable understanding of the crop, the weeds, and the tools available and refine the program based on performance and any new weed issues that arise.

Herbicide Registration on California Tree and Vine Crops -*(updated November 2015 - UC Weed Science)*

	Herbicide-Common Name *(example trade name)*	Site of Action Group[1]	Almond	Pecan	Pistachio	Walnut	Apple	Pear	Apricot	Cherry	Nectarine	Peach	Plum / Prune	Avocado	Citrus	Date	Fig	Grape	Kiwi	Olive	Pomegranate
			----- tree nut -------				- pome -		---------stone fruit ---------												
Preemergence	dichlobenil *(Casoron)*	L / 20	N	N	N	N	R	R	N	R	N	N	N	N	N	N	N	R	N	N	N
	diuron *(Karmex, Diurex)*	C2 / 7	N	R	N	R	R	R	N	N	N	R	N	N	R	N	N	R	N	R	N
	EPTC *(Eptam)*	N / 8	R	N	N	R	N	N	N	N	N	N	N	N	R	N	N	N	N	N	N
	flazasulfuron *(Mission)*	B / 2	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	R	N	N	N
	flumioxazin *(Chateau)*	E / 14	R	R	R	R	R	R	R	R	R	R	R	NB	NB	N	NB	R	N	R	R
	indaziflam *(Alion)*	L / 29	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	R	N
	isoxaben *(Trellis)*	L / 21	R	R	R	R	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	NB	R	NB	NB	NB
	mesotrione *(Broadworks)*	F2/27	R	R	R	R	N	N	N	N	R	R	R	N	R	N	N	N	N	N	N
	napropamide *(Devrinol)*	K3 / 15	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	R	R	N	N
	norflurazon *(Solicam)*	F1 / 12	R	R	N	R	R	R	R	R	R	R	R	R	R	N	N	R	N	N	N
	oryzalin *(Surflan)*	K1 / 3	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	R
	oxyfluorfen *(Goal, GoalTender)*	E / 14	R	R	R	R	R	R	R	R	R	R	R	R	NB	R	R	R	R	R	R
	pendimethalin *(Prowl H2O)*	K1 / 3	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	R	R
	penoxsulam *(Pindar GT)*	B / 2	R	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	pronamide *(Kerb)*	K1 / 3	N	N	N	N	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	rimsulfuron *(Matrix)*	B / 2	R	R	R	R	R	R	R	R	R	R	R	N	R	N	N	R	N	N	N
	sulfentrazone *(Zeus)*	E / 14	N	N	R	R	N	N	N	N	N	N	N	N	R	N	N	R	N	N	N
	simazine *(Princep, Caliber 90)*	C1 / 5	R	R	N	R	R	R	N	R^{+}	R	R	N	R	R	N	N	R	N	R	N
Postemergence	carfentrazone *(Shark)*	E / 14	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	clethodim *(SelectMax)*	A / 1	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	N	R	N	N	NB	N	NB	N
	clove oil *(Matratec)*	NC[3]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	2,4-D *(Clean-crop, Orchard Master)*	O / 4	R	R	R	R	R	R	R	R	R	R	R	N	N	N	N	R	N	N	N
	diquat *(Diquat)*	D / 22	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB	NB
	d-limonene *(GreenMatch)*	NC[3]	R	R	R	R	R	R	R	R	R	R	R	N	R	N	R	R	R	N	N
	fluazifop-p-butyl *(Fusilade)*	A / 1	NB	R	NB	NB	NB	NB	R	R	R	R	R	NB	R	NB	NB	R	N	NB	NB
	glyphosate *(Roundup)*	G / 9	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
	glufosinate *(Rely 280)*	H / 10	R	R	R	R	R	N	N	N	N	N	N	N	R	N	N	R	N	N	N
	halosulfuron *(Sandea)*	B / 2	N	R	R	R	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
	paraquat *(Gramoxone)*	D / 22	R	R	R	R	R	R	R	R	R	R	R	R	R	N	R	R	R	R	R
	pelargonic acid *(Scythe)*	NC[3]	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	N
	pyraflufen *(Venue)*	E / 14	R	R	R	R	R	R	R	R	R	R	R	N	N	R	R	R	R	R	R
	saflufenacil *(Treevix)*	E / 14	R	N	R	R	R	R	N	N	N	N	N	N	R	N	N	N	N	N	N
	sethoxydim *(Poast)*	A / 1	R	R	R	R	R	R	R	R	R	R	NB	NB	R	NB	NB	R	N	NB	NB

Notes: R = Registered, N = Not registered, NB = nonbearing. This chart is intended as a general guide only. Always consult a current label before using any herbicide as labels change frequently and often contain special restrictions regarding use of a company's product.

[1] Herbicide site of action designations are according to the Herbicide Resistance Action Committee (letters) and the Weed Science Society of America (number) systems. NC = no accepted site of action classification; these contact herbicides are general membrane disruptors.

Leaffooted Bug – What We Know and What We Need to Know

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Introduction

In September to October, adult leaffooted bug (LFB), *Leptoglossus zonatus* (Dallas) begin their overwintering cycle by moving out of almond and pistachio orchards to sheltered sites forming aggregations of five to 500 individuals (Daane, et al. 2008) . Typically aggregations form under the bark of eucalyptus, in citrus, olive and pomegranate orchards (Daane, et al. 2007). Although the existence of a male pheromone associated with mating and aggregation have been supported (Wang, et al. 2000), we do not fully understand the cues that initiate these behaviors. As early as late-February LFB begin dispersing from aggregations; however, the occurrence of warm temperatures likely play a major role so this could vary among years. During March the adults begin to disperse into almond just as nuts have reached the "pea-sized" stage. LFB feeding at that stage causes nuts to abort and significant economic damage can occur (Daane, et al. 2008). Although the University of California has monitoring recommendations, such as visual inspection for adults, dropped nuts, and nuts with gummosis (Fig. 1), damage often occurs before LFB is detected. Essentially, no effective method exists to detect early-season infestations.

The standard large bug management recommendation includes a pyrethroid insecticide application at mid-season (Zalom, et al. 2014). Although effective, the already heavy reliance on that chemistry in arthropod management programs has drawbacks such as resistance developing in some navel orangeworm populations and adverse effects on natural enemies (Provost, et al. 2003, Roy, et al. 2005). In field experiments, we evaluated the residual effectiveness of Belay (clothianidin), Beleaf (flonicamid), Bexar (tolfenpyrad), Closer (sulfoxaflor), Exirel (cyantraniliprole), and Sivanto (flupyradifurone), against two pyrethroid insecticides, Brigade (bifenthrin), and Warrior (lambda cyhalothrin) as potential replacements. Our results indicated that of these insecticides, only Brigade had sufficient residual activity of manage LFB.

Material and Methods

Cold cabinet. A replication consisted of 10 individuals at approximately a 50:50 male / female ratio placed in a plastic cup with a single green bean. We evaluated LFB survival after being exposed to temperature treatments of 0, -2, -3, -6, -9, and -17 °C (32, 28.4, 26.6, 21.2, 15 and 1.4 °F) for periods of 3, 4, or 6 hours. For at least two hours prior to the cold treatments, bugs were kept at a control temperature of 45°F. After each cold treatment replicates were placed back in the control temperature and mortality evaluated after 24 h. Each treatment was replicated at least six times.

Monitoring traps. Sticky traps, were constructed from 15.2 x 20.3 cm (6 x 8 inch) Plexiglas sheets covered with clear sticky card (Alpha Scents, West Linn, OR). Ten red, green, white, yellow, or clear traps were constructed. Color traps were spray painted with Krylon (Cleveland OH). A single replicate consisted of five traps, one of each color, placed one per/tree in a tree-row of pomegranate. Within and between rows, traps were separated by approximately 60 and 300 feet respectively. The orchard had a heavy population of LFB and traps were checked bi-weekly from Mar – Jul.

Plant volatiles. Commercially available almond, avocado, coconut, peanut, and walnut oil were evaluated for attraction. Approximately 3 ml were placed on filter paper and placed in a small cage containing five, nymphs, and adult male and female LFBs. LFB were observed each ½ h over a period of four hours. Attractiveness was scored as LFB resting on the filter paper.

Results and Discussion

Cold cabinet

- LFB survival did not significantly decrease at low temperatures between 0 and -2 °C (32 and 28.4 °F) for up to 6 hours; and to 26.6 for up to 4 hours.
- Survival degreases to ~25% when exposed to 26.6 for 6 hours.
- Survival ranged between 30 and 20% when exposed to 21.2 for 3, 4, or 6 hours.
- Essentially no LFB survived at 15.8 or 1.4 °F (Fig. 2).

Color sticky traps

- No adult or nymphs were capture on any of the color sticky traps

Plant volatile

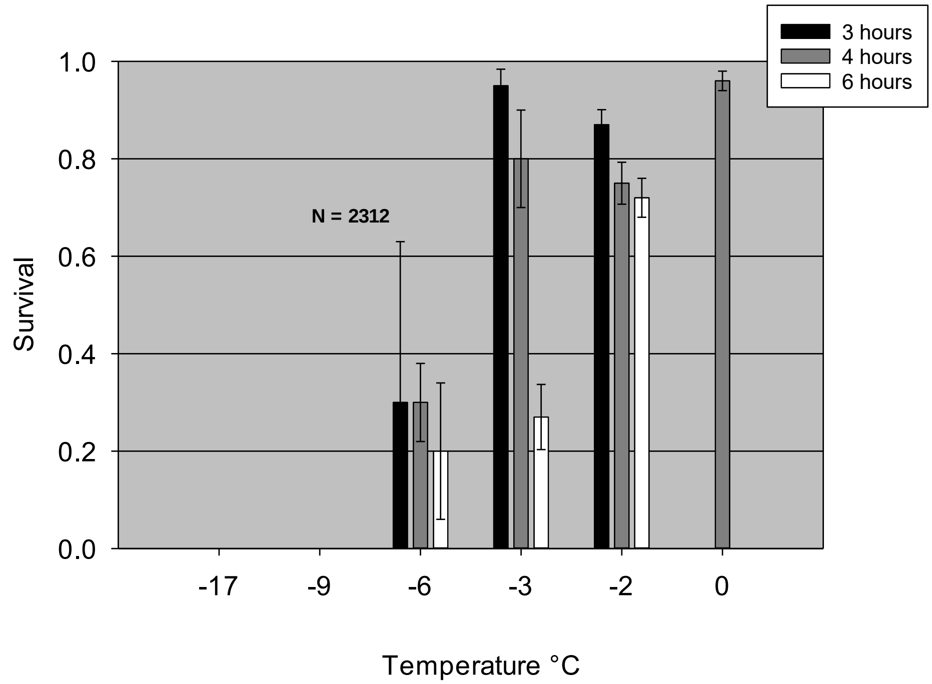
- Avocado, almond, coconut, peanut, or walnut oil did not attract adult or nymph LFB
- Whole ground pistachio attracted nymphs

Early work by Daane et al (2010) suggested that LFB suffered significant mortality when temperatures fell below ~27 °F. They did not, however provide a temporal estimation of how long LFBs must be exposed to that temperature before mortality occurs. Our data suggest that cold temperature of ~27 °F can play a role in decreasing overwintering populations. This does not occur, although until they are exposed for at least 6 hours, a condition that does not commonly occur within almond-growing areas. An important consideration of our results is the variation that can occur between laboratory and field conditions. During the winter of 2016, we will closely study LFB aggregations under field conditions.

Although the color of sticky traps that we tested did not attract LFB, there may be other color or color combinations that attract LFB. For example, color could play a critical role in attracting LFB to pomegranate fruit. The commercial oil products that we tested did not provide any detectable level of attractiveness that could be utilized as a lure. One reason that this occurred is that processing the oil for human consumption may have modified and/or eliminated any attractive volatile compounds. The most encouraging result of our study was the strong attraction of LFB nymphs to whole-ground pistachio. Early-season monitoring for nymphs is not practical, since the presence of nymphs indicate that adults have been present for at least seven to 10 days. If however, adult females are attracted and lay eggs near the pistachio food source, it could be a valuable tool for monitoring. In other words, a lure containing whole-ground pistachio volatiles could be used as a tool to monitor for females moving into almond via the appearance of egg-laying.

We know that LFB has a host range including several crops important to the San Joaquin and Sacramento valleys. The pest overwinters in aggregations outside of almond orchards in host plants including citrus, Cyprus, eucalyptus, palms, and most notably pomegranate. And the species is difficult to manage due to the lack of monitoring tools and effective residual insecticides. To better manage LFB, we need to know how to more effectively monitor during March and April to determine when populations initially move into almond. Although a mating and aggregation pheromone exists, we need to determine the specific compounds involved in those behaviors. Also, we have a very limited understanding of attractive plant volatiles and must better understand the chemical ecology of LFB to develop an effective monitoring lure. Finally, to improve IPM in almond and other hosts, we must better understand how to use reduced-risk insecticides as a management option.

Fig. 1. Clock-wise, almond nut with evidence of LFB feeding damage i.e. gummosis, red sticky trap, adult LFB, and LFB nymphs feeding on whole-ground pistachios in a mesh bag.



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Impacts of Canopy Management on Powdery Mildew in Table Grapes

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Introduction

Various canopy management practices, including leaf thinning and canopy hedging, are routinely performed on grapes in California. Leaf thinning, which usually entails removing the basal leaf closest to grape clusters, is common on both high value wine grapes and most table grapes. Hedging is performed to some degree on most grapes in the San Joaquin Valley, both to facilitate harvest and tractor operation and to influence vine canopy structure (Hashim-Buckley).

There are several advantages to leaf thinning and hedging. One advantage is that both practices have been shown to reduce humidity around clusters, which significantly reduces both powdery mildew and botrytis (Carroll, Delp). A second advantage is increased light entering the canopy. Increased UV exposure can increase the percentage of fruiting buds, which influences yield the following year. UV light also kills powdery mildew spores, which can reduce incidence of infections (Austin). Another advantage of canopy management is that opening up the canopy facilitates spray coverage (Austin). To provide control of powdery mildew, oils and/or fungicides should coat clusters and both the upper and lower leaf surfaces. The more leaf layers that are present in the canopy, the more difficult it is to adequately protect all susceptible plant tissue.

Many studies have examined the impact of leaf thinning and hedging on wine grapes (Austin, Chellemi, El-Razek, Smart), but few corollary studies have been performed on table grapes. Table grapes typically have much larger canopies and trellises which may influence the results of these practices. And while sun can be an advantage, it may also sunburn grapes or cause green grapes to become an amber color, which makes them unmarketable. Sunburn and discoloration are typically worse on western and southern sides of vines, which receive more sun exposure. This study was conducted to examine the impact of hedging and thinning, both on the entire canopy versus only the side with less sun exposure, on powdery mildew incidence and marketable yield.

Materials and Methods

The experiment was conducted in 2015 in an established ‘Autumn King’ vineyard with a gable trellis. ‘Autumn King’ is a popular, late-season, white seedless grape developed by the USDA-ARS. This cultivar was released in 2006, and was formerly known as C10 (Hashim-Buckley). Normal disease, pest and weed control was conducted in the same manner as the rest of the grower’s vineyard. The vines were planted 2001 in an East-West orientation on a large 4-wire gable trellis. Plots consisted of five consecutive vines in a row, and there were six replicate plots per treatment in a randomized complete block design. Two vines were left between plots as a buffer. The treatments were as follows:

1. Untreated Control
2. Leaf thinning on the eastern canopy side before veraison
3. Leaf thinning on the eastern canopy side after veraison
4. Hedging
5. Leaf thinning on the eastern canopy side before veraison, plus hedging
6. Leaf thinning in the eastern side of the canopy after veraison, plus hedging
7. Leaf thinning on the eastern and western sides of the canopy before veraison, plus hedging
8. Leaf thinning on the eastern and western sides of the canopy after veraison, plus hedging
9. Grower's standard: multiple leaf thinning and moderate hedging

Leaf thinning was performed once in treatments 2, 3, 5, 6, 7 and 8. In the grower's standard treatment, leaves were thinned four times throughout the season, and only hedged enough to prevent canes from growing across rows (about four to six inches). In treatments 4 through 8, vines were hedged on both sides to the third wire in the trellis (about twelve inches).

Light interception in the fruiting zone of the canopy was measured before and after each treatment and before harvest with a ceptometer (Model AccuPAR LP-80, Decagon Devices, Pullman WA). Temperature and humidity were determined throughout the season using appropriate probes and sensors connected to a data logger (EM50 Digital Data Logger, Decagon Devices, Pullman WA). Monitoring devices were placed in the fruit zone of the canopy, with one on each side of the trellis, in three replications of treatments.

Powdery mildew infections on bunches were assessed in each test plot for incidence and severity. The percentage of clusters per vine with evidence of powdery mildew were counted before harvest. Sunburn was assessed in each plot by counting the number of sunburned berries in each cluster. Bunches were monitored every two weeks from June to October. A random sampling of 25 berries per treatment/replication combination were assessed for yellow discoloration using a colorimeter (CR-400, Konica Minolta, Japan).

Berry samples were collected from each replicate at harvest. Samples were taken by randomly removing berries from different areas of clusters on the vine (approximately 100 berries total per vine). Fifty berries were be crushed and filtered. Juice was used to determine soluble solids and titratable acidity. Soluble solids were determined using a hand-held temperature compensated refractometer. Acidity was determined using a 5 mL aliquot of juice with 0.1 N NaOH to a pH endpoint of 8.2 with an automatic titrator. Berry length and diameter were determined by placing the remaining berries in a trough so that their ends (lengths) or equators (diameters) touch. The cumulative length was averaged for individual berry length and diameter.

Marketable clusters were removed from each vine, weighed and counted. Clusters were rated as culls if defects, including powdery mildew, bunch rot and/or yellowed berries could not easily be removed by trimming. Cull clusters were removed from the vine after harvest, weighed and counted. All data was analyzed using SAS 9.4. ANOVA and means separation (Tukey test) for statistical significance was performed for each treatment on all experimental parameters. Contrasts were conducted to compare thinning treatments before versus after veraison and both sides of the canopy versus eastern side only.

Results and Discussion

Light levels were increased significantly in the fruiting zone from both hedging and leaf thinning treatments (data not shown). However, levels of humidity were not significantly affected by treatment. The percentage of infected berries in an individual cluster was never greater than 15%. Most infected clusters contained only one to three infected berries. Due to the difficulty of accurately assessing such small percentages of disease on clusters of varying size, only disease incidence data was taken. Leaf thinning on both eastern and western canopy sides after veraison significantly reduced the incidence of diseases clusters by over 35% compared to the untreated control and thinning both canopy sides before veraison (Figure 1). However, other treatments were not significantly different from either the best and worst treatments.

Treatment rankings were fairly consistent between percentage of diseased clusters and marketable yield. Thinning only before veraison resulted in both the highest incidence of powdery mildew and the lowest yield. There were no significant differences in combinations of leafing both sides of the canopy versus only the eastern side. However, the grower's standard produced significantly higher yields than thinning both sides of the canopy after veraison and hedging alone. Color was not significantly influenced by treatment and no sunburn was observed (data not shown). Berry size and weight, soluble solids, and titratable acidity were also not significantly different among the tested canopy management practices.

Based on contrasts results, thinning only the eastern canopy sides versus both does not have a significant impact on disease incidence. This may suggest that growers do not need to thin both canopy sides, which could reduce labor costs for thinning by 50%. However, thinning before veraison versus after significantly reduced powdery mildew incidence. Further experiments need to be conducted in more locations and trellis systems to determine whether this information would benefit most table grape growers in the San Joaquin Valley.

It is interesting to note that, while leafing both canopy after veraison and hedging alone have relatively high disease incidence (19% and 17%, respectively), the combination of these two treatments has a low disease incidence (10%). Future experiments will be conducted as a split plot or split-split plot design to determine if interactions between treatment combinations exist.

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Table 1. Comparison of canopy management treatment combinations on percentage incidence of powdery mildew in table grapes

Description	Mean Square	F Value	P value
Leafing both sides versus eastern side only	0.0128	2.99	0.093
Leafing before versus after veraison	0.0266	6.23	0.017*

*Value significant at less than *P* 0.05

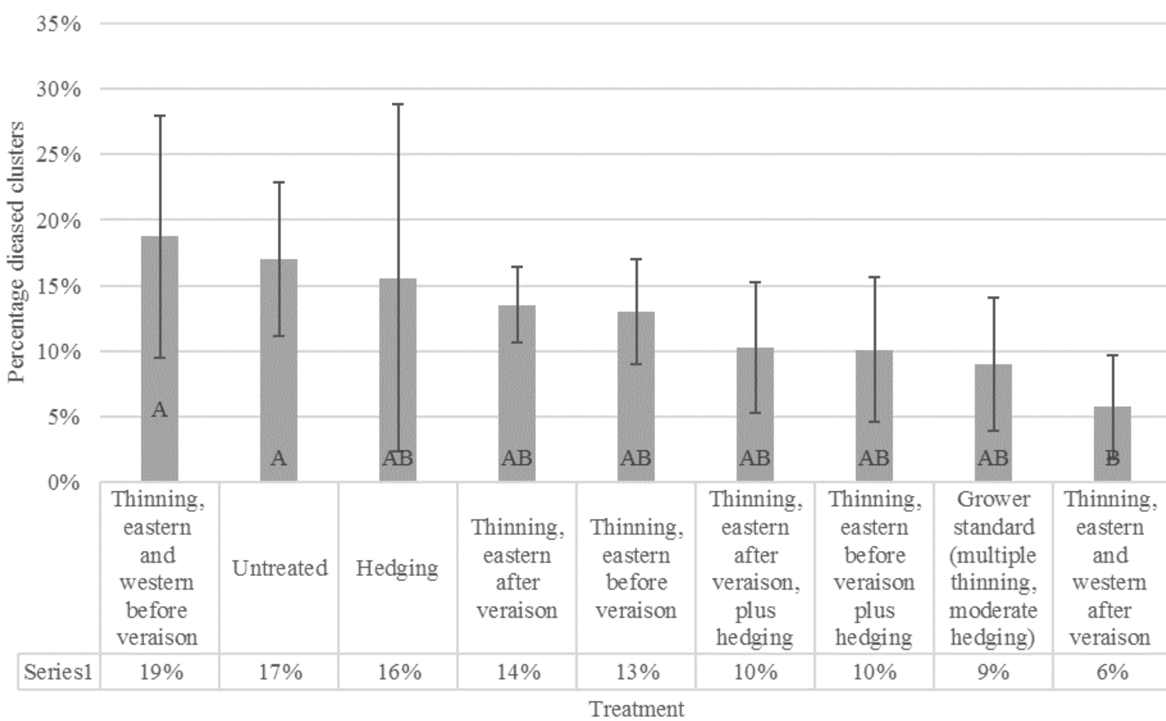

Figure 1. Effect of canopy management practices on powdery mildew incidence in table grapes

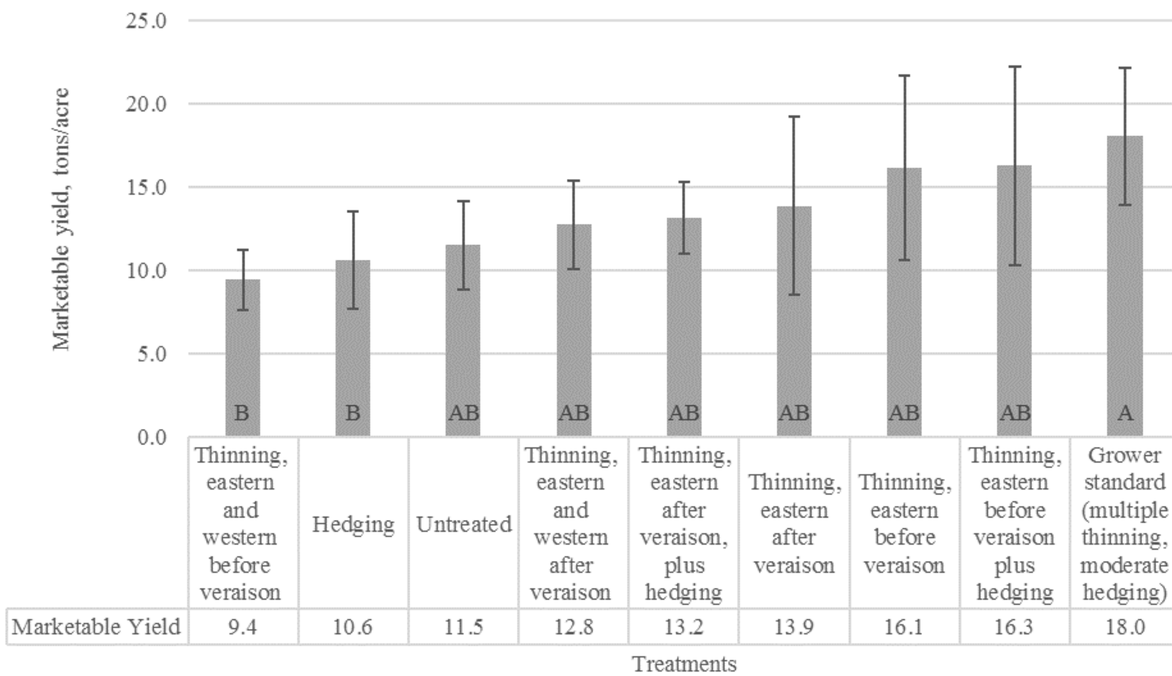

Figure 2. Effect of canopy management practices on table grape yield

American Society of Agronomy

California Chapter

Session 7

Manure and Organic Amendments

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Compost for Improving Processing Tomato Yield

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Summary

Processing tomato yield responses to supplemental applications of 10 tons per acre of shallowly incorporated, composted poultry manure have been as much as 40% above the grower standard nutrient management practice. Yield responses also occurred with supplemental applications of manufactured NPK at similar rates and placement to mimic macronutrients in the composted manure treatment. The results indicate yield increases may occur in soils with potassium levels below 200 ppm using an ammonium acetate extraction method and not exceeding 2% of the cation exchange capacity, as a secondary indicator. All field tests were conducted in commercial fields in the Yolo and Solano counties area of the lower Sacramento Valley.

Introduction

Composted animal manures have not been a common fertilizer source nor a nutrient supplement in conventional processing tomato production in California's Central Valley. Field studies were conducted which initially targeted treatments with potential to reduce premature vine senescence. Premature vine senescence common to Sacramento Valley processing tomato production occurs approximately 5 weeks before harvest with a decline in plant vigor. As vines collapse, fruit become sun-damaged and yield is reduced. While the cause of 'vine decline' has not been identified, a complex of soilborne pathogens is suspected. Treatments included the application of biocides, fungicides and biologicals to suppress the pathogens, the addition of composted poultry manure to stimulate microbes and supplemental nutrients to support plant vigor and growth. While disease level was not affected, only the composted manure treatment increased yields. Nutrient management became the focus of the research after the initial several years of field tests, while fungicides and biological materials were dropped in favor of applications of synthetic NPK fertilizers and synthetic potassium fertilizer sources.

Materials and Methods

Two field tests per year from 2011 to 2013 were evaluated in commercial fields with a history of vine decline. Selected fields were irrigated by buried drip irrigation to facilitate applications of conventional fungicides and biological agents. The experimental design was a randomized complete block with 4 replications with each row representing a plot. Row lengths tended to be more than 1,000 feet long and most beds were on 5-foot centers. Materials over the years included conventional fungicides, biologicals, a preplant biocide, NPK fertilizers and composted poultry manure (Table 1). Well-aged, composted poultry manure was applied on the bed top in a continuous pile on 100 feet of row ahead of shallow, springtime seedbed tillage. In later years, materials included sulfate and chloride potassium sources and in one test, potassium carbonate.

Yields were measured by hand harvest of a 15-foot subsection of row in 2011 and 2012. In subsequent years, 100-foot plot lengths were mechanically harvested using the grower's commercial equipment with yields measured using a portable weigh-scale trailer. Fruit pH, °Brix and color were measured from a subsample of non-defect, red ripe fruit by the Processing Tomato Advisory Board.

Soil exchangeable K was measured by atomic emission spectrometry following ammonium acetate extraction (Thomas, 1982). The relative abundance of K was expressed as a percent of milliequivalents of base cations (Ca, Mg, Na and K) based on this extraction. The field sites were used only in a single year while two of the earlier test fields were retested, but not positioned over the original test locations.

Results and Discussion

The presence of soilborne pathogens and the deficiency of plant nutrients may contribute to vine decline. Commercially available products were selected in an attempt to suppress soilborne pathogens (fungicides and biological), to stimulate soil microbial populations (biologicals and composted manure) and to provide supplemental nutrients to support plant vigor and growth. All treatments were supplemental to the grower fertilizer program with generally robust nitrogen and phosphorus applications to support high production. Cultural practices beyond the application of treatments were those of the commercial growers including standard nutrient management.

Disease incidence was assessed periodically and samples were processed in the lab to identify disease-causing organisms. At several sites, Verticillium wilt was widespread. At a few sites, Fusarium wilt, Fusarium crown and root rot were common. Vine decline was observed to varying degrees in all sites; however, the incidence of recovery of pathogens in the laboratory (data not shown) was not affected by any treatment.

Yields were generally increased in the plots with composted chicken manure. Marketable yield increased in select fields. On a percentage basis, the yield increases were equivalent to 32%, 41% and 25% in 2011, 2012 and 2013, respectively. The results indicate yield increases to composted poultry manure applications are related to soils with potassium levels below 200 ppm and potassium levels not exceeding 2% of the cation exchange capacity (Tables 2 and 3).

Conclusion

Yields in fields with a history of vine decline were generally increased with the addition of composted manure. A few processing tomato growers are now including the use of manure as part of their commercial farming practice. The contribution by composted poultry manure of supplemental nutrients, especially in soils with low potassium, is considered to be the primary benefit of this practice.

The studies reported herein did not demonstrate a direct link between improved yield and suppression of soilborne pathogens. The incidence of soil pathogens in soil samples was not responsive to any of the treatments.

Yield responses to composted manure applications appear to be linked to low soil potassium levels, but may additionally have been a result beyond supplementing with macronutrients. The benefit of composted poultry manure beyond the initial year was not followed.

Acknowledgement

We thank the California Tomato Research Institute for funding support and the generous contribution of cooperating growers J.H. Meek and Sons, Timothy Farming & David Viguie Farming, Payne Farms, Harlan Family Ranch, Don Beeman Farms, Joe Muller Ranches and Barrios Farms. Additionally, potassium fertilizer was donated by Agriform. Composted poultry manure was supplied by UC Davis Ag Sustainability Institute's Russell Ranch project.

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Table 1. Treatment list of chemicals, biologicals, fertilizers and composted manure at 6 field sites in the lower Sacramento Valley, 2011-2013.

		2011 site 1	2011 site 2	2012 site 3	2012 site 4	2013 site 5	2013 site 6
1	Non treated	+	+	+	+	+	+
2	Tenet (*Trichoderma)*	+	+				
3	Quadris+Ridomil (azoxystrobin & mefenoxam)	+	+	+	+		
4	Serenade Soil *(Bacillus subtilis)*	+	+	+	+		
5	Vapam	+		+	+		
6	Vapam fb Tenet	+					
7	Vapam fb Quadris+Ridomil	+					
8	Vapam fb Serenade Soil	+		+	+		
9	Tenet+Serenade Soil		+				
10	Serenade Soil+Quadris+Ridomil		+				
11	SoilGard *(Gliocladium virens)*		+				
12	Potassium multiple chemigation			+	+		
13	Actinovate *(Streptomyces lydicus)*			+			
14	LH Organics Soil System 1 (*various)*					+	+
15	Vermicompost					+	
16	NPK compost mimic					+	+
17	Nutrients luxury+K chemigation					+	+
18	Regalia *(Reynoutria sachalinensis)*					+	
19	JH BioTech Promot (*Pisolithus tinctorius, Trichoderma)*					+	+
20	Fontelis (Penthiopyrad)						+
21	Converted Organics SoilStart LC 1-1-1 (*composted food waste*)						+
22	Composted poultry manure 10 tons/acre	+	+	+	+	+	+
23	Composted poultry manure 5 tons/acre					+	+
24	Composted poultry manure 20 tons/acre			+	+		

Figure 2. Influence of soil K level (in ppm) on processing tomato yield response to composted poultry manure, Yolo-Solano, 2011-2014.

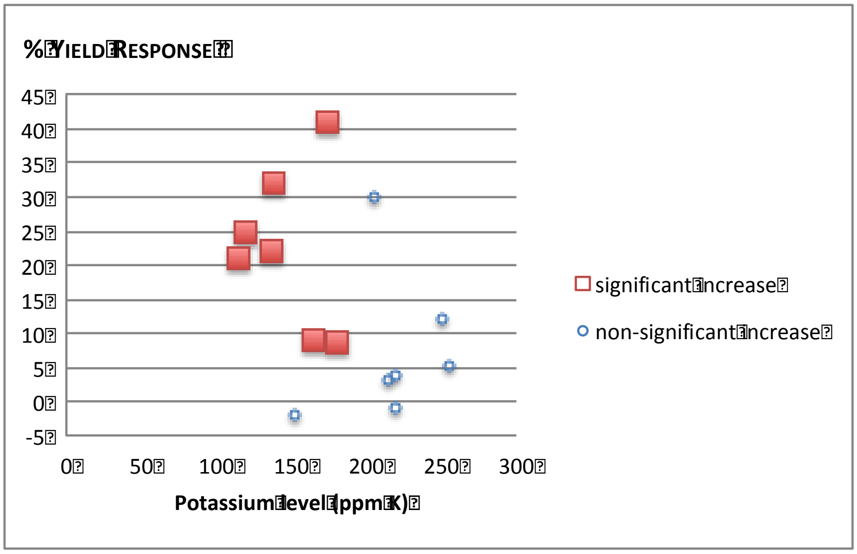
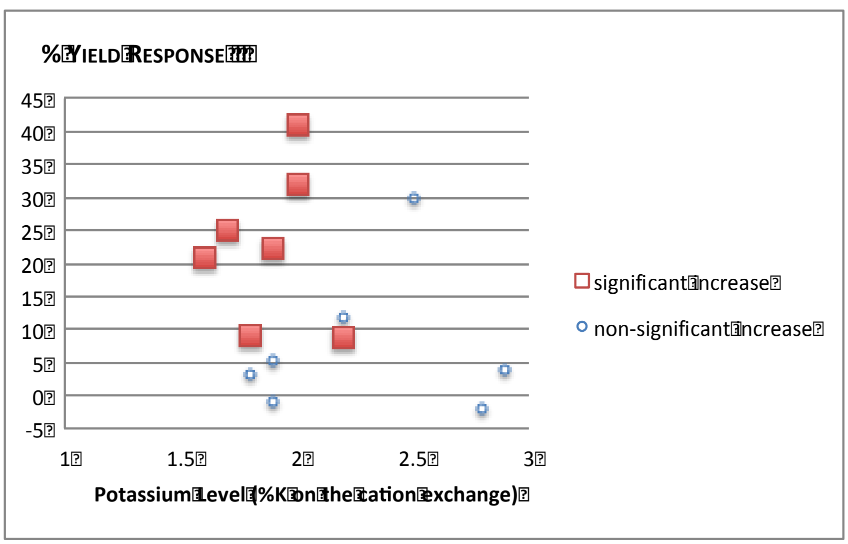


Figure 3. Influence of % K of the cation exchange capacity on processing tomato yield response to composted poultry manure, Yolo-Solano, 2011-2014.



Fertilizers from anaerobic digester systems

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Key words: *Anaerobic digestion, digestates, nutrients, by-products, crop response*

Anaerobic digester systems. Anaerobic digestion (AD) refers to the fermentation of organic substrates like organic residuals from diverse feedstocks including municipal solid wastes (MSW, particularly food wastes and yard wastes like lawn clippings), largely human wastes processed at waste water treatment facilities (WWTF), and manures of various types (in California, especially dairy manures). Under anaerobic conditions, adapted microorganisms convert fermentable substrates (volatile solids, VS) to organic acids, methane, CO_2 and other organic and inorganic compounds. Much of the organically bound nitrogen in feedstocks is converted to inorganic ammonium ($NH_{4)}$. There are several types of AD systems that range from simple covered lagoons to more complicated, highly engineered systems (Table 1/ Figure1). These design characteristics influence the characteristics of AD residuals or digestates. For example, dry AD systems produce few liquid materials and most of the residual products are lower moisture solids and commonly used for compost production or direct application. More traditional and common wet AD systems require higher moisture contents and produce significant amounts of liquid materials. For wet digestion, digestate handling systems can include solid-liquid separation, storage, and post AD processing to create new fertilization products. These differences among systems, combined with post AD digestate treatments, add complexity and uncertainty to any discussion about the fertilizer value of AD system residuals. The original nutrients, trace elements and salts present in pre-digestion feedstocks are largely preserved in AD systems, though their form commonly is altered, especially N. Any nutrient management issues associated with manure feedstocks on farms or at MSW processing facilities will still have to be addressed following AD treatment. Nutrient management problems may be easier to solve if fertilization products and soil amendments of commercial value can be made from surplus inputs that find uses off the farm.

New state policies supporting AD systems. Many current and new state policies are creating conditions that will lead to the increased use of anaerobic digestion technology to manage diverse organic residues. As a consequence, the amount of AD digestates that must find uses especially application to land, will increase. The state's new Scoping Plan[3] for the Global Warming Solutions Act (AB 32) and several related state policies in influencing bioenergy,

[3] http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm

biofuels, the management of municipal solid wastes[3], soil quality, carbon offsets and accounting, and short-lived climate pollutants (SCLP)[4] all provide direct or indirect support for the construction and operation of AD facilities. The state's Low Carbon Fuel Standard creates a market for low carbon intensity fuels. Biogas from AD systems using residual MSW and dairy manures are among the lowest carbon intensity biofuels, and will help provide an economic incentive for their development. There is a shortage of such fuels, increasing their value. . Federally, a change to the renewable fuel standards (RFS) program in 2014[5] allowed biogas to qualify as a cellulosic biofuel, and since then significantly more biogas has been produced than cellulosic ethanol which the original mandates were created to stimulate[6]. Organic waste recycling mandates have become increasingly stringent in California (AB 1826, AB 876) and both industrial and municipal entities are responsible for implementing recycling plans that eliminate the use of landfills as a means of disposing these materials. AD combined with composting provides an avenue for beneficial use of MSW residues, so this use is expected to increase. In the farm sector, the state's new short lived climate pollutant plan specifically targets methane reduction from agriculture, especially from anaerobic storage of manures, for reduction. AD of manures and methane capture is an important strategy for reducing this source of SLCP emissions and likely to increase rapidly in the near future. The state's Healthy Soils Initiative[7] will provide support for additional use of organic materials in farm soils, creating potentially large markets for AD residuals.

AD digestates. Waste Water Treatment Facilities (WWTF) in California produce about 688,000mtdry matter (DM)of biosolids in 2014 (Kester, 2015) , the majority of which went to land application. Land applied biosolids are first processed using an aerobic process to treat pathogens and degrade some organic materials. At many of the larger WWTFs, residuals are used in AD systems to generate methane for power at the same WWTF. The residuals derived from the digesters commonly are composted aerobically and then land applied or used for cover at landfills (Fig. 2). A number of public and private entities are involved with these efforts. Materials for land application must meet state standards established by Cal Recycle.[8] Selected data on typical composition from one average compost analysis from a study supported by Cal Recycle is presented in Table 3.

Dry AD systems operate at 20 to 45% total solids and produce higher moisture residuals that are suitable for composting. Three large-scale systems using MSW and yard wastes as feedstocks are in operation or soon will be in operation in the Bay area and southern California (Fig. 1). Composts have long been used and recommended as soil amendments for farming and provide an important source of fertility for many smaller-scale organic farms in the state. Limits for typical compost characteristics are given in Table 3 as listed by Cal Recycle, but even well-

[3] http://www.leginfo.ca.gov/pub/15-16/bill/asm/ab_0851-0900/ab_876_bill_20151008_chaptered.pdf
[4] http://www.arb.ca.gov/cc/shortlived/shortlived.htm
[5] http://www.epa.gov/renewable-fuel-standard-program
[6] http://www.americanbiogascouncil.org/pdf/ABC%20Press%20Release-EPA%20Final%20RVOs%202014-16.pdf
[7] https://www.cdfa.ca.gov/EnvironmentalStewardship/HealthySoils.html
[8] http://www.calrecycle.ca.gov/Laws/Regulations/Title14/ch31a5.htm#article7

made composts can vary, Table 3. Composts made from dairy manure solids or scraped manures may be less variable than other composts made from more diverse sources such as food scraps or seasonal processing wastes.

High moisture AD systems use lower DM substrates (less than 20% total solids) and produce digestates with larger amounts of water. These digestates can be managed in ways similar to manures stored in anaerobic lagoons on dairy farms if the opportunity for direct land application is available. Alternatively they can be further processed and diverted to other uses on farms or sold for horticultural uses. Commonly, high moisture digestates go through a separation process or set of processes to remove most of the coarse, solid materials remaining after AD (typically less fermentable cellulosic and lignin compounds, animal hair, etc.). The means used for separation are typical of those used for manure management systems and include rotating screens, brush rollers, vibrating screens, weeping walls, and screw and belt presses, resulting in different amounts and sizes of unfermented materials, depending on the equipment used (Burton, 2007; Fig. 3). In separated digestates, the majority of the P remains in the solid fraction, while soluble N and K, and soluble salts are concentrated primarily in the liquid fractions (Table 4, Barzee et al., 2015; Moeller and Miller, 2012, Nkoa, 2014, Zhang, 2015).

More than 8500 AD systems have been built in Germany in recent years, many on farms, and the largest amount of data on AD disgestates and their performance when used for crop production is available from German and other European sources (Nfoa, 2014; Moeller and Miller, 2012; Bonetta et al., 2015; Gutser, 2005; Insam et al.,, 2015). Compared to undigested manures, Moeller and Miller (2012) report that AD digestates from manures, energy crops or mixtures have higher ammonium (NH_4) to total nitrogen (N) ratios, decreased organic matter contents, decreased total and organic carbon contents, significantly reduced biological oxygen demand (BOD) characteristics, elevated pH values, smaller C:N ratios, and reduced viscosities compared with undigested animal manures (Table 3). One of the potential advantages of using AD systems with dairy manure is that converting most organic N in manure to soluble NH_4 could allow for greater control in the management of manure N on cropland (Chang et al., 2005; Campbell-Mathews, 2004). For non-farm based AD systems using MSW feedstocks, the soluble N fraction can be concentrated and used for fertilizer production or high analysis organic fertilizer amendments.

Much P is bound to particulate materials in AD digestates, and most P occurs in the solid phase of separated AD digestates (Barzee et al., 2105; Zhang et al., 2015; Moeller and Miller, 2012). Potassium salts remain in solution in wet AD digestates. Other salts, including Na and Cl remain soluble in AD liquid effluents and can be removed using rigourous membrane separation (Nkoa, 2014; Burton, 2007). The total salt content in manure can be approximately similar to total N, but can bemore or less in MSW derived AD digestates depending on feedstock source concnetrations (Zhang et al., 2015). If AD digestates become available on a large scale as seems likely, the salt content of some digestates, especially those associated with co-digestion of MSW or industrial wastes with animal manures, may become a management issue that complicates their use if used off farm.

The degree to which nutrients and salts are extracted from AD residuals will depend on regulatory mandates driving the use of AD systems, co-credits for GHG reduction and carbon storage, and the costs and needs for by-product fertilizer and organic amendment materials. On dairy farms with surplus nutrients, or if co-digestion with additional materials (new inputs containing nutrients and salts) occurs on such farms (El Mashad and Zhang, 2008), off-farm uses will likely be necessary. Coppege et al (2012) in a case study of a large dairy in Washington State reviewed three processes for P recovery from manures: Screening/settling to capture fine solids particularly focused on P recovery, crystallization as struvite (magnesium ammonium phosphate hexahydrate) to create a slow release P fertilizer, and combined ammonia stripping and phosphorus settling. All of these processes except screening and settling were not commercially viable at the time of the study. Much work and development remains to be done to create viable new fertilization products from AD residuals, and entrepreneurial opportunities exist for the development of new fertilization by-products.

The uses of AD digestates and fertilizer co-products. A large literature on dairy manure management has developed over many years (Chang et al., 2005; Campbell-Mathews, 2004; Pratt et al., 1973; Salter and Schollenberger, 1939), but much less known about the use of AD digestates. The AD residual materials produced by digesters can take several forms and vary in moisture and nutrient content and availability, carbon content, salt content, trace elements and other metals, salts, and product safety. The creation of specialized fertilizer and soil amendment products is foreseen and thought desirable by many authors, but research in this area is just emerging (Gorrie, 20140; USEPA, 2011; Coppedge et al., 2012; Moeller and Miller, 2012; Nkoa, 2014). This variability contributes to diverse, sometimes contradictory reports about the use of AD materials for field and horticultural crop production (Nkoa, 2014). Evaluating the efficacy of organic amendments is complicated and diverse reports about the value of AD digestates are reflected in the older manure management literature as well. Most large dairies in California use anaerobic storage lagoons, which are known to emit large amounts of CH_4. These lagoons function like anaerobic digesters but do not capture biogas and are managed variably. The *California Committee of Experts* (Chang et al., 2005) evaluated manure management and use on dairy farms in the central valley and found large variations in practices, and even greater differences in the efficiency of manure nutrient utilization. They estimated that atmospheric losses of N in all forms ranged from 20 % to 40 % and, that nutrient application to farms as manure was often inefficient, and that nutrients were over-applied. More recently, using mass balance calculations, Harter and Lund (2012) identified significant amounts of excess N applied to crops on all farms in the Tulare Basin region, with a large potential for N loss to groundwater. Campbell-Matthews (2004) has carried out extensive research and extension work on dairy farms and existing manure management systems in the San Joaquin Valley . She found extensive losses of applied N in a series of trials, emphasizing the difficulties of effectively applying current dairy manures under commonly found conditions in California. Letey and Vaughn

(2014) quantify the difficulty of managing variable inputs given diverse soils, crops, and irrigation systems.

Compared to engineered AD systems, lagoon residuals are likely to be more variable, and tend to have a larger, more variable amount of N found in an organic, insoluble form. AD residuals tend to be more uniform than the raw manure or other feedstocks that enter them and N occurs predominantly as NH_4 in AD digestates, which provides opportunities for more precise land application and use on crops (Moeller and Miller, 2012, Nkoa, 2014; Zhang, 2015; Insam et al., 2015; Borbatta et al., 2015). Compared to undigested animal manures, the fertilization properties of AD digestates are reported most commonly to lie between manures sand inorganic fertilizers, and at times to equal those of fertilizers (Nkoa, 2014). Separated liquid AD digestates are reported to be approximately equivalent to soluble N/K fertilizers when applied to crops (Moeller and Miller, 2012). However, like manure, AD digestates should be managed based on farm crop nutrient budgets. The use of AD systems will not reduce the amounts of nutrients and salts that must be managed on dairies or in MSW processing facilities. If surplus nutrients are present on the farm in excess of amounts needed by crops or allowed under nutrient management plans, off-farm uses must be developed. With respect to other emissions, especially greenhouse gas emissions (GHG), Miranda et al (2015) carried out a meta-analysis of reported values of digestate characteristics and reports on GHG emissions from the use AD digestates derived from dairy manure. They found that GHG emissions were reduced on average compared to manure systems without AD by 40% to 60% and that nutrient use efficiency by crops tended to be better if AD digestates were used compared to traditionally managed manures.

The performance of AD digestates from municipal solid wastes is less well characterized. Zhang (2015) has carried out extensive work on AD systems for manure and food waste, and is a leader in the statewide process of AD system expansion. Her group currently is evaluating post AD digestates from New Hope Dairy under laboratory and field conditions and comparing results with AD digestates from MSW sources from Clean World (Barzee et al., 2015). An extensive system of characterization is being used for materials derived from the differing AD systems. In their current project funded by CDFA, they characterized the solid and liquid fractions for the contents of organic matter, nutrients and salts. They also processed the digestate through screening and filtration systems to produce solids and liquid products. Solids are dried and made into pelletized fertilizer and compost products. They found that removal and export of the suspended solids fraction will reduce the nitrogen and phosphorus contents of residual digestates by 60% and 80% respectively. The performance of these materials with processing tomatoes as a test crop is still being evaluated.

Composts and other solid, fibrous products. A number of raw manure and AD digestate treatment processes are possible; leading to diverse fertilizer products or materials. Most processes start by separating coarse solids from liquids. Particle size distribution of manure, applications of separated fractions, and the distribution of various chemical constituents in different sizes are important parameters for designing and selection of liquid-solid separation equipment.   For example, most organically bound nitrogen and most phosphorus in AD digestates are contained in the solids. Separating solids from raw or digested manure or MSW will create two fractions, solids rich in organic nitrogen and phosphorus, and liquids rich in ammonia, soluble phosphorus and potassium. They may be further processed or used to match a particular crop's needs or for particular market purposes. The solid fraction could be separated into coarse and fine fractions based on particle sizes. Coarse solids mainly consist of fibers and are good materials for animal bedding or for soil organic matter improvement. They may be used to make other biomaterials or products like compost and biomass pellets. Fine solids have higher nutrient contents and may be used as organic fertilizer products (Zhang et al. 2015). One suggestion for the use of AD residuals from manure is to create a peat moss substitute from the solid fraction, while recycling the liquids on near the farms where they are produced. The solid fraction of AD digestates, separated in wet AD systems, has significant economic potential in the horticultural industry as a replacement for peat moss or other media used for potting purposes. It may also be useful for mulches in horticultural applications (Informa Economics, 2013; Quantis, 2013). The safety of products used off-farm, especially those used directly by the public at large is an important consideration (Bonetta et al., 2015; Insam et al., 2015).

A large number of organic fertilizer products are sold to support growing demand for organic fertilizer products, many at very high cost per unit of nutrient sold (Jenner, 2011). Increasing their supply will reduce the cost of organic production. AD digestates largely qualify as organic amendments under European standards (Nkoa, 2014), and are likely to qualify under American standards as well (USEPA, 2011; Zhang, et al., 2015; Ma et al. 2015). Current products commonly contain 5 to 6% soluble N (Jenner, 2013), but analyses vary. Individual products must be registered with CDFA as an organic input material (OIM)[9]. It is unknown how many AD residual materials have been registered at this time.

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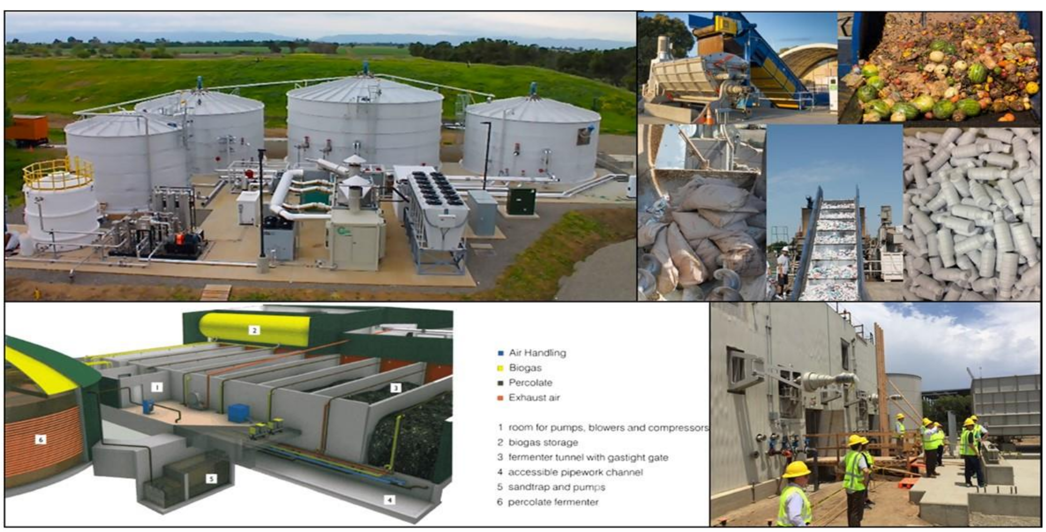

Above: Wet AD system processing food wastes on UC Davis campus. Below, Dry AD engineered by Kompoferm (Germany), and CR&R dry AD system in Perris, CA, July-2015.

Fig. 1. Examples of AD systems

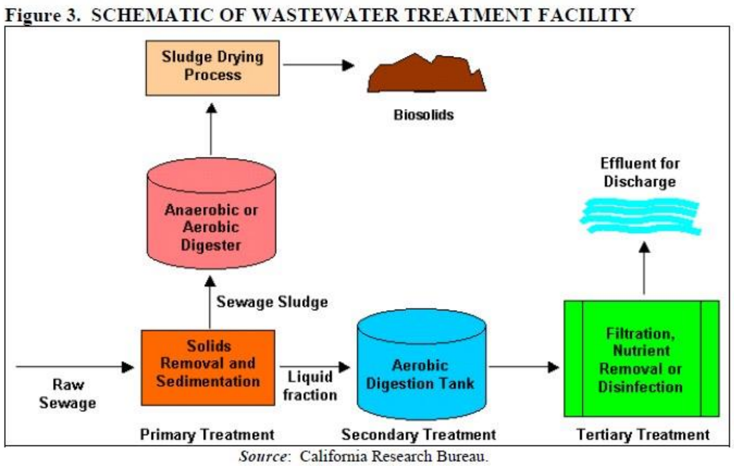

Fig. 2. From WERF, 2011.

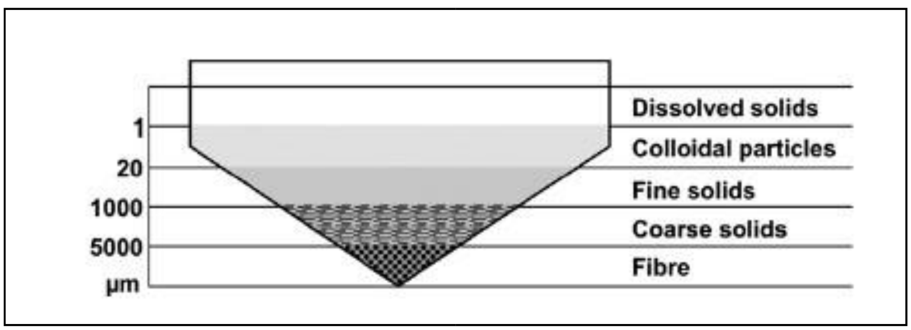

Fig 3. Solid fractions in animal manure that can removed by common separation technologies. (Burton, 2007).

Table 1.

AD system types, digestates and products							
system type *Temperature range* *feedstock mgmnt*		**High moisture AD**				**Low moisture (dry) AD**	
		Mesophilic continuous	plug flow	Thermophilic continuous	plug flow	Mesophilic plug flow	Thermophilic plug flow
Products	Low moisture solids /composts	**X**	**X**	**X**	**X**	**X**	**X**
	Slurries /liquids	**X**	**X**	**X**	**X**		
	concentrated organic fertilizers	**X**	**X**	**X**	**X**	**?**	**?**
	Struvite/ other P materials	**X**	**X**	**X**	**X**	**?**	**?**
	Livestock bedding	**X**	**X**	**X**	**X**		
	Fiber products /peat	**X**	**X**	**X**	**X**	**?**	**?**

.

Table 2 . Average values of diverse biosolids compost samples (WERF, 2011)

Biosolids compost (ave. of multiple samples)					
Constituent	**units**	**DW**	**as received**		
DM	%		**40.6**		
Org matter	%	**62.5**	**37.1**		
C:N ratio		**23**	**23**		
total N mg/kg **1.3 0.79** NH4-N mg/kg **570 340**					
NO3-N	%	**40**	**24**		
Org-N	%	**1.2**	**0.71**		
P (as P2O5)	%	**0.98**	**0.58** total P	mg/kg	
4300	**2600** K (as K2O)	%	**0.77**	**0.45**	
total K	mg/kg	**6400**	**3800**		
Na	%	**0.074**	**0.044**		
Cl	%	**0.11**	**0.062**		
EC5	mmhos/cm	**2.4**			
pH			**7.7**		
adapted from WERF					

Table 3. Quality Standards for Finished Compost (CalRecycle, 2004)
http://calrecycle.ca.gov/organics/Products/Quality/CQStandards.htm

Quality Standards for Finished Compost

Indicator	Quality Standard for Finished Compost	
Visual	All material is dark brown (black indicates possible burning). Parent material is no longer visible. Structure is mixture of fine and medium size particle and humus crumbs.	
Physical	Moisture: 30-40%, Fine Texture (all below 1/8" mesh)	
Odor	Smells like rich humus from the forest floor; no ammonia or anaerobic odor.	
Nutrient	Carbon:Nitrogen Ratio	<17:1
	Total Organic Matter	20-35%
	Total Nitrogen	1.0-2.0%
	Nitrate Nitrogen	250-350 PPM
	Nitrite Nitrogen	0 PPM
	Sulfide	0 PPM
	Ammonium	0 or trace
	pH	6.5-8.5
	Cation Exchange Capacity (CEC)	>60 meq/100g
	Humic Acid Content	5-15%
	ERGS Reading	5,000-15,000 mS/cm
Microbiological	Heterotrophic Plate Count	1×10^{8} - 1×10^{10} CFU/gdw
	Anaerobic Plate Count	Aerobes: Anaerobes at 10:1 or greater
	Yeasts and Molds	1×10^{3} - 1×10^{5} CFU/gdw
	Actinomycetes	1×10^{6} - 1×10^{8} CFU/gdw
	Pseudomonads	1×10^{3} - 1×10^{6} CFU/gdw
	Nitrogen-Fixing Bacteria	1×10^{3} - 1×10^{6} CFU/gdw
	Compost Maturity	>50% on Maturity Index at dilution rate appropriate for compost application.
	Compost Stability	<100 mg O^{2}/Kg compost dry solids-hour
	E. coli	< 3 E. coli/g
	Fecal Coliforms	<1000 MPN/g of dry solids
	Salmonella	< 3 MPN/4g total solids

Table 4. Range of AD digestate characteristics compared to undigested cattle manure. (Adapted from Moeller and Miller, 2012, Table 2).

Effects of AD on manure feedstocks			
Constituent	**Units**	**Value**	**Compared to pre-digested liquid manures**
DM	%	1.5 - 13.2	-1.5 to -5.5
Org. matter	% DM	64-75	-5 to -15
Total N	% DM	3.1-14	increases with C loss
total NH4	kg/Mg (FW)	1.2-9.1	no change
NH4-N:total N	%	44-81	depends on manure storage
Total C	% DM	36-45	- 2 to -3
C:N ratio		3.0-8.5	-3 to -5
Total P	% DM	0.6-1.7	depends on manure storage
Total P	kg/Mg (FW)	0.4-2.6	no change
water soluble P	% of total P	25-45	-20 to -47
Total K	% DM	1.9-4.3	depends on manure storage
Total K	kg/Mg (FW)	1.2-11.5	depends on manure storage
pH		7.4 -9.0	+0.5 to + 2.0
Based on Moeller and Miller, 2012.			

Table 5. Range of AD digestate characteristics after solid-liquid separation (various methods) (Adapted from Moeller and Miller, 2012)

Post AD analyses in separated liquid /solid fractions			
Constituent	Units	Liquid fraction	Solid traction
DM	%	4.5 to 6.6	19.3 to 24.7
Org. matter	% DM		40 to 86
Total N	% DM	7.7 to 9.2	2.2 to 3.0 ***total NH4***
	kg/Mg (FW)	1.8 to 3.0	2.6 to 2.7 ***NH4-***
N:total N	%	40 to 80	26 to 50
Total C	% DM	48	40
C:N ratio		3.7 to 4.8	11.2 to 19.3
Total P	% DM	0.4 to 0.7	1.9
Total P	kg/Mg (FW)	0.7 to 1.0	2.0 to 2.5
Total K	% DM	3.9	3.6
Total K	kg/Mg (FW)	3.5 to 5.2	3.4 to 4.8
pH		7.9	8.5
Based on Moeller and Miller, 2012.			

Contribution of Nitrogen Mineralization to Crop Available Nitrogen

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Introduction

California is a highly productive agricultural region. Its nutrient intensive production, however, has led to increased groundwater nitrate concentrations with a large proportion of this nitrate likely originating from fertilizer use in agriculture. California growers are now facing increasing pressure to reduce nitrogen (N) losses in crop production. However, growers also need to maintain high yield levels to remain competitive. This is only possible when N inputs from all sources can be quantified and fertilizer application rates can be adjusted accordingly. The major sources of non-fertilizer N include soil residual nitrate, nitrate in the irrigation water, and N mineralized during the growing season from organic material, such as soil organic matter, plant residues, manure and compost (Figure 1). In addition, some N is added to fields through atmospheric deposition.

This summary shall provide an overview of the contribution of organic material to crop N availability. In my presentation at the meeting I will discuss these sources in more detail with examples from trials from California.

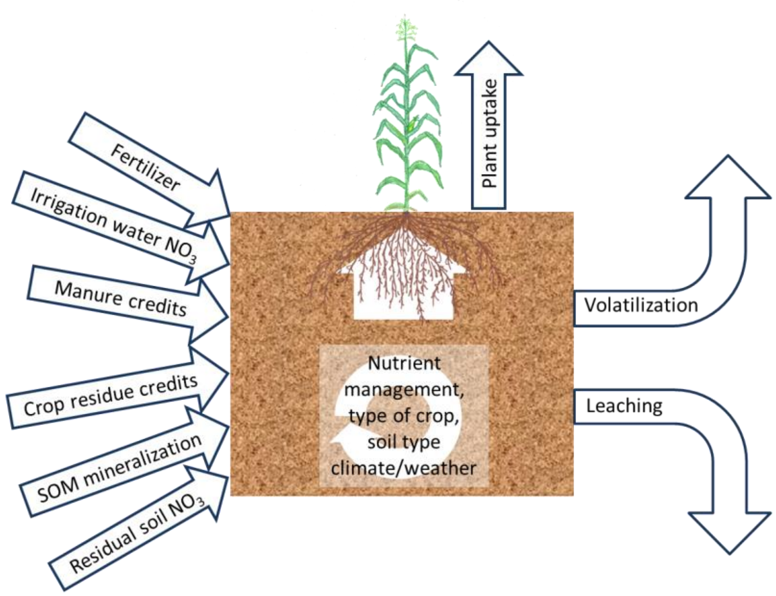

Fig. 1: Overview of the most important site-specific factors affecting crop N availability.

Soil organic matter

Although many productive mineral soils contain several thousand pounds of N per acre, most of it is in the form of organic matter and not directly available to crops. The decomposition and mineralization of soil organic matter can provide significant amounts of crop available N in the form of ammonium, which may be further converted to nitrate, both of which are readily plant available forms of N. It is often assumed that between 1 and 3% of soil organic N is mineralized during the growing season (Bremner, 1965; Gaskell et al., 2006). However, the timing of N mineralization may not coincide with crop N demand. Many biological and chemical soil tests intended to provide a better estimate of net N mineralization have been proposed, but none of them has found widespread adoption. One weakness of these methods is that they do not take into account soil temperature. Nitrogen mineralization is a microbial process which strongly depends on soil temperature. California's crop production is highly divers and crops are planted and grown at different times during the year under a wide range of climatic conditions (Figure 2). This makes the development and calibration of soil tests a challenging task.

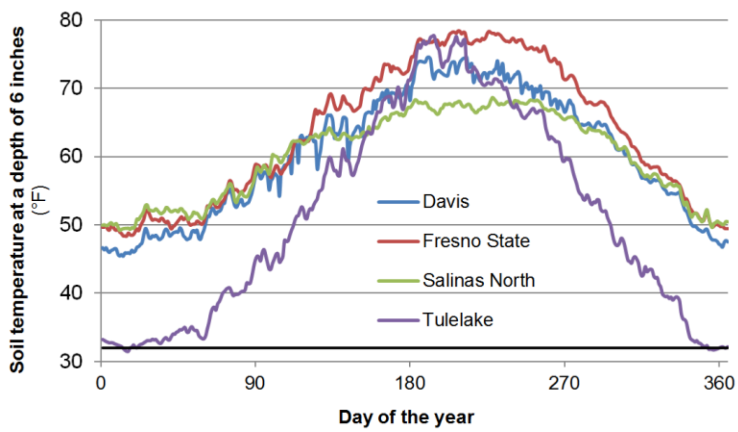

Fig. 2: Changes in soil temperature during the year at selected locations in California at a depth of 6 inches (Data source: http://www.cimis.water.ca.gov/)

Crop residue N credits

The N content of crop residues strongly affects the amount and timing of N released after incorporation. The N content is either expressed in % N in the dry matter or as the carbon (C) to N ratio of the residues. As the C content of most crop residues is between 40 and 45% of the dry mass, a C to N ratio of 20 corresponds roughly to an N content of 2%. Generally, residues with a C to N ratio of 20 or less result in net N mineralization. Examples for residues with a high N content are legume residues and residues from vegetables such as lettuce and broccoli. These residues decompose quickly and the N is made plant available by the decomposer community. In contrast, straw from small grains and corn stover have a wide C to N ratio and N is released only slowly. When the C to N ratio is wider than approximately 30, residual soil mineral N may initially be immobilized by soil microorganisms, temporarily reducing the amount of N available to crops.

Organic amendments

Nitrogen in organic amendments occurs mainly in organic forms and as ammonium. The ammonium is directly available to plants provided it is not lost to the atmosphere in the form of ammonia. Ammonium contents of organic amendments vary widely depending on the material and its handling. Corral scrapings, composted manure, lagoon sludge and mechanical screen solids from dairies generally contain little ammonium-N, ranging from 0-6% of the total N (Pettygrove, 2009). In poultry manure, ammonium-N may comprise 14-17% of the total N (Gale et al., 2006), while ammonium may account for one to two thirds of the total N in dairy lagoon water (Pettygrove, 2009; Campbell-Mathews et al., 2001).

As is the case with soil organic matter, the organic N in amendments is not directly available to plants and must be mineralized by soil microorganisms. When comparing a wide range of organic amendments, the total N concentration has been found to be a good predictor of N availability in organic amendments (Hartz et al., 2000). However, the opposite may be true when comparing a material before and after composting. During composting, microorganisms respire CO_2, resulting in a mass loss. Even though ammonia may be lost when N rich substrates are composted, the relative N content (in % of the total mass remaining) generally increases. At the same time readily available material is degraded and more recalcitrant material is left behind. Therefore, composts generally have a favorable C to N ratio, but the N is released at a slow rate.

Only a proportion of the N in manure and compost becomes available to the following crop, with the remainder contributing to increased soil organic matter contents and N mineralization during the following years. When manure is applied continuously for a long time, the soil organic matter content reaches a new equilibrium and the N mineralized from recent and past manure applications may roughly equal the total amount of N added with manure the present year. It has been estimated that in fields with at least 3-7 years of regular manure additions, the manure application rates can be reduced to the point that total manure N applied is approximately equal to projected crop demand (Chang et al., 2007; Crohn, 2006). With composts it takes longer to reach equilibrium. However, one challenge is that N mineralization is not limited to the growing season. Some N will be mineralized before planting and after harvest.

Residual soil nitrate

Residual nitrate present in the soil profile in spring can be leftover fertilizer N from the previous year or it may have been mineralized from organic material since the harvest of the previous crop. How much these two sources contribute to the residual nitrate measured depends on crop management, soil properties and weather conditions, including precipitation and temperature. For this reason, residual soil nitrate levels are highly variable and samples need to be taken every year.

Soil residual nitrate can be a significant source of crop available N. A nitrate-N concentration of 10 ppm in one foot of the soil profile corresponds to roughly 35-40 lbs N/acre. Not all the nitrate present in spring in the top foot or two of the profile may be available for plant uptake. Nitrate is very mobile in the soil and can move with the irrigation water below the root zone when water applications exceed evapotranspiration (ET).

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American Society of Agronomy

California Chapter

Session 8

GHG and VOC's in
Farming Systems

Session Chair:

Eric Ellison

Greenhouse Gas Emissions – Does Agriculture Really Make a Difference?

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The global food production system is responsible for a significant contribution to greenhouse gas emissions. Estimates of greenhouse gas (GHG) production vary widely, from 8% of the total U.S. greenhouse gas emissions (Fig. 1), to much higher numbers if all transportation, marketing, packaging, and associated food-related activities are considered.

The main contributions of GHG from agriculture are emissions of nitrous oxide (N_2O) from soil and methane (CH_4) from ruminant livestock. It is estimated that soils and livestock (at 40% and 25%, respectively) account for about two-thirds of GHG emissions, with the remaining third coming from manure storage, exhaust from farm equipment, and CO_2 emitted from soil.

Emissions of N_2O are especially important because its heat-trapping potential is approximately 310 times greater tha CO_2. Even though N_2O constitutes only a small part of U.S. GHG emissions, it is important because agriculture is its major source, and its close link with soil management and N fertilizer. Losses of N fertilizer as N_2O are usually relatively small from an agronomic perspective, but still make a significant contribution as a GHG (Mikkelsen and Snyder, 2012).

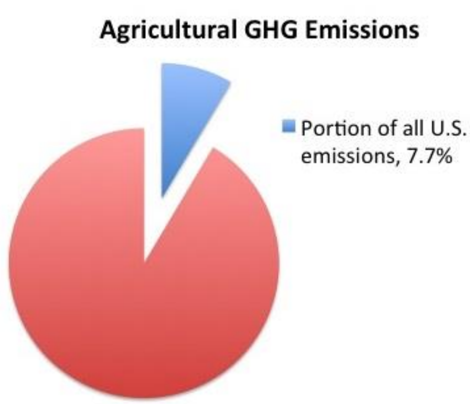

Figure 1. The EPA (2015) estimates that the agricultural sector is responsible for 7.7% of total U.S. greenhouse gas emissions.

Nitrous oxide emissions result from natural biological soil processes of nitrification and denitrification. The concentration of inorganic N in the soil is key in determining the magnitude of N_2O emissions. However numerous soil environmental factors, such as temperature, pH, soil texture, water-filled pore space, and soluble organic carbon also control rates of N_2O production. Although considerable research has been conducted to measure N_2O emissions from soil, fertilization and crop management practices are very site specific, making it challenging to predict the extent of N_2O loss. It is recognized that there is no single set of management practices that will increase productivity and reduce N_2O emissions equally well across broad geographies, but several basic nutrient and water management practices should be considered to minimize emissions (Lindquist et al., 2012).

THE BASICS: Right Source, Rate, Timing, Placement of Nitrogen Fertilizer

The foundation of most aspects of nutrient stewardship relies on the principles of using the right source, at the right rate, at the right time, and with the right placement. Mismanagement of the appropriate rate, source, timing, or placement of fertilizer N, and lack of proper balance with other essential nutrients will increase overall N loss and N_2O emissions.

Right Rate:

When N is applied above the economic optimum application rate, or when available soil N (especially nitrate) exceeds crop uptake, the risk of increased N_2O emissions rises. A meta-analysis by Van Groenigen et al. (2010) found a direct relationship between surplus soil N and yield-scaled emissions of N_2O (Fig. 2). Their analysis showed that when more N is applied than taken up by the crop, the risk for N_2O losses increases dramatically. When the appropriate amount of N fertilizer is added (Right Rate), there is no increase in N_2O losses compared with conditions where N fertilizer applications are drastically slashed. This demonstrates that arbitrary reductions in N fertilizer use below the agronomically appropriate rate may not result in decreased losses of N_2O. Since nitrate serves as a primary substrate for denitrification, it is important to minimize any excess accumulation in the soil.

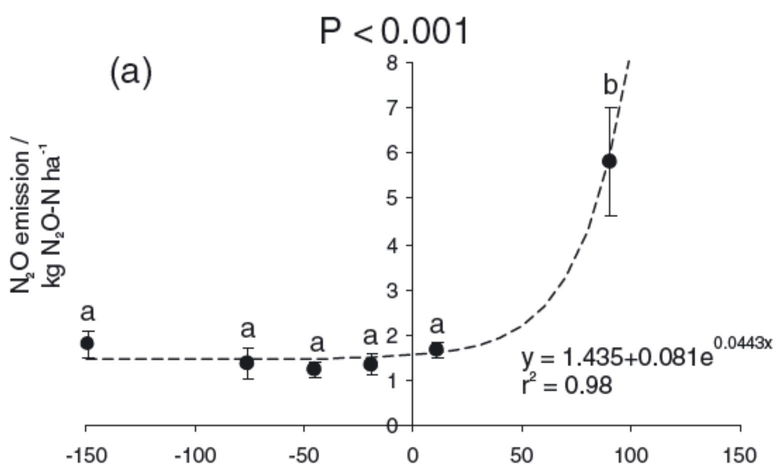

Figure 2. Meta-analysis results showing the relationship between N surplus and yield-scaled N_2O emissions. N surplus is defined as above-ground N uptake minus N application rate. Error bars denote standard errors (Van Groenigen et al., 2010). Left of zero on the x-axis indicates deficient N and right of zero indicates surplus N.

Right Source:

The source of added N fertilizer can have a significant effect on N_2O emissions. Anhydrous ammonia is sometimes identified as the N fertilizer most prone to N_2O losses, in part due to its placement in a concentrated band beneath the soil surface. Other N fertilizers that are initially alkaline in reaction (such as urea) can produce elevated N_2O emissions, especially when placed in a subsurface band. There is considerable interest in the use of enhanced-efficiency N fertilizers and additives as a means of reducing N_2O emissions. The effectiveness of enhanced-efficiency products often varies depending on site-specific cropping and environmental factors. For example, polymer-coated urea was effective at reducing N_2O emissions in some studies, but not in others. Similarly, nitrification and urease inhibitors show promise for reducing N_2O losses in many environments, but their effectiveness varies across farming ecosystems (Halverson et al., 2014).

Research conducted by the USDA-ARS has shown that enhanced-efficiency fertilizers can produce similar yields with lower emissions of greenhouse gases (Fig. 3). For example, work in Colorado measured a 60% reduction in N_2O emissions from irrigated soils and a 30% reduction for nonirrigated crops from their use.

When cover crops and legumes are used in crop rotations, they also can contribute to N_2O losses as they decompose. However, non-legume cover crops will reduce the concentration of inorganic N in the root zone, making it less susceptible to N_2O loss.

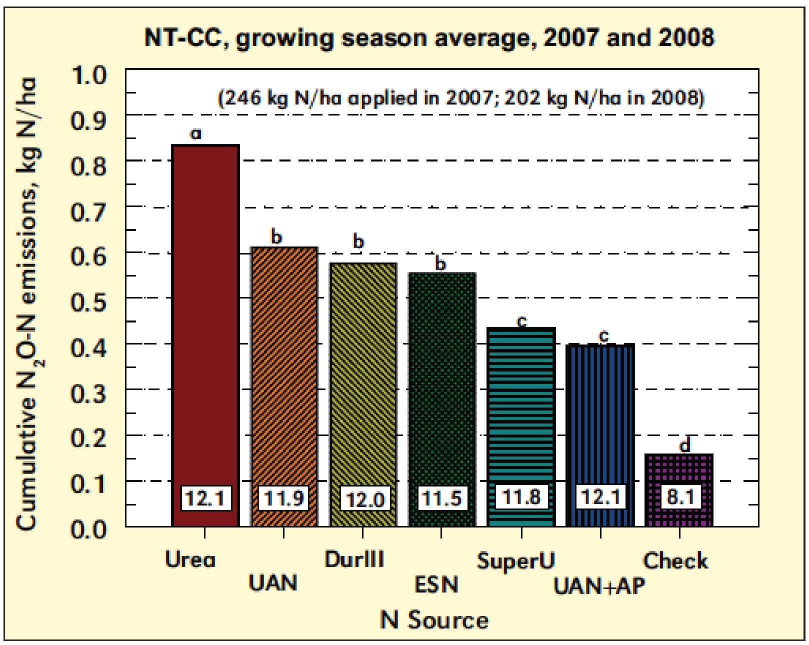

Figure 3. Average growing season N_2O emissions as a function of N source in a no-till continuous corn irrigated cropping system near Fort Collins, Colorado. Average grain yields (Mg/ha) are shown in a white box within each bar. Bars with same letters above are not significantly different at p = 0.05. DurIII and ESN are polymer-coated urea. Super U is urea with both a urease and nitrification inhibitor. (Halvorson et al., 2009).

Right Time:

In a notable review, Robertson and Vitousek (2009) stated that "Mismatched timing of N availability with crop need is probably the single greatest contributor to excess N loss in annual cropping systems." Improving the synchronization between plant demand and available N in the soil is an essential step for improving nutrient efficiency and reducing both gaseous and leaching losses. When N is applied during a time of low plant demand, there is increased risk of various losses. Minimizing the exposure of inorganic N in the soil by using multiple split applications or controlled-release fertilizers have shown promise in reducing N_2O emissions and leaching to groundwater when managed properly.

Right Place:

The effect of proper placement on minimizing N_2O emissions is not consistently understood. For example, in a review of over 800 studies, Bouwman et al. (2002) concluded that N_2O emissions were lower with subsurface injection compared with surface broadcast applications. However, other studies have not shown consistent effects of placement on N2O emissions. There are many site-specific factors that still need to be considered when selecting the right placement of N fertilizer to minimize N_2O losses, especially as it interacts with irrigation water.

A fundamental challenge with N fertilizer management is to maximize the amount that is used by the crop. Although N use efficiency has increased in the major crops in the U.S. in recent decades, there is still a need to further improve crop recovery and minimize farm losses (Snyder et al., 2014). In California, there is urgent need to simultaneously reduce nitrate leaching losses and GHG emissions, while sustaining production of crops that are exported around the world.

Other Agricultural Sources of Greenhouse Gas

When agricultural lime ($CaCO_3$) is added to soil to increase pH, a portion of the carbonate is released as CO_2. The most common N fertilizers (urea, anhydrous NH_3, UAN) generate at most 3.6 lb. of lime needed per lb. of N to balance the acidity they produce. Soil acidification is also associated with proton excretion by plant roots and removal of basic cations in crop harvests and the acidity of rainfall

The application of urea $[CO(NH_2)_2]$ fertilizer to soil results in a loss of the CO_2 that was added during manufacturing or from biological production. Urea is hydrolyzed to ammonium, hydroxyl, and bicarbonate. The bicarbonate then decomposes to water and releases CO_2.

Flooded rice is also another potential source of CH_4 emissions. On a global scale, flooded rice production is a significant contributor to agricultural GHG emissions. Snyder et al. (2009) made the following observations about making progress in reducing agricultural GHG emissions:

- Appropriate N fertilizer use helps increase biomass production necessary to help restore and maintain soil organic carbon levels;

- Best management practices for fertilizer N play a large role in minimizing residual soil nitrate, which lowers the risk of increased N_2O emissions;

- Differences among fertilizer N sources in N_2O emissions depend on site- and weather-specific conditions;

- Intensive crop management systems do not necessarily increase GHG emissions per unit of crop or food production; they can help spare natural areas from conversion to cropland

and allow conversion of selected lands to forests for GHG mitigation, while supplying the world's need for food, fiber, and biofuel.

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Sources and Mitigation Potential for Nitrous Oxide from Agricultural Activities in California

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Introduction

California's agriculture sector emitted 32.1 Tg CO_2e, or 7.0% of the state's total of 457 Tg CO_2e in 2009 (CARB 2011). The relative contribution of greenhouse gases from California agriculture differs substantially from that of the total emissions from the state. Most notably, nitrous oxide emissions only make up 3% of total emissions across all sectors but up to 33% of emissions from the agricultural sector (Table 1). Similarly, carbon dioxide accounts for a smaller proportion of emissions in agriculture (9%) than it does across all sectors of California (86%). The concern associated with N_2O is that it has a significantly higher (~300 times CO_2) global warming potential compared to other greenhouse gases.

Table 1. California Agricultural Emissions by Gas in 2009 and the Ten-Year Average

	2009	2000-2009 Average
Greenhouse Gas	**Tg CO_2e (% of Total)**	**Tg CO_2e**
CH_4	18.7 (58%)	17.1
CO_2	2.8 (9%)	4.3
N_2O	10.6 (33%)	10.4
Total	**32.1**	**31.8**

Source: CARB (2011).
Note: Tg = 1 million metric tons

Emissions from California agriculture come from a variety of sources, but three sources account for nearly 90% of total emissions (Table 2): manure management (32.2%), enteric fermentation (fermentation that takes place in the digestive system of animals; 28.9%), and agricultural soil management (the practice of utilizing fertilizers, soil amendments, and irrigation to optimize crop production; 28.1%). These three sources and energy use from agricultural activities (8.2%) make up over 97% of emissions from agriculture (CARB 2011).

Table 2. California Agricultural Emissions by Source in 2009

Agricultural Source	2009 Emissions (Tg CO_2e)	Percentage of Total
Manure management	10.34	32.2
Enteric fermentation	9.28	28.9
Soil management	9.02	28.1
Energy use	2.63	8.2
Rice cultivation[a]	0.58	1.8
Histosol cultivation[b]	0.16	0.5
Residue burning	0.06	0.2

Source: CARB 2011.
[a] Primarily methane emissions
[b] Primarily N_2O emissions combined with loss of soil C as CO_2

Methods

The available scientific literature was evaluated with the goal of determining the biophysical mitigation potential of various crop management practices relevant to California agriculture. Published studies in peer- reviewed literature were the primary basis for the review; other sources of information were theses, dissertations, and government reports. In Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: In a synthesis of the Literature, Eagle et al. (2012) examined biophysical mitigation potential of 42 agricultural land management activities. A subset of those crop management activities most relevant to California agriculture was used to determine the biophysical mitigation potential of various crop management practices in California. For any given management activity, the approach determined the management treatment considered the most widely practiced by growers. Within each reviewed activity, the “standard” or “conventional” management practice was treated as the baseline emissions value. The effects of alternative management practices on emissions were then assessed relative to this baseline conventional treatment—for example, conventional tillage, which is widely practiced in California’s annual systems. These comparisons produced a biophysical mitigation potential, defined as the difference between the control treatment and the alternative management activity. Positive values reflect a net increase in mitigation potential, as greenhouse gas (GHG) emissions are reduced relative to the control. Negative values reflect a net decrease in mitigation potential, where emissions are increased relative to the control.

Key Findings

- Agriculture contributes approximately 7% of California’s total GHG emissions; less than 3% coming from croplands.
- Relatively few field studies conducted in California rigorously examine GHG emissions from changes in agricultural management activities and practices. Thus, more research could inform future management and policy alternatives.
- Average GHG emissions from urban land uses are orders of magnitude higher than those from California croplands (approximately 70 times higher per unit area), therefore farmland preservation, more than any other management activity, will likely have the single greatest impact in stabilizing and reducing future emissions across multiple land use categories.
- More than half of California croplands are devoted to perennial agriculture; a relatively large proportion (34%) is in orchards and vineyards. Studies indicate that perennial crop emit significantly less N_2O than annual row crops. These perennial systems likely mitigate a relatively large amount of GHG emissions when converted from annual crops (ranging from 2.92 to 5.24 t CO_2e ha^{-1} yr^{-1} (Eagle et al. 2012)), but the magnitude of emissions reduction remains uncertain.
- Increasing N fertilizer rates generally leads to increases in N_2O emissions. However, N fertilization is imperative to maintain the productivity of California cropping systems. An arbitrary reduction of N fertilization rates is often not economically feasible for growers and has large implications for state, national, and global food security. Efforts to increase N-use efficiency by avoiding N rates that greatly exceed those required for economically optimum yields offers moderate potential to reduce N_2O emissions—a particular concern given rapid adoption of micro-irrigation practices that necessitate reassessment of N fertilizer rates. Likewise, calculations of yield-scaled emissions should be more frequently employed to evaluate N_2O emissions relative to the productivity of the cropping system.

- Substituting a lower-emitting N fertilizer source offers moderate potential to reduce N_2O emissions (-0.16 to 1.85 t CO_2e ha^{-1} yr^{-1}). However, very little information on California-specific cropping systems exists. The best solutions would provide comparably priced fertilizers that require no major modifications to current management practices.
- There are few field experiments examining the effects of N placement and timing for California cropping systems.
- Moderate reductions in N_2O emissions are possible with N fertilizer efficiency enhancers, such as polymer-coated fertilizers (35%), nitrification inhibitors (38%), and urease inhibitors (10%). These products can enhance the efficiency of N fertilizers by helping match N availability with crop demand. However, these products are not widely used in California cropping systems due to concerns regarding their cost. Their efficacy in micro-irrigation systems is likely diminished, because N-use efficiency is increased by fertigation.
- Irrigation technologies such as sub-surface drip irrigation offer opportunities to reduce N_2O emissions (0.31 to 1.26 t CO_2e ha^{-1} yr^{-1}) with co-benefits of improved yield and water use for some cropping systems.
- Conservation tillage practices have had very poor adoption rates in California relative to other regions in the United States. Although these practices generally provide a number of agronomic and environmental benefits, their potential to mitigate GHG emissions in California—studies show ranges from -0.69 to 0.65 t CO_2e ha^{-1} yr^{-1}—are highly uncertain.
- Cover crops and organic amendments' effect on emissions are not well understood in California. These crops and amendments offer opportunities to reduce synthetic N inputs and increase internal nutrient cycling efficiencies, but they may also increase direct N_2O emissions (in particular, leguminous cover crops). Limited studies demonstrate that N_2O mitigation potential ranges from -1.69 to 0.89 t CO_2e ha^{-1} yr^{-1}.

For further details on this report see Culman et al., 2014.

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Dairy Sustainability and Carbon Footprint Implications[1]

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Production efficiency in the dairy industry can be defined as minimizing the amount of inputs (e.g., feed, fossil fuels) and outputs (e.g., ammonia, NH_3; greenhouse gases, GHG) to produce a given quantity of milk or meat. The present paper will focus on the dairy example. Production efficiency improvements can come from minimizing waste, maximizing a dairy cow's milk production, and maximizing the proportion of her life spent in peak milk production without sacrificing animal health and well-being. To a degree, when milk production per cow is improved, the life-cycle emissions of dairy production decrease per unit of milk (i.e., per kg of 3.5% FCM; VandeHaar and St-Pierre; 2006). This is achieved through a dilution of maintenance costs per kilogram of FCM at the level of both the individual cow and the entire US dairy production system. Cows that produce more milk reduce the proportion of total consumed feedstuffs going toward maintenance energy costs (Moe and Tyrell, 1975; Bauman et al., 1985; VandeHaar, 1998). Secondarily, more milk per cow can decrease the total lactating herd size needed to produce a given quantity of milk (Capper et al., 2008, 2009). Past improvements demonstrate the ability of production efficiency to decrease the environmental impact per unit of milk. Capper et al. (2009) found that historical advances in genetics, nutrition, and management of dairy farms allowed dairy production in 2007 to emit 43% of the CH_4 and 56% of the N_2O that were emitted in 1944 to produce one billion kilograms of milk. As the following sections demonstrate, more opportunities for improving a dairy's production efficiency exist that could lead to further reductions in emissions per kilogram of FCM, not just here in the US but globally.

Heifer Management.

Replacement heifers are an important part of the life-cycle emissions of a kilogram of FCM. Before calving, heifers are consuming inputs and producing both GHG and air pollutants without contributing to the production of milk. In the milk-fed stage of a heifer's life, she can efficiently convert consumed energy and protein into lean body tissue without depending on emission-producing rumen microbes. Recent research has found that increasing and altering the nutrients supplied to milk-fed calves can improve growth rates and feed efficiency (Brown et al., 2005; Bascom et al., 2007; Hill et al., 2008). "Intensified" feeding programs for dairy heifers have been shown to lower age at first calving (Raeth-Knight et al. 2009), with no reduction (Van Amburgh et al., 1998) or even an improvement in first-lactation milk yield (Drackley et al., 2007). Both decreasing the current national average age at first calving of 25.2 months (USDA, 2007) and increasing first-lactation milk yield could improve milk's life-cycle production efficiency and decrease emissions per kilogram of FCM. Colostrum administration is another aspect of heifer management that can affect GHG and air quality emissions per kilogram of FCM. Dairy calves depend on passive immunization from the absorption of antibodies in colostrum to provide adequate immunity during their early life stages (Robison et al., 1988).

[1]Excerpts from: Contemporary environmental issues: A review of the dairy industry's role in climate change and air quality and the potential of mitigation through improved production efficiency S. E. Place and F. M. Mitloehner. J. Dairy Sci. 93:3407-3416.

Failure of passive transfer of immunity leads to increased mortality and morbidity and decreased growth performance (Robison et al., 1988; Beam et al., 2009). Administering the proper quantity of high quality colostrum within the first few hours of life has been shown to improve long-term animal health and first-lactation performance (DeNise et al., 1989; Faber et al., 2005). Beam et al. (2009) estimated that failure of passive transfer occurs in 19.2% of US dairy heifer calves; therefore, decreasing this incidence could substantially decrease death and performance losses and lessen emissions per kilogram of FCM.

Herd Health.

Herd-health challenges affect per-unit of-milk emissions by increasing mortality and losses of saleable milk and decreasing reproductive performance and milk production efficiency. Herd health is influenced by many factors, including management, nutrition, the environment, and social stressors. Over the past 25 yr, the dairy industry has steadily shifted its structure toward fewer farms with larger herds and fewer workers per cow. In 2008, 3,350 US dairy farms with 500 or more cows (approximately 5% of total dairy operations) produced 58.5% of the nation's milk with 54.9% of the nation's dairy cows (NASS, 2009). Along with the industry's consolidation, milk production per cow has doubled over the past 25 yr, although it appears that disease incidence has remained stable (LeBlanc et al., 2006). However, the productive life of Holsteins in the United States born in 2000 decreased by 3.95 months compared with Holstein cows born in 1980 (Dechow and Goodling, 2008). Thus, opportunities exist for the dairy industry to advance production efficiency by improving herd health to simultaneously enhance milk production, reproductive performance, and cow longevity. When dairy cattle transition from a pregnant, non-lactating state to a lactating state, they face a tremendous change in their metabolic requirements (e.g., Ca requirements are estimated to increase 4-fold on the day of parturition; Overton and Waldron, 2004). Consequently, most health concerns arise during the transition period. Approximately 75% of disease occurs within the first month after calving (LeBlanc et al., 2006), and a study of Pennsylvania dairy herds found that 26.2% of dairy culls occur from 21 d before to 60 d after calving (Dechow and Goodling, 2008). Recent research has linked disease incidence and excessive negative energy balances during the transition period with significant decreases in milk yield and reproductive success during the subsequent lactation (Drackley, 1999). Further research into the biology and management of transition cows and the extension of this critical knowledge to commercial herds can enhance the life-cycle efficiency of the US dairy production system. Environmental or social stressors can decrease the production efficiency of the cow and subsequently increase the emissions of each kilogram of milk that she produces. Heat stress has been estimated to cost the dairy industry nearly $1 billion per year in decreased milk production, reproductive performance, and increased death losses (St-Pierre et al., 2003). With regard to social stress, grouping animals according to size and age and minimizing overcrowding can improve DMI, consequentially improving milk production (Grant and Albright, 2001). Improving cow cooling during hot summer months and grouping animals to minimize behavioral stress has been the focus of research to improve farm profitability, but these improvements have the potential to decrease emissions per kilogram of FCM as well. Mastitis is a herd-health challenge that can affect emissions per kilogram of FCM by decreasing milk production performance and increasing losses of saleable milk. Hospido and Sonesson (2005) analyzed the environmental impact of mastitis using an LCA of dairy herds in Galicia, Spain. The authors found that decreasing the clinical mastitis rate from 25 to 18% and the subclinical mastitis rate from 33 to 15% reduced the GWP of a unit of milk by 2.5% (Hospido and Sonesson, 2005) because of increased input-use efficiency, decreased losses of milk production, and a decreased amount of waste milk. Lameness is a critical herd-health concern that seems to have worsened over the past 25 yr (LeBlanc et al., 2006). Lameness or injury is responsible for approximately 20% of mortalities and 16% of selective culls in mature US dairy cows (USDA, 2007). In addition to decreased survivability, lameness causes decreased milk production (Warnick et al., 2001) and poorer reproductive performance in affected cows (Garbarino et al., 2004). Improved facilities, management, nutrition, and genetics all have the potential to decrease the incidence of lameness (Baird et al., 2009) and decrease emissions per kilogram of FCM.

Nutrition and Feed Production.

The nutrition of dairy cattle greatly determines the emissions produced directly by the ruminant animal and its waste. Diet composition can alter rumen fermentation to reduce the amount of CH4 produced (Ellis et al., 2008) and, as previously discussed, the NH3 emissions produced from the manure (James et al., 1999; VandeHaar and St-Pierre, 2006). The substrates used by methanogens are byproducts of structural carbohydrate fermentation; thus, high concentrate diets containing more nonstructural carbohydrates can lead to decreased CH4 emissions (Lana et al., 1998; Ellis et al., 2008). However, diets very high in concentrate (such as those fed to the majority of US beef feedlot cattle) can decrease rumen pH and lead to rumen acidosis (Owens et al., 1998). Furthermore, very high concentrate diets diminish the principal environmental benefit of dairy cows: their ability to convert cellulose, indigestible to humans and the Earth's most abundant organic molecule, into high-quality proteins for human consumption (Oltjen and Beckett, 1996). Therefore, the CH4 produced by dairy cattle cannot simply be seen as a gross energy loss and GHG source but is a necessary consequence of transforming inedible fibrous forages and byproducts (e.g., almond hulls, citrus pulp, distillers grains) into food and fiber products fit for human use. Nonetheless, substantial reductions in CH4 emissions can be achieved without feeding high levels of concentrates by altering the previously mentioned nutritional factors: microbial-altering feed additives, dietary lipids, and forage processing and quality (Johnson and Johnson, 1995). Feed additives, such as the ionophore monensin, can change microbial processes in the rumen to potentially improve feed efficiency and reduce CH4 emissions (Tedeschi et al., 2003). However, research with monensin has shown conflicting results (Guan et al., 2006; Odongo et al., 2007; Hamilton et al, 2009; Hook et al., 2009), which suggests a need for more in-depth research on its effect on rumen microbial populations and the metabolism of dairy cows. Alternatives to ionophores such as probiotics (e.g., yeast), essential oils, and biologically active plant compounds (e.g., condensed tannins) have shown promise for CH4 reductions; however, most research to date has been conducted in vitro and more in vivo studies are needed to evaluate the effect of these alternatives on CH4 and their commercial viability (Calsamiglia et al., 2007; Beauchemin et al., 2009b). Dietary lipids, specifically unsaturated fatty acids, have the potential to act as an alternate H sink in the rumen, thereby reducing the H available to methanogens and the CH4 produced (Ellis et al., 2008). Additionally, CH4 reductions from feeding dietary lipids can be attributed to their suppression of fiber-digesting bacteria and toxicity to protozoa closely associated with methanogens (Hristov et al., 2009). Johnson et al. (2002) tested the ability of canola and whole cottonseed to reduce CH4 and found no difference in emissions when compared with a control diet, whereas other researchers have found crushed canola seed to have a CH4-suppressing effect (Beauchemin et al., 2009a). The inconsistency of the effect of dietary lipids on CH4 is due, in part, to the variation in diets, the fatty acid profile, amount and form of the lipid source, and the length of the feeding trial, because the rumen ecosystem may adapt to lipid supplementation (Martin et al., 2008; Beauchemin et al., 2009a). Although lipids do have the potential to reduce CH4 emissions, consideration must be given to their adverse side effects of reducing DMI or decreasing milk fat when fed at levels over a critical threshold (Giger-Reverdin et al., 2003; Martin etal., 2008).

Furthermore, the source and availability of lipids must be considered, because price will dictate their commercial adoption, and long-distance transport of lipid sources may defeat their emission-reducing potential by increasing fossil fuel combustion. Forage quality and management can affect both air quality and GHG emissions per kilogram of FCM. Fermented feeds are a major source of VOC (Alanis et al., 2008) and require substantial fossil fuel inputs during their production (de Boer, 2003; Schils et al., 2007); therefore, minimizing dry matter loss throughout the production, storage, and feeding of these feedstuffs will decrease the air quality and climate change impact of each kilogram of feed. Higher quality forages, produced by ideal crop production, harvesting, and preservation practices, maximize DMI and milk production (Oba and Allen, 1999). Additionally, forages with higher digestibility and higher rates of passage out of the rumen have the potential to reduce enteric CH4 emissions for each unit of feed consumed (Johnson and Johnson, 1995). So-called precision feeding that closely matches the nutrients needed by the dairy cow for maintenance, growth, lactation, and gestation to the supplied dietary nutrients can minimize the environmental impact of the cow's excreta (Tylutki et al., 2008).

Precision feeding requires nutritional models with sufficient accuracy and a level of management that can reduce the feeding system's variation (Wang et al., 2000). By constantly monitoring the dry matter and nutrient composition of feedstuffs, dairy producers can avoid expensive overfeeding and minimize nutrient excretion that can lead to emissions. The potential reduction in NH3 emissions by more tightly managing the CP content of the diet to match the animal's needs is substantial because most of the N fed over requirements is excreted as urinary urea-N. Castillo et al. (2001) found that cows with intakes of 419 g of N/d had similar milk production as cows consuming 516 g of N/d; however, 74% of the extra 94 g of N/d was excreted as urinary urea-N, which could be lost to the environment as NH3 emissions. Moreover, a precision feeding strategy decreases the amount of refusals, which may become waste on a dairy or be fed to other production groups (e.g., lactating cow refusals fed to heifers) that have dissimilar nutrient needs, thereby increasing the likelihood for higher nutrient excretion (St-Pierre and Thraen, 1999). Additionally, closely monitoring and ensuring the correct nutrition of individual groups of animals can minimize the risk of other nutritionally influenced diseases and conditions, such as ketosis, lameness, and prolonged anestrous (Lucy, 2001; Roche, 2006). Overall, managing feed and feeding programs to minimize waste while maximizing milk production can improve farm profitability and decrease the life-cycle emissions per kilogram of FCM.

Reproduction.

Perhaps not as apparent as nutrition, reproductive performance greatly affects emissions per kilogram of FCM. Dairy cows that have extended calving intervals because of conception failure spend more time out of peak milk when feed conversion into milk is most efficient. The total productive lifetime of many dairy cows is determined by reproductive performance, because reproductive problems are responsible for 26.3% of the selective culls in the United States (USDA, 2007). Over the past 30 yr, the reproductive performance and productive lifetime of dairy cattle have substantially decreased while milk production has increased (Lucy, 2001; Dechow and Goodling, 2008). The negative effect per kilogram of FCM emissions caused by declining reproductive efficiency has likely been offset by increases in milk production per cow. However, restoring reproductive performance in combination with increased milk yield would further reduce emissions per kilogram of FCM. Garnsworthy (2004) modeled the environmental impact of reproductive performance and milk production in the United Kingdom. The model found that both higher milk yield and improved reproductive performance (better estrus detection and conception rates) contributed to reduced CH4 and NH3 emissions because of the smaller lactating and replacement herd population required to meet UK production quotas (Garnsworthy, 2004). The cause of the decline in reproductive efficiency of dairy cattle is multifaceted and is not completely understood currently (Ingvartsen et al., 2003), because reproductive success is influenced by nutrition, genetics, health disorders during transition, management, and the environment (Lucy, 2001).

The level of reproductive success across all US herds is variable by region, breed, and management (Norman et al., 2009), suggesting that improvements are achievable. Encouragingly, recent data show that the long-term trend of decreasing reproductive performance and survivability may be slowing or reversing (Hare et al., 2006; Norman et al., 2009). Extensive research in dairy cattle reproduction is needed to identify the factors impeding fertility and to further develop strategies to improve reproduction on commercial herds. Wide adoption of these successful reproductive strategies could potentially lengthen the productive life of the US dairy cow and lower emissions per kilogram of FCM. Sexed semen is a reproductive technology that has the potential to both help and hurt the impact of the dairy industry on air quality and climate change per kilogram of FCM. If used selectively, sexed semen can increase the rate of genetic gain in dairy cattle, allowing advantageous traits to become ubiquitous in the entire dairy cattle population (De Vries et al., 2008). Furthermore, on average, heifer calves are smaller than bull calves and cause fewer dystocias, which may allow for earlier breeding of heifers, and fewer mortalities and health problems (Weigel, 2004). However, if all animals are bred with sexed semen (or even all heifers), the replacement population for the US dairy herd will increase in size. To keep the total population of dairy cattle at a level that does not create an oversupply of milk, the lactating cow cull rate must increase. Again, this can be advantageous, because poor performing animals and those with poor genetic merit would likely be culled, but in the context of environmental impact per kilogram of FCM, the widespread use of sexed semen could increase emissions per kilogram of FCM by shortening the total productive lifetime of dairy cows. Furthermore, a larger replacement herd size means more nonproductive emissions for each kilogram of FCM produced.

Overall, this paper shows that some of the most important gains that can be achieved in mitigation of dairy environmental impacts are tightly connected to efficiencies around feed and feeding as well as reproductive management.

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American Society of Agronomy

California Chapter

Session 9

Biologicals for Enhancing Crop Growth

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How Can a Grower Make Informed Decisions for the Use of Bio-stimulants?

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Over the past several years, Salinas Valley produce growers initiated development of a survey to create a more manageable process by which they might screen products that purport to offer a sweeping array of benefits for production, conservation, and/or the financial bottom line of their businesses. The template shared here is the result of a joint effort of a diverse group of stakeholders all sharing a common interest of supporting both emerging technologies and efficient use of grower time as they consider use of new products, services and technologies.

One grower describes demand for this effort as follows: "*As a grower who has been bombarded with "miracle" products for the last 45 years, I and others in the Ag industry felt the need for a screening process to truly see if there is merit to some of these products. Promises of increased yields and quality, and reduced water and fertilizer inputs were the norm, but alas, most if not all of these products fell short of their stated goals. Many of these products showed positive results in the Midwest and in areas where conditions were less than ideal. In the Salinas Valley most of our soils have been treated with care and are realizing close to maximum potentials in yield and quality. Because of mandated improvements to ground and surface water, we are always seeking ways to reduce inputs and this seems to have created a feeding frenzy for "snake oil" sales. Our goal is to find those few worthy products that can help us achieve these goals in the most efficient manner possible.*"

The intent of the template was to guide those marketing products, services or technologies to use agronomic terms to explain where and when benefits might be expected, with reference to specific cropping systems, soil, climate, and other site specific conditions. Data demonstrating benefits, with clear description of conditions in which effects were noted, is called out as a critical element to support consideration of the use of the product, service or technology.

By sending a clear signal to those creating and marketing new products, technologies and services about what kinds of information growers seek as they consider innovative approaches, those developing these emerging tools may tailor presentations that effectively capture grower attention. With good grower engagement to trial new strategies, an efficient feedback loop can help pinpoint emerging tools and strategies that work in site-specific, well-described cropping situations.

Those who wish to describe their product, service or technology may pay a fee to have it included in a Central Grower Shipper database available to its members. A PDF of the template (shown below) is available at no cost via a link on the B-Connect Ag Innovation Website (http://steinbeckinnovation.org/bconnect/).

Ag Innovation B-Connect Product Service Summary Form

Technological innovation and prioritization of new scientific studies drive Salinas and Pajaro Valley (S&PV) agriculture's ability to thrive, lead, and self-sustain. While there are many ideas, there's not a mechanism in place for farmers or researchers to funnel, objectively review, and publicly test these ideas. This survey builds a framework to draw in ideas that are reviewed with consistent, objective metrics. Your survey answers will be made public for use by farmers and other interested parties.

Product Category
You may check up to three boxes. Please indicate by numbering 1-3 top categories that apply.

- ☐ Fertilizer
- ☐ Pest Control
- ☐ Disease Control
- ☐ Soil Conditioner
- ☐ Water Treatment
- ☐ Sanitizer
- ☐ Food Safety Related
- ☐ Conservation Support
- ☐ Water Conditioner
- ☐ Mechanical/Electronic
- ☐ Other (please describe:____________________________)

What are you looking for?

- ☐ Funding
- ☐ Peer-Reviewed Trials
- ☐ Connection to Industry

Company Identification

1. Company Name
2. Contact for more information about product (name, phone, email)
3. In which state (or, if not within the United States, country) is your company based?
4. How long has your company been in business?
5. Do you define your company as a start-up?
    a. If so, what are your primary funding sources?

Product Identification

1. Product Name
2. Product Manufacturer
3. Product Labeled As (trade names if using chemical materials)
4. Where available for purchase, name and contact information for sales agent, if appropriate

5. Please provide *detailed* description of product (e.g. active ingredient(s), how it is manufactured/procured/derived, lab analysis of material, etc.) to the level you are able.
6. Is this product's ingredient(s) and process for use in compliance with CA regulatory requirements?
7. What crops or range of crops do you expect to achieve best results with this product?

Product Summary (Optional)

You may include a brief description highlighting key information from the detailed summary this sheet requests. Maximum length 250 words. Longer summaries will not be included.

Please provide information to answer the following questions with as much detail as possible.

Product Profile Questions

1. Benefits
   1.1. Please provide 3rd party, independent research findings (e.g. data, with accompanying statistical analysis, summary of key results and discussion) demonstrating the effect of the product. Include description of conditions under which tested (e.g. what crops, soil, irrigation type, climate, etc.)? Please include as much detail as possible re: acreage required of trials, replications, randomization, sampling methods, dates of trial, management etc. If available, please include photos showing control vs. treatment.
      1.1.1. Please provide URL links to any 3rd party, independent research findings, peer reviewed findings, and/or local trial details.
   1.2. What are the expected benefits of using the product? Please be as precise as possible (e.g. increased yield/crop quality, reduced pest/disease damage, conservation benefit, etc.)
   1.3. What are the processes (e.g. mode of action) by which the product achieves those benefits? Please use the principles of plant and soil science to describe (e.g. increases soil flocculation to improve infiltration, plant growth hormone to stimulate cell division, etc.).
   1.4. What is the expected monetary value of those benefits and how are they realized (e.g. reduced fertilizer cost, reduced water use, increased yield/quality, reduced pest/disease loss, etc.)?

2. Costs
   2.1. What are the expected costs per acre for the product as used during production of a crop? Please show calculations in terms that are most relevant for the product, for example, grower cost per unit, application rate or acres treated per unit, expected number of applications. If expected cost for use of the product differs among crops or production conditions, please describe those differences.
   2.2. What is the recommended application rate? If appropriate please provide range for different settings, crops or conditions.
   2.3. What are the costs per acre for the product at the recommended application rate?

2.4. What additional expenses could be incurred in use of the product (e.g. new equipment needs, staff training, staff time, etc.)?
2.5. What changes in production practices are needed to use the product (e.g. compatibility with existing management practices/materials, new or modified equipment needs, altered management schedule, etc.)?

3. Factors that Affect Performance
   3.1. Under what conditions does the product provide the most benefits? Please provide data to document any statements.
   3.2. Under what conditions is the product least likely to provide benefits, or may actually be deleterious? Please provide data to document any statements.
   3.3. What are the soil, weather, biotic, management, and other factors that most meaningfully affect the performance of the product? Please provide data to document any statements.

4. Instructions for Use of the Product
   4.1. What are the instructions that you would provide to growers to commercially use the product in the Salinas and Pajaro Valleys?
   4.2. How would overall production practices needed for and resulting from use of the product differ from current practices? Please include any notable impact on production of subsequent crops, overall farming practices, or other changes not directly related to the treated crop.

5. Regulatory Considerations
   5.1. Does your product require regulatory approval?
      5.1.1. If so, which regulatory agencies will be involved?
   5.2. Does this product qualify for use in organic production?
      5.2.1. If so, has it been approved by the Organic Materials Review Institute?
   5.3. Does this product replace something already in use?
      5.3.1. If so, why would this provide a better solution?

Results from Real World Replicated Testing of Several Biostimulants, Making Sense of the Data

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Introduction

Holden Research and Consulting specializes in conducting applied research in the areas of nutrient and pest management for coastal California grown crops including winter and summer vegetables, avocados, citrus, grapes, and berries (blueberries, raspberries, and strawberries). Holden Research has been active full time in Ventura county and statewide since 2002 with previous trials dating back to 1984, having completed 1200 field trials. More recently these trials have focused on improving nutrient use efficiency (NUE) of crop required elements, improving production under drought conditions, and discovery and development trials in the area of biologicals and biostimulants.

Defining Biostimulants

From a regulatory perspective there is currently no official recognition or definition for Biostimulants. Products such as seaweed extracts, humic-fulvic acids, other plant based extracts, fermentation process metabolites, biological spore packages, etc. fall into this category. The European Biostimulants Industry Council (EBIC) defines biostimulants as: "Plant biostimulants contain substance(s) and/or micro-organisms whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance/benefit nutrient uptake, nutrient efficiency, tolerant to abiotic stress, and crop quality." The Biostiumulant Coalition is a group of American companies seeking to help clarify this class of materials. "The Biostimulant Coalition is a group of interested parties cooperating to proactively address regulatory and legislative issues involving biological or naturally-derived additives and / or similar products, including but not limited to bacterial or microbial inoculants, biochemical materials, amino acids, humic acids, fulvic acid, seaweed extract and other similar materials."

What are Biostimulants and How Do They Work?

There are many opinions, theories, and questions on the actual mechanisms that apply to these products. The purpose of this investigator's work has to demonstrate the products functionality through real world testing and data collection of information that is important to growers. These projects have been designed to separate the theory from the true functionality of the products under both non-stress and stress environments that can be abiotic or biotic. Though some of these products may act like plant growth regulators (PGR), they generally do not fall into the classical definition of a PGR. Many of these products do not have one well defined molecule, but rather a "soup" of molecules as seen in humic acids and seaweed extracts derived from Ascophyllum nodostrum. They all seem to be supplemental in nature and not primarily needed such as the seventeen essential plant elements. In fact they seem to shine under abiotic stress environments and less so under more ideal growing situations. There is no one common denominator, beyond the above definitions that tie these products together. They are generally organic, that is from a carbon source, may or may not be "alive", and many times as mentioned before a "soup" of multiple molecules.

Web Sites Cited

Webpage for European Biostimulants Industry Council: http://www.biostimulants.eu/
Webpage for Biostimulants Coalition: http://www.biostimulantcoalition.org/about/

A Review of Commercial Biostimulant Products

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The global biostimulant market is growing at a rate of 12.5% per year, and is predicted to reach a value of $2524.02 million by 2019 (Rohan, 2016), however there is not a clear definition of what a biostimulant is, which leads to challenges for regulators, pest control advisors, growers, and the general public. In California, the Department of Food and Agriculture states that "biostimulant" is not allowed on fertilizing material labels, as it is not defined, and is misleading (California Department of Food and Agriculture, 2013), however many products are still marketed as biostimulants. Several groups have attempted to define biostimulant, most notably the European Biostimulant Industry Council (EBIC), and the Biostimulant Coalition. In 2011 EBIC adopted the following definition "Agricultural biostimulants include diverse formulations of compounds, substances and other products that are applied to plants or soils to regulate and enhance the crop's physiological processes, thus making them more efficient. Biostimulants act on plant physiology through different pathways than nutrients to improve crop vigour, yields, quality and post-harvest shelf life/conservation" and additionally specifies that biostimulants have different mechanisms than fertilizers, with no direct action against pests or disease (http://www.biostimulants.eu/2011/10/biostimulants-definition-agreed/).

The Biostimulant Coalition considers biostimulants to be products that "when applied in small quantities, enhance plant growth and development help improve the efficiency of plant nutrients, as measured by either improved nutrient uptake or reduced nutrient losses to the environment, or both; or Act as soil amendments, with demonstrated ability to help improve soil structure, function or performance and thus enhance plant response; or Contribute to all of the above functions" (http://www.biostimulantcoalition.org/about/). Several published papers have also attempted to define biostimulants. This category of products is growing, and needs regulatory clarity (Jones, 2015). The lack of clarity about biostimulants has contributed to confusion to the consumer.

Based on the above definitions, and recent research on signaling during plant stress, Brown and Saa (2015) hypothesize that "biostimulants benefit plant productivity by interacting with plant signaling processes thereby reducing negative plant response to stress." Several main categories of plant biostimulants have been identified (du Jardin, 2015); humic and fulvic acids, protein hydrolysates and amino acids, seaweed extracts and botanicals, chitosan and other biopolymers, inorganic compounds, beneficial fungi, and beneficial bacteria. Biostimulants are a very diverse set of products, ranging from single compounds, to multiple compounds, and microorganisms. Many of these biostimulants have multiple modes of action, and the bioactive compounds have not been fully characterized in these products. The functions of these different bioactives are very diverse within the plant, and sometimes benefits claimed in advertising materials do not seem to be substantiated by research, often benefits demonstrated with one product are claimed by another. Benefits claimed by biostimulants tend to be similar, and include increased tolerance to abiotic stress (drought, salinity, cold), increased nutrient uptake, improved yield and quality, increased biotic stress resistance, higher plant vigor, and increased root growth (Calvo et al., 2014).

Although there are similar claims between different biostimulants, products will have varying modes of action and different benefits due to the diverse range of ingredients and bioactives. Even products from the same 'class' of products can have very different properties. Research using quantitative nuclear magnetic resonance spectroscopy (qNMR) was able to detect differences in the compounds present in commercial seaweed extract products made from different seaweed species (Craigie et al., 2007). It is expected that different compounds present in different extracts will have different activity. Craigie, McKinnon, & Walter (2007) also found that commercial seaweed extracts produced from the same seaweed species (*Ascophyllum nodosum*) showed differences in qNMR spectra, indicating that different methods used to process the seaweed also can have a significant impact on biostimulant properties and bioactivity. This adds to complication in evaluating efficacy of different extracts, as each product needs to be evaluated independently, and results from one biostimulant cannot be assumed to be the same for another product, even for the same class or type of biostimulant.

Many biostimulants are produced from natural products (Calvo et al., 2014; du Jardin, 2015), and therefore the potential for variability in the manufactured product is high. There are few published reports that look at the consistency of the presumed active ingredients of biostimulants, and research shows variability in responses to commercial biostimulants. This consistency of the retail product is very important to ensure consistent results in both research trials and practical applications in the field. For example, seaweeds have different types of growth periods throughout the year, depending on species and growing location (i.e. dormant, reproductive, and vegetative). The differences in the raw material, based on growth period, may impact the bioactive compounds in the finished product. Research looking at seasonal variation in polyamines (one of the presumed bioactives in a biostimulant made from the seaweed *Ecklonia maxima*) showed that the levels of putrescine and spermine in both the seaweed stipe and frond varied significantly, not only throughout the year, but also between years (Papenfus et al., 2012). This same work also found that the levels of these polyamines varied significantly in the commercial seaweed extract also. Similar work looking at levels of plant growth regulators (PRGs) in a commercial seaweed extract showed inconsistencies in levels based on storage time (Stirk et al., 2013), and storage conditions (Stirk et al., 2004), however a recent publication (Wally et al., 2012) questions the presence of biologically active levels of PGRs in seaweed extracts. Craigie et al. (2007) used qNMR to demonstrate that there can be consistency in *Ascophyllum nodosum* seaweed extract biostimulants regardless of location and time of year the raw material was harvested, indicating that the process used to make the extract can impact consistency.

A growing body of published research demonstrates the benefits of biostimulants for use in agricultural productions, however this category of crop inputs has a large number of unsubstantiated claims, and it is clear that a solid research base demonstrating consistency and efficacy of a particular biostimulants is necessary to ensure the value of these inputs.

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American Society of Agronomy

California Chapter

Session 10

Salinity Management

Session Chairs:

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Physiology of Salinity Stress in Almond

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Introduction

Almond is classified as a salt-sensitive crop and salinity is increasing in all almond growing regions of California. It will become a greater problem as the availability and quality of irrigation water is reduced. Information about the physiological effects of salinity stress on almond trees and the tolerance mechanisms that impact the performance of almond trees in saline environments is very limited. The relative contributions of salinity-induced water stress and specific ion toxicities to the impact of salinity on almond trees in the short and long term are not documented. While trials and observations indicate that there is a wide diversity of tolerance to salinity among the available rootstocks and cultivars, the physiological basis for these differences has not been elucidated.

In addition to selection of tolerant rootstocks and cultivars, salinity management strategies typically include application of sufficient water to leach salts from the effective root zone. How limited high-quality irrigation water should be utilized for best results in terms of salinity management in almond orchards has not been investigated. In-season recovery treatments with high-quality irrigation water may alleviate salinity stress to an extent that cannot be solely explained by leaching.

Micro-irrigation imposes unique challenges for salinity management because it causes a heterogeneous distribution of salts in the soil profile. In contrast to flood irrigation, in which salts are leached to below the root zone, salt deposition under micro-irrigation is toward the edge of wetting pattern in both lateral and vertical directions. The water and ion uptake responses and root plasticity of almond rootstocks under non-uniform salinity stress need to be determined to understand almond response to salinity under such field conditions and develop grower-accessible management guidelines.

Materials and Methods

In order to study the relative salinity tolerance of different rootstocks and almond cultivars, young grafted almond trees were grown in pots under open field conditions, using a calcined clay product with excellent drainage and aeration properties as the growth medium. In these 4-replicate experiments, different rootstock-cultivar combinations were subjected to 3 different irrigation water salinity levels: control (EC_w = ~0.8 dS/m), low salinity (EC_w = ~2.8 dS/m), high salinity (EC_w = ~4.8 dS/m). The salinizing agent was NaCl. Data were collected for 2 growing seasons. The high-salinity trees received a recovery treatment with control solution toward the end of the first season but the low-salinity trees did not. Growth data were obtained from canopy size estimates based on the digital analysis of periodically taken tree photographs (ImageJ) as well as from trunk diameter measurements. Leaf and woody tissue samples were collected and analyzed for mineral concentrations including Na and Cl.

A specific recovery experiment was set up in the second year of the project. Young Nonpareil and Monterey almonds grafted on Nemaguard were grown in pots under open field and subjected to salinity treatments as described above. In this 4-replicate experiment, the salinity treatments were applied for 9 weeks in the first stage and then followed by 5 weeks of recovery treatment with control solution in the second stage. The effects of the in-season recovery treatment on the growth of almond trees and tissue Na and Cl levels were studied.

The responses of different almond rootstocks to non-uniform salinity stress were investigated in a hydroponic split-root study conducted under greenhouse conditions. The root systems of non-grafted rootstock plugs were divided into two halves, and the plants were grown for several weeks with complete nutrient solution before the following treatments were started: control / control, control / salinity (60 mM NaCl), salinity (60 mM NaCl / salinity (60 mM NaCl). The effects of uniform vs. non-uniform salinity stress on plant growth, water uptake and tissue ion accumulation were determined.

Results and Discussion

The 1st-season data showed that Nemaguard was the most salt-sensitive rootstock. Hansen536 conferred higher salinity tolerance to the scion while Empyrean1 and Viking conferred the highest level of tolerance. The leaf Na and Cl accumulation was negatively correlated with apparent salinity tolerance. So, leaves of Nonpareil accumulated the highest levels of Na and Cl when grown on Nemaguard and the lowest levels when grown on Empyrean1 or Viking. Leaf Cl levels were typically one order of magnitude higher than leaf Na levels. Under these conditions, Cl was responsible for most of the salt damage. The 2nd-season data for leaf Na and Cl concentrations (Fig. 1) were generally in agreement with the 1st-season data. However, the differences between the leaf Cl levels of trees grown on Hansen536, Empyrean1 and Viking disappeared in the 2nd-season.

In the 1st season, all almond cultivars grown on Nemaguard appeared to be similarly sensitive to salinity stress as they all accumulated high levels of Cl in their leaves and Cl was the principal toxic agent. Nonpareil stood out with its low leaf Na levels, which was attributed to its exceptional ability to store Na in woody tissues. The 2nd-year data confirmed this finding and also revealed that Nonpareil and Mission may in the long term accumulate lower amounts of Cl in their leaves than Monterey and Fritz (Fig. 2).

Data collected at the beginning of the 2nd season made it possible to evaluate the carry-over effects of salinity in the previous year in terms of leaf Na and Cl load (Figs. 1 and 2). Low-salinity trees had higher carry-over concentrations of Na and Cl than high-salinity trees because high-salinity trees received a recovery treatment in the 1st season but low-salinity trees did not. This clearly shows the effectiveness of recovery treatment in minimizing the ionic carry-over effect of salinity stress. The high leaf carry-over Na concentration measured in trees grown on Nemaguard and treated with low salinity indicates that the Na accumulation problem may become worse over the years if no recovery treatments are applied.

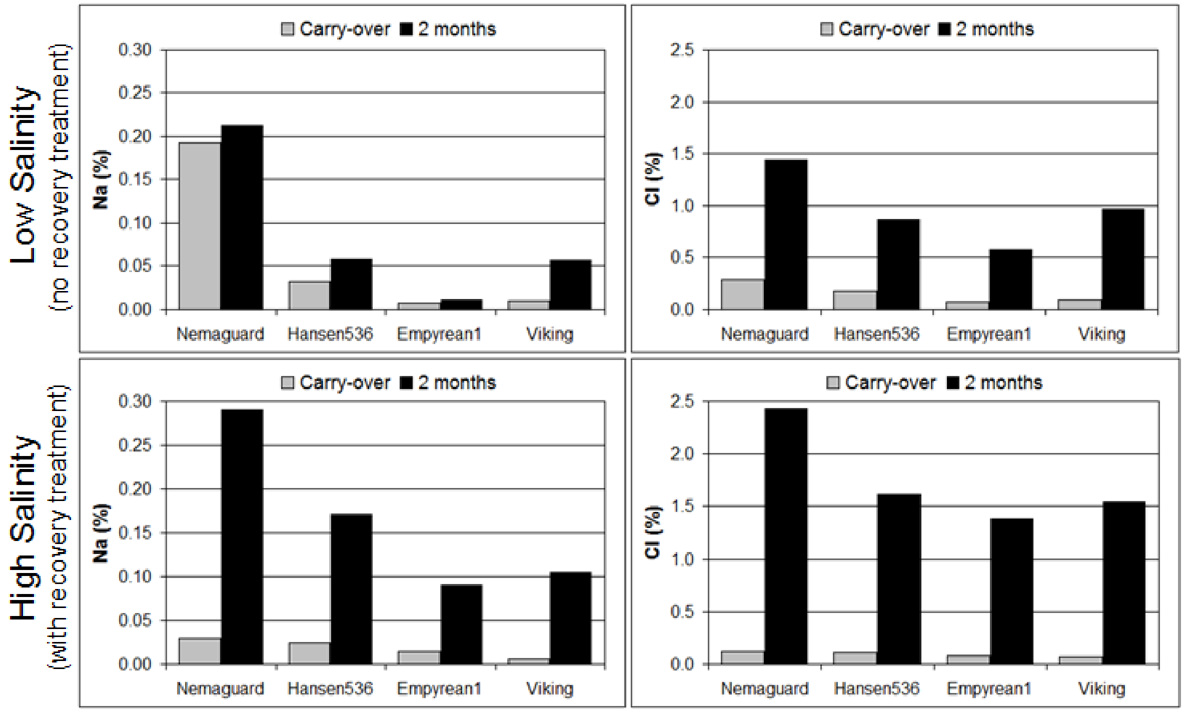

Fig. 1: 2nd-season leaf Na (left) and Cl (right) concentrations of Nonpareil trees grown on different rootstocks (Nemaguard, Hansen536, Empyrean1 and Viking) and treated with low (20 mM NaCl) (top) and high salinity (40 mM NaCl) (bottom). Gray bars show the carry-over effect of salinity before the start of 2nd-season treatment and black bars show the levels 2 months after treatment.

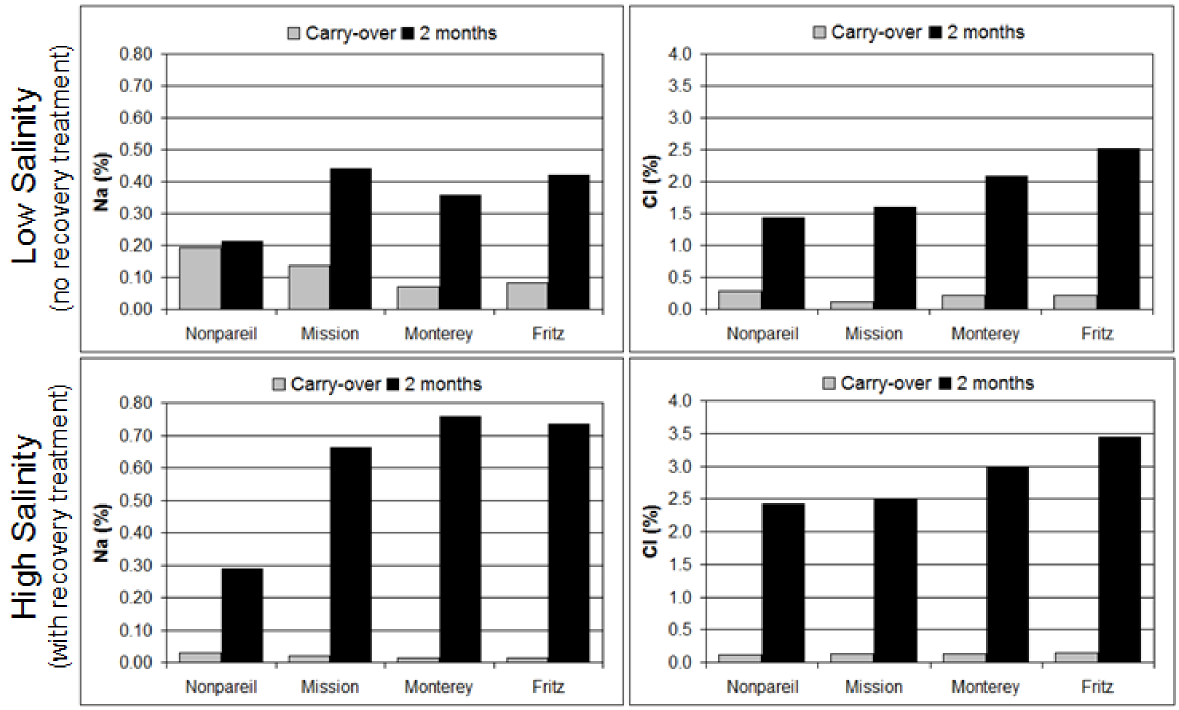

Fig. 2: 2nd-season leaf Na (left) and Cl (right) concentrations of different almond cultivars (Nonpareil, Mission, Monterey and Fritz) grown on Nemaguard and treated with low (20 mM NaCl) (top) and high salinity (40 mM NaCl) (bottom). Gray bars show the carry-over effect of salinity before the start of 2nd-season treatment and black bars show the levels 2 months after treatment.

The single-season recovery experiment demonstrated that in-season recovery treatment with high-quality irrigation water was very effective in reducing the average leaf and wood Na and Cl concentrations after both low and high salinity treatments (Fig. 3). According to the growth data obtained from this experiment, the decreases in the average tissue concentrations of Na and Cl were mostly attributable to dilution due to biomass production during the recovery stage. This experiment also confirmed that Nonpareil more efficiently excluded Na from its leaves than Monterey by allocating more Na to its woody tissues.

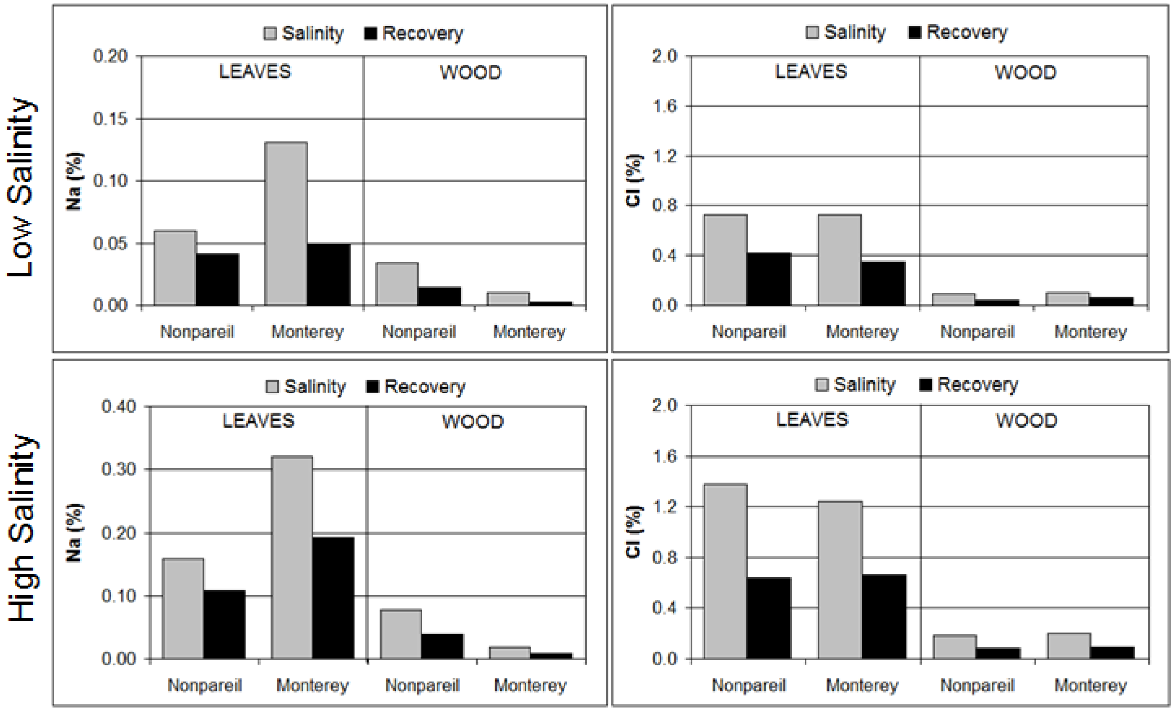

Fig. 3: Leaf and wood Na (left) and Cl (right) concentrations of Nonpareil and Monterey almonds grown on Nemaguard and treated with low (20 mM NaCl) (top) and high salinity (40 mM NaCl) (bottom). Gray bars show the concentrations at the end of the salinity treatment stage (9 weeks) and black bars show the concentrations at the end of the recovery treatment stage (5 weeks).

In the split-root experiment, non-uniform salinity treatment significantly increased the share of control side (R1) and decreased the share of salt-treated side (R2) in the total water uptake of all rootstocks just 1 day after treatment (Fig. 4). This immediate response cannot be explained by root biomass distribution. The shares of R1 and R2 in the total water consumption remained mostly unchanged during the course of 3 weeks. At the end of the experimental period, the dry weight of R2 was significantly lower than that of R1 for Hansen536 and Empyrean1 but not for Nemaguard and Viking. So, while all rootstocks prefer taking up water from the higher-quality zone, this response may not correlate with root growth response, at least in the short term. When compared to uniform salinity, non-uniform salinity treatment resulted in markedly lower tissue Na and Cl concentrations. The leaf Na levels were particularly reduced by non-uniform salinity. Under non-uniform salinity, considerable concentrations of Na and Cl were also measured in R1, which indicates that both toxic ions circulate in the plant and may be retranslocated to the roots.

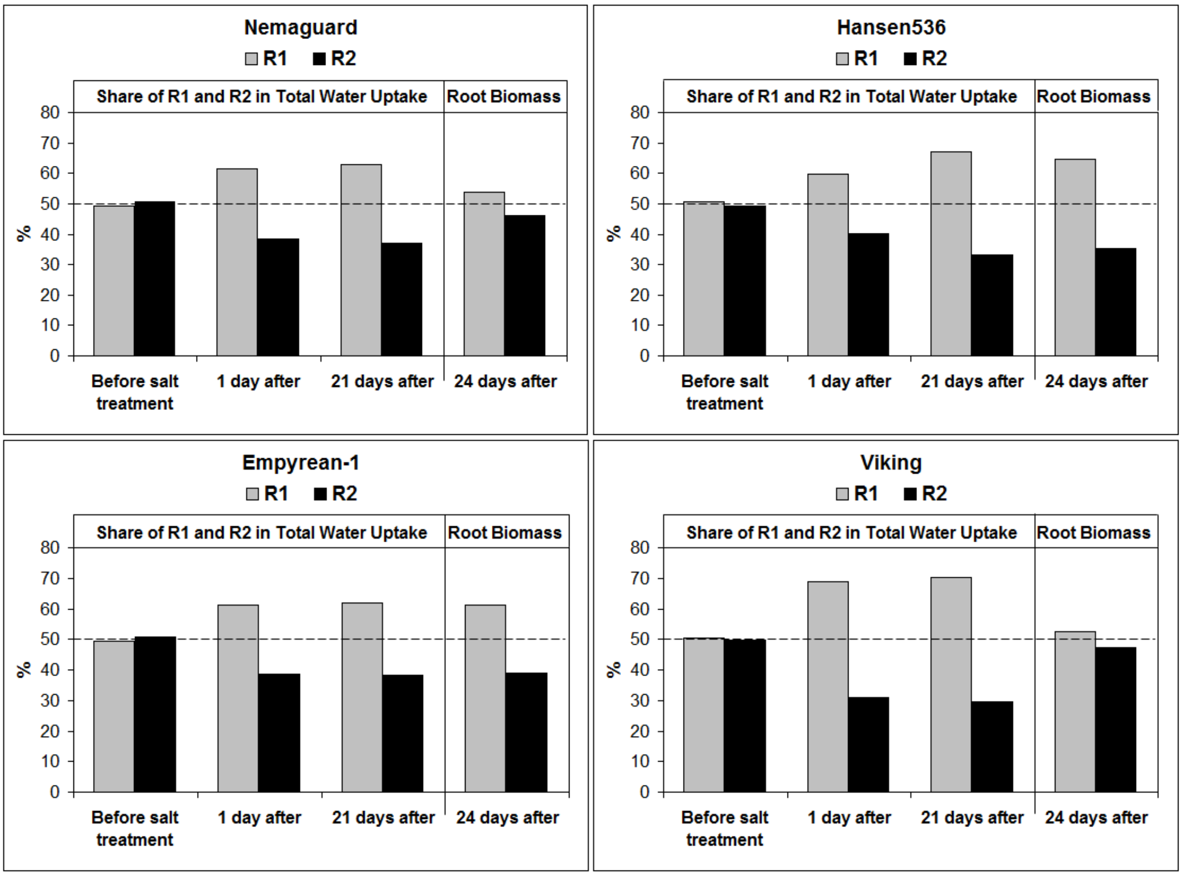

Fig. 4: Percent shares of root half 1 (R1) and root half 2 (R2) in total water uptake before, 1 day after and 21 days after non-uniform salinity treatment (R1: control; R2: 60 mM NaCl) and root biomass distribution 24 days after treatment in hydroponically grown Nemaguard, Hansen536, Empyrean-1 and Viking rootstocks

Conclusions

Rootstock selection is critical for salinity management in almond production. The highest leaf Na and Cl levels in Nonpareil trees were obtained when they were grafted on Nemaguard whereas the lowest levels were obtained when they were grafted on Empyrean-1 or Viking. Among the tested cultivars, Nonpareil stands out due to its ability to exclude Na from leaves by allocating significantly more Na to woody tissues. Cultivar selection also affects the leaf Cl accumulation significantly. When the salinizing agent is NaCl, Cl accumulates faster to toxic levels in almond leaves than Na. In general, salinity tolerance of almond negatively correlates with leaf Na and Cl levels. Recovery treatments can effectively reduce leaf and wood Na and Cl concentrations and minimize the carry-over effects of salinity stress. Under non-uniform salinity, rootstocks preferentially absorb water from the less-saline zone. Partial root access to higher-quality water significantly lowers the Na and Cl levels in shoot tissues.

Drainage Reuse by Grassland Area Farmers: the Road to Zero Discharge‡

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Drainage water reuse to irrigate salt tolerant crops is one of several management practices implemented by the Grassland Area Farmers to reduce discharge of drainage waters to the San Joaquin River. This activity started in 1998 when 1,200 acre-ft of drainage water was used to irrigate about 400 acres of pasture; in 2012, 23,700 acre-ft of drainage water was applied to 5,140 acres of lands cropped with Jose tall wheatgrass, Bermuda grass, alfalfa, and pistachios. This presentation describes how reuse fits into the other regional drainage management activities including source control, groundwater management, and salt disposal, in order to minimize the volume of drainage water generated by irrigation and to achieve the water quality objectives set out by the Central Valley Regional Water Quality Control Board. As of 2012, the drainage volume discharged to the San Joaquin River has been reduced from 57,600 in 1995 to 10,500 acre feet, an 82 % reduction, with corresponding reductions in selenium (92%), boron (72 %) and salt loads (84 %). This presentation concludes with the management and treatment objectives that need to be accomplished to achieve zero discharge.

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Water Management Practices/Leaching Requirements under Water-Limited Conditions

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Abstract

Leaching of salts from the crop root zone is an integral part of water management in irrigated agriculture. The leaching requirement is dictated by the crop salt tolerance, the water quality, the soil type and the production goals. The interaction of these components is discussed as a basis for the grower to decide on a water management strategy that fits the cropping and water availability. There is no single water management strategy that will fit all situations and the grower needs to develop a strategy that fits the situation. The final strategy will be determined based on the volume and quality of available water which requires a detailed water balance calculation for the proposed cropping pattern.

Introduction

Control of salinity in the crop root zone is a critical component of irrigated agriculture and leaching is the control method that is routinely practiced. This requires application of water in excess of the crop water requirement, which creates a problem during periods of limited water supply. California is currently in the fourth year of what has been deemed one of the worst droughts on record and the surface water supply to agriculture has been limited to non-existent during the past 2 years. The question is whether leaching is a necessity during periods of limited water supply and what the alternative for leaching during these periods is. Hanson (1991) declared that "Even in Drought, Leaching is the Answer to Excessive Soil Salinity", and the key was accurately estimating the water required. The premise was that you could always provide leaching but the scale will be limited to the available water supply. An accurate estimate of the water will always be required when planning cropping and the need for leaching and the extent of leaching possible. Since Hanson made that statement; there has been additional research that has modified the leaching requirement and the extent of required leaching (Letey et al, 2011; Corwin et al. 2007).

The type of crop, annual or perennial, will also affect the water allocation and leaching strategy. With annual crops you have the option of not planting the crop and salinity is not an issue, which is not the case with a perennial crop that will require irrigation. Another consideration is that perennial crops are not typically salt tolerant and are irrigated with low salinity water and are not planted in saline soils which will be an important consideration for salinity management. The exception is on the westside of the San Joaquin Valley where perennial crops have been planted on moderately saline soils. During the drought the irrigation supply has been with saline water (1 dS/m) instead of the good quality water from the Central Valley Project (CVP). The accumulation of salt in the root zone will not require annual leaching when low salinity water is being used. There are agronomic alternatives that will impact the water requirement, e.g. heavy pruning of trees and vines to reduce canopy size, will reduce the water requirement and thus the applied water and salt which will reduce the rate of salt accumulation and the need for leaching. This will result in loss of production for a period of time. The water management strategy that is selected will depend on the crop, the irrigation water quality, the irrigation system type, soil salinity, soil type, availability of alternative water supply, and productions goals. These will be discussed in the following sections as they relate to developing a water management strategy.

Leaching Requirement

The leaching requirement (LR) has been defined as the minimum amount of water that needs to go through the crop root zone to maintain the average root zone soil salinity below a threshold value (Maas 1990) that results in loss of production (Staff 1954). This is not to be confused with the leaching fraction (LF) which is the amount of water that leaves the bottom of the root zone during irrigation. The leaching fraction is typically greater than the leaching requirement and as a result there has not been a reason to add additional water to the crop water requirement to provide leaching. This was the case when surface irrigation was the principal method of irrigation and irrigation efficiencies were less than 80% efficient. Improving irrigation design and management and water management has resulted in improved irrigation efficiency and distribution uniformity, so the leaching fraction has begun to approach the leaching requirement. Also, irrigation has evolved from a distributed supply to a point source, surface irrigation and sprinklers to drip, which has required a new consideration of the determination of the leaching requirement (Hanson et. al, 2008)

The original recommendations for leaching were based on a steady state concept of mass balance below the root zone that is defined by the ratio of the concentration (C) of salt in the drainage water (dw) to the concentration of salt in the irrigation water (iw) $C_{dw}/C_{iw} = D_{iw}/D_{dw}$ and the depth (D) of irrigation water and drainage water (Letey, et al. 2011). Corwin et al. (2007) evaluated both steady-state and transient analysis of the leaching requirement and determined that the steady state approach over-estimated the leaching requirement. A similar conclusion was reached by Letey et. al (2011). Any water management strategy to provide leaching during periods of limited water supply should be designed to minimize the need for leaching. This will be done by reducing the total volume of salt that has to removed which implies that that the volume of irrigation water needs to be reduced or the quality needs to be improved or modified.

Developing Strategies

There is no simple answer to the question as to how to manage salinity during periods of limited water supply since each situation will be unique, thus there is no single strategy that will fit all situations. Each strategy will depend on considering the crop, crop salt tolerance, water quality and supplies, irrigation system, soil type, soil salinity, and production goals. The cropping pattern will be the first consideration in developing a management strategy. Is it a perennial, annual, a combination and what are the annual crops? With annual crops the decision might simply be to plant or not to plant if the crop is grown during the spring and summer months. If it is a fall to winter crop with a low water requirement, the decision will be determined by the total water supply and the need to meet the water requirement for a perennial crop. Fall and winter crops have the advantage of rainfall to provide both crop water requirement and leaching. In this instance the LR would not be an issue but the total water supply then becomes a critical component. A detailed estimate of water requirement would be computed for each crop and the water would be allocated on based on the estimated crop water requirement. This estimate will include the efficiency of the irrigation system and a shift from surface to pressurize methods will result in water being available for leaching or additional acreage.

The second aspect of the cropping is the crop salt tolerance and the irrigation water quality, the soil salinity, and the presence of shallow groundwater. If the crop is salt sensitive and the water is low in salinity, then leaching will not be a problem in the short term and leaching will not be required and rainfall may provide adequate salinity control. However, if the crop is salt sensitive and the water supply contains some salt then salinity control may be an issue. If it is an annual crop the acreage can be adjusted to accommodate some leaching. A perennial crop poses a different problem since the acreage has already been determined and the water supply is probably determined. If the original supply was low salinity water there should not be a problem with salinity but with meeting the crop water requirement. In this case strategies will have to be developed to reduce the water requirement. If poor quality water is available then leaching will be required and the extent will be based on the crop salt tolerance, the water salinity and the total supply. If the supply is not limited then leaching will be an alternative.

Another aspect of the water quality crop interaction is the question of crop productivity. The Maas-Hoffmann equation (Maas and Hoffman 1977) demonstrates a yield reduction as the crop salt tolerance threshold is exceeded. If water supply is limited, it would be possible to limit the total leaching and accept some loss of production.

It is important to realize that rainfall is another high quality supply that can be effectively used to provide leaching. In the Central Valley, the drought is a consequence of the lack of stored snow in the Sierra and not the lack of rain during the growing season. Even in extreme droughts like the current one, there has still been rainfall during the winter months that can be used to provide leaching. This will require that a field be prepared to maximize infiltration. The surface should be disked to break up crusts; this might include providing gypsum if sodicity is a problem. A cover crop can be used to improve infiltration and small depressions constructed to store water are an alternative.

The timing of the leaching will be critical as well, if you decide to provide additional water during the growing season. Leaching is required to minimize stress induced by osmotic potential, in combination with soil matric potential. Using this concept, one would suggest that the leaching be timed to minimize stress during critical growth periods. It would parallel the concepts developed for deficit irrigation strategies that reduce applied water during non-critical growth and development stages and meet the crop water requirement during the critical stages of plant development. Thus additional water or better quality water would be applied during a critical period.

If the goal of leaching is to minimize stress, an alternative when using poorer quality water will be to increase the frequency of irrigation. By reducing the irrigation interval it is possible to maintain a higher soil water matric potential and the combined effect of soil matric potential and osmotic potential will be reduced. The higher water content will improve leaching when you decide to provide the extra water. Remember that the plant will look at the average soil water content and use water from the zone with highest water potential. This means that the consideration needs to be given to the root distribution of the plant and how much of the soil profile has to be maintained to minimize stress levels.

The irrigation system being used will affect the water management strategy. With surface irrigation the entire area will be leached which will require significantly more water than a drip system. Sprinkler irrigation will also cover the entire area, however, intermittent sprinkler irrigation has been demonstrated to be more effective and use less water than surface methods. An important consideration is how much of the area needs to be leached? The reality of the situation is that the root zone is the only region that needs to have the salinity maintained at a threshold value and areas outside of that zone are not important. With this strategy the water required for leaching can be significantly reduced. Surface systems will leach the entire surface unless efforts are made to restrict the infiltrated area. Even a furrow system will have lateral flow and eventually cover the entire area. Drip and micro-sprays are effective in concentrating the area being leached and will reduce the total area and soil volume that is leached. With micro irrigation systems, the root system will be concentrated around the water source which is the only area needed to be leached, and this is considerably less that than the entire area of the field. Burt and Isbell (2005) effectively used dual drip lines to leach an orchard. With this system only 1/3 of the area was being leached and the total applied water was reduced by approximately half of what would be required using sprinklers.

Hanson et al. (2008) demonstrated with a model that effective leaching occurred with a subsurface drip system and that currently methods to characterize leaching through a water balance approach were not suited for drip irrigation. They demonstrated that the leaching fraction ranged from 7.7 to 30.9% as the applied water increased from 60 to 115% of potential evapotranspiration of the tomato crop. The crop will respond to time-averaged soil salinity, so it is important to consider effective rainfall, along with the applied irrigation water, to determine the average salinity of the applied water. This leads to a strategy of cyclic application of good and poor quality water and cropping that will accommodate the changes. The good quality water can provide the leaching along with rainfall. This requires two sources of water that have different qualities.

One approach to deciding the need for leaching relates to the concept of average water quality over the entire year. The decision to leach needs to consider all the water that will be used during the year to determine the average water quality and compare that to the crop salinity threshold. It is possible that infiltrated rainfall will be sufficient to provide the quality needed to maintain the crop during the following growing season.

Soil type will also have a significant impact on leaching. Sandy, sandy loam and similar textured soil have less capability to store salt and are easily leached and rainfall may be sufficient to maintain salinity. As the texture progresses to silt and clay loam it becomes more difficult to leach. The finer-textured soils will, in general, have higher salinity levels and will be harder to leach due to lower values of saturated hydraulic conductivity than in the sandy soils. Clay soils are cracking soils that create a bypass that reduces the effectiveness of leaching. With clay soils it is important to manage the soil water content to prevent cracking and high frequency irrigation may be an important strategy.

The basic premise has been that we are attempting to maintain full production through salinity management. The crop and water quality interactions dictate the amount of leaching that is required to meet a particular production goal. If you are willing to accept a yield loss, the need and extent of leaching required will be reduced.

Putting it all together

There is not a single strategy of leaching during periods of limited water supply. It will require the grower to look at the cropping pattern, the available water supply and quality and determine the production goals and alternatives. After these analyses a plan can be developed to provide the leaching that may be required.

One of the first steps is to evaluate what are the current salinity management practices and what is the current state of salinity in the field. This requires a field investigation typically with a EM-38 (electromagnetic sensor) or similar device that can quickly define the areal and vertical distribution of salinity. If salinity levels are acceptable for the given crop then leaching will not be required, but maintaining high levels of irrigation efficiency and distribution uniformity will be essential. If there are areas with high salinity levels, then targeted leaching could be considered, or not planting those areas and allocating the supply to the remaining area. This small change could provide the additional water needed when leaching is required. Annual salinity investigations will determine the need for leaching.

If leaching is required then a detailed water balance should be made as the basis for allocation of water supplies. This may include deficit irrigation strategies that will extend the available water supply. The first estimate of the LR can be made using the steady state equation developed by Rhoades (1974) that incorporates a linearly-averaged root zone and crop tolerance. The equation is:

$$L_r = EC_i/(5\ EC_e)^{*} - EC_i$$

where EC_i is the electrical conductivity of the irrigation water and EC_e^{*} is the linear-averaged root zone salinity of the saturation extract of the crop and is equivalent to the threshold value of the Maas-Hoffman equation. Recall that this is a steady state model and it overestimates the requirement. This provides the starting point for the water allocation to leaching and meeting the crop water requirement.

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Title of Paper: **Response of Transplanted Tomatoes to Pre-plant Herbicides**

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ABSTRACT:
Processing tomato planting in the San Joaquin Valley has transitioned to the use of transplants, buried drip irrigation, and shallow tillage. The use of pre-plant herbicides in tomato production was generally safe and caused no negative effects on plant health, until recent years. In 2009, stunted tomato transplants were discovered in fields that were previously treated with pre-plant herbicides. It was suspected that the breakdown of pre-plant herbicides was facilitated more when deep tillage was done after harvest than under the current grower practices. Therefore, two greenhouse studies were conducted in Fresno, CA in summer 2014 and 2015 to assess plant injury to simulated residues of pre-plant herbicides. The objective of these studies was to evaluate above- and below-ground response of transplanted tomato to pre-plant herbicides. The herbicides were trifluralin (Treflan), *s*-metolachlor (Dual Magnum), and pendimethalin (Prowl H_2O) at doses of 0, 0.5, 1, 2, 4, and 6 ppm in 2014. In 2015, the doses were reduced to 0, 0.03, 0.06, 0.12, 0.25, and 0.5 ppm. The experimental design was a two factor randomized complete block with four replications. Sampled field soil was mixed with herbicides and placed in 3 gallon pots. Tomato seedlings were transplanted and grown for 45 days. Plant height, chlorophyll concentration of leaves, and stomatal conductance were monitored weekly. At 45 days, plants were clipped and separated to determine leaf area and dry biomass. Non-linear regression models were used to calculate the dose required to reduce biomass by 50% ($GR_{50\%}$). Results from both studies showed that the three herbicides caused root reductions at 0.5 ppm rates, with pendimethalin having a lower potential to cause injury than the other two herbicides.

Title of Paper: Impact of Salinity on Biological Nitrogen Fixation in Alfalfa (*Medicago sativa*) and its Response to Applied Mineral Nitrogen

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ABSTRACT: As irrigation water supplies become scarce in California, more saline water will likely be used to irrigate field crops and forages. A valid research question to ask is how salinity impacts biological nitrogen fixation (BNF) and its contribution toward fulfilling the nitrogen requirements of alfalfa. Soil salinity is a spatially complex and dynamic property of soil that influences crop yields. Alfalfa roots contain nitrogen-fixing bacteria, *Sinorhizobium meliloti* which allows the plant to utilize atmospheric nitrogen to fulfill its N requirement. Salinity can affect the plant's ability to fix N, even if the native rhizobia are known to be present. Our greenhouse experiment compared inoculated (Inoc) and non-inoculated (Non-Inoc) seeds of alfalfa (variety 'Highline') grown under low salinity (1.5 dS/m) and high salinity (9.5 dS/m) irrigation in combination with 3 levels of applied N: 0 ppm (N1), 50 ppm (N2) and 150 ppm (N3) in the form of calcium nitrate. Two seedlings were transplanted into each pot and grown for 216 days under the respective treatments. Applied mineral N significantly ($P<0.05$) increased cumulative shoot dry matter (DM) yield in both inoculated and non-inoculated treatments with a 54% increase in N3 as compared to N1 treatments. Salinity significantly reduced cumulative shoot DM in both Inoc and Non-Inoc treatments. Salinity and nitrogen did not have significant effects on root dry weight ($P>0.05$), but nodule numbers were significantly reduced (~70-90%) in the N3 treatments. N-level significantly affected tissue-N which was higher in the N2 and N3 treatments (as compared to N1) for both Inoc and Non-Inoc groups. N^{15} stable isotope analysis will be used to compare the fraction of assimilated N coming from biological nitrogen fixation (vs. mineral N) under LS and HS irrigation.

Solution Center for Nutrient Management

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Abstract

The Solution Center for Nutrient Management (http://ucanr.edu/sites/Nutrient Management Solutions/) is an outreach program of the University of California (UC) Sustainable Agriculture Research and Education Program. The Solution Center strengthens the connection between nutrient management research and the California agricultural community, with the ultimate goal of increasing the sustainability of nutrient management strategies on California's diverse farms. Through education and participatory outreach, the Solution Center assists farmers and their advisors to navigate through the ever-expanding body of knowledge on nutrient management practices, including environmental co-benefits as well as trade-offs, financial costs and farm management implications. The long-term goals of the Solution Center are to ensure long-term profitability of farms with reduced environmental and human health impacts, and to assist farmers to address the growing body of state regulations around nutrient management. The poster introduces the Solution Center concept and approach and the outreach elements included (ranging from a searchable online database to interactive field days). It also provides a sampling of science-based information about specific agricultural management practices that have the potential to reduce greenhouse gas emissions, which is currently one of several focal topics of the Solution Center.

Evaluation of vermicompost in specialty crop production: Effect of vermicompost on drainage water quality and nutrient uptake in strawberry

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The use of vermicompost is suggested as a method to reduce nitrogen losses in crop production; however, it is unclear whether and how vermicompost can affect water quality after a significant irrigation or rainfall event. The objectives of this experiment were to: a) determine the concentration of nitrate-nitrogen in drainage water from vermicompost-amended media planted with strawberry (*Fragaria* x *ananassa* var. *"*Portola*"*) in a greenhouse setting, and b) determine nitrogen uptake and storage in strawberry grown in vermicompost-amended media. Bare-root strawberry plugs were grown in individual one-gallon plastic pots. The treatments consisted of two media: 1) - peat:perlite soil-less mix, and 2) - fine sand soil, and three levels of vermicompost addition: 0%, 10%, 25% by weight, and a biweekly synthetic fertilizer treatment of 150 mg N-P-K L^{-1}, were evaluated in a full factorial randomized block design. Drainage water from each plant was collected for 16 weeks and analyzed for nitrate-nitrogen concentration and electrical conductivity (EC). High amounts of nitrate leaching across all vermicompost - amended media was observed during the first two weeks of drainage collection relative to non vermicompost-amended media. In the sand media, the 25% vermicompost treatments leached an average of 1937 mg L^{-1} nitrate while the 0% vermicompost treatment leached an average of 37 mg L^{-1} nitrate during the first two weeks of collection. Nitrate leaching and EC significantly decreased over time across all treatments. High nitrate leaching may have been a consequence of the vermicompost feedstock, which is high in salinity and nutrient content. These data suggest vermicompost addition rates of 10% and 25% by weight may facilitate high initial nitrate leaching, which can negatively affect water quality and environmental health.

The effects of rate and application timing of urea fertilizer on yield and grain protein between wheat varieties and residual soil nitrate in the San Joaquin Valley

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Abstract

This study aimed to demonstrate the effect of N fertilizer management on wheat yield and quality and soil nitrate leaching in the San Joaquin Valley. In the 2013 and 2014 growing years, trials were conducted to test the effects of variety, total N applied, and application timing of urea fertilizer. Three varieties, Blanca Grande 515 (hard white), Summit 515 (hard red), and Volante (durum) were fertilized in split applications at the pre-plant, tillering, boot, and flowering stages of wheat development. Total rates of lbs N/acre varied slightly between years, but followed the pattern of residual N only (40-80), low N (130-180), intermediate (225-300), and high (330) with residual soil N always credited. In both years, Blanca Grande grain protein (>13%) was always significantly higher (P=0.02) than that of Volante (~12%), and Summit 515 protein was intermediate. As expected, low rates of fertilizer corresponded with significantly lower yields (P<0.001) for all varieties (< 3 tons/acre), and higher rates corresponded with higher yields (> 3.5 tons/acre). Application timing also had a significant effect (P<0.001) on protein content, where high and low applications at pre-plant yielded the least protein (~10%), and intermediate to high rates balanced among applications yielded the highest protein (~14%). With regard to post-harvest residual soil nitrate, high rates applied near pre-plant showed the highest rates of residual nitrate at depths of 6-8 feet, where high rates applied near flowering tended to leave residual nitrate near the top 2 feet of the soil profile. Split application timings that were more balanced tended to leave the least amount of residual soil nitrate at any depth.

Title of Paper: Influence of shade and soil moisture on the efficacy of postemergence herbicides on junglerice (*Echinochloa colona*)

Author: Ryan Cox, Larissa Larocca de Souza, Mala To, and Anil Shrestha

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ABSTRACT: Junglerice (*Echinochloa colona*) is a problematic weed in California and its postemergence control is now further compromised by the presence of glyphosate-resistant (GR) populations in the Central Valley. Two postemergence alternatives that have been identified are sethoxydim and glufosinate. However, the performance of these herbicides can be influenced by environmental conditions such as light intensity and soil moisture. A study was conducted in Fresno, CA to evaluate the effect of light intensity and soil moisture levels on the efficacy of sethoxydim, glufosinate, and glyphosate on junglerice plants grown in pots containing field soil. Three levels of shade (70%, 50%, and 0%, i.e. no shade) and three soil moisture regimes (100%, 50%, and 25% of field capacity) were imposed. The plants were treated with label rates of the selected herbicides and an untreated control was also included. Mortality of these plants were evaluated every 7 days after treatment and aboveground biomass was recorded at 28 days after treatment. Results indicated that plant mortality was affected differentially by light intensity, moisture level, and herbicide type. There was a significant interaction between light intensity and soil moisture level. Interactions occurred between moisture level and herbicide type under shade but not under full sun. Among the herbicides compared, glufosinate was the best treatment under all levels of shade and moisture conditions. Control of junglerice with sethoxydim was lower under shaded and low moisture conditions, whereas control with glyphosate was better under shaded conditions at 100% and 75% FC moisture conditions. Therefore, both shade and soil moisture conditions should be taken into consideration when selecting postemergence herbicides for control of junglerice as these conditions can vary especially in orchards and vineyards

The use of disease severity variables in predicting efficacy of Fusarium Race 4 Resistance Selection

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Abstract

In 2015, 85 Upland (*Gossypium hirsutum* L.) accessions from the USDA-ARS Cotton Collection and 126 F6 Pima-S6 x Pima-S7 (*G. barbadense* L.) recombinant inbred lines were evaluated for disease performance under pressure of *Fusarium oxysporum* f. sp. *vasinfectum* race 4 (FOV4) in a replicated field trial in the central San Joaquin Valley of California. Statistical analyses were performed to test the efficacy and biological importance of several variables with respect to each one's ability to aid the selection of FOV4 resistant lines. Disease severity was measured by foliar symptoms (FS), vascular root staining (VRS), and plant survival (PS). Plant vegetative growth was measured as emergence, plant height, and number of main-stem nodes. We analyzed the relationships of these variables to evaluate the predictability of one variable response from the other variable observation. Selected results from this research demonstrated that FOV4 FS was a reliable predictor of VRS in Pima cotton (r = 0.80), but less so within the *G. hirsutum* collection (r = 0.54). In Pima, VRS was highly negatively correlated with 8 weeks PS (r = -0.73), a relationship not as dramatic in Upland cotton. Number of nodes and plant height were always well correlated within the two groups (r = 0.84 and 0.73 for Pima and Upland, respectively). Finally, analyses showed a statistically significant tendency toward increased variability with decreased symptom severity. In other words, the worst observed symptoms were proven to be most reliable for ejecting poor performing lines, providing a better resistance selection efficacy.

Title of Paper: Field Performance of 21 Alfalfa (*Medicago sativa*) Varieties under Saline Irrigation: shoot dry matter yield and soil salinity distribution

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ABSTRACT: California has been facing a drought that is reducing irrigation water supplies and the quality of the applied water. Alfalfa is considered to be moderately salt tolerant (Mass and Grattan, 1999), with a yield loss threshold of 2 dS/m ECe (soil salinity). However, recently published data (Cornacchione and Suarez, 2015) and results of our first field trial suggest a yield loss threshold of 5-6 dS/m ECe). To assess the field performance of new alfalfa varieties bred for salt tolerance, a variety trial was planted in October, 2014 at the UC Westside Research and Extension Center (Five Points, CA). Twenty-one varieties were planted in low salinity (LS) and high salinity (HS) basins, which were irrigated with water averaging 1.05 and 10.0 dS/m ECw, respectively. Cumulative shoot dry matter yield for 5 cuts (June to October, 2015) ranged from 1.80 to 2.14 Kg/m^2 in the low salinity treatment and from 1.53 to 1.99 Kg/m^2 in the high salinity treatment. Relative yield (HS/LS) ranged from 75.1 % to 100%, suggesting that the new varieties are more tolerant than those assessed in previous studies. Soil salinities in June ranged from 2.14 to 7.35 dS/m ECe (LS basin) and from 5.89 to 11.09 dS/m (HS basin) for the 0-90 cm soil depth. In October, soil salinities ranged from 2.59 to 4.95 dS/m ECe (LS basin) and from 8.93 to 13.61 dS/m (HS basin) (0-90 cm depth). Data from EM-38 surveys shows greater spatial variability in soil salinity in the HS basin, as compared to the LS basin. Shoot dry matter yields will be correlated to soil salinities in order to estimate the alfalfa yield loss threshold under these saline conditions.

Title of Paper: Salt Tolerant Cactus Pear in the San Joaquin Valley: A Comparison of Production Methodologies

Authors: J. Hurst, and J.T. Bushoven

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ABSTRACT: The western San Joaquin Valley is host to saline soils and ground water with high boron and selenium as a legacy of the region's ancient marine past. Drought has exacerbated conditions in the area, rendering many fields unfit for crops that had previously been grown using surface water. To provide a viable crop using low quantities of saline water, the USDA has developed four varieties of salt-tolerant prickly pear cactus (*Opuntia ficus-indica)* for fruit production, dubbed the "Seleno" series. When grown on the high selenium soil of the west side, they produce nutraceutical fruit rich in Se-containing compounds and antioxidants. Unfortunately, desirable fruit and growth characteristics are not found together in a single variety. Two varieties (Seleno-Orange and -Green) have superior salt-tolerance, but also have small cylindrical fruits that drop from the plant once ripe. The other pair of cultivars (Seleno-Red and –Purple) produces large globular fruits that stay on the plant when ripe, but do not perform as well as their sister cultivars at high salt levels. Grafting offers a simple way to quickly combine the desirable characteristics from two cultivars. *In situ* and *in vitro* methods for the production of grafted salt-tolerant prickly pear cactus were examined. Fungal contamination proved to be a substantial obstacle to traditional grafting and initiation of sterile cultures *in vitro*. Scion cultivars displayed a much higher rate of shoot induction and multiplication compared to rootstocks. Overall, *in vitro* production of grafted plants has the potential to produce very high numbers of plants, but at a smaller size than traditional grafting methods. Plant size could affect survivorship in field settings, where herbivory is a major cause of plant mortality.

Title of Paper: **Testing the efficacy of bio-insecticides to control *Lygus* bugs (Hemiptera: Miridae) in alfalfa seed production**

Authors: Francisco Llamas-Gonzales1 Bruce Roberts1 Antonino Cusumano2 & Jorge M. Gonzalez

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ABSTRACT:

Seed production of Alfalfa can be affected by damage from piercing sucking insects with Lygus bugs being the pest of major concern for alfalfa seed growers. Considerable effort has been made to find insecticides that effectively control *Lygus* populations. The aim of our research was to test two biological pesticides (MBI-203, MBI-206) unregistered in seed alfalfa against two registered synthetic pesticides (Sivanto 200SL, and Beleaf 50 SG) for control of *Lygus* on Alfalfa seed production. A field trial was conducted on the College Farm at California State University, Fresno. The two biological pesticides (MBI-206, at 0.5 and 1gal/Ac, MBI-203 at 2 lb/Ac) and the two commonly used synthetic pesticides (Beleaf 50 SG at 2.8 oz/Ac; Sivanto 200SL at 2 lb/Ac) were tested in a randomized block design with four replications. Sampling of Lygus populations were done for each block (and replications) prior to application then 5 and 10 days post application, and one day prior to the second application, plus 3 and 12 days post application. Analysis comparing populations of other piercing insects, predators and parasitoids were also done. Our preliminary assessments indicate that the experimental pesticides (MBI- 206 at both rates) and Sivanto 200SL had the best effects in diminishing *Lygus* populations. Effects on other pests and on natural enemies will be presented. This project was supported by the California Seed Alfalfa Research Board.

Title of Paper:

A comparison between the efficacy of automated thinners and hand thinning of lettuce

Authors:
Elizabeth Mosqueda[1], Richard Smith[2], Anil Shrestha[1]

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ABSTRACT:

A comparison between the efficacy of automated thinners and hand thinning of lettuce

Elizabeth Mosqueda[1], Richard Smith[2], Anil Shrestha[1].

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California's agriculture industry has been hindered by a severe labor shortage in recent years, especially in highly labor intensive commodities such as vegetable crops. In 2012, growers in the Salinas Valley began using automated lettuce thinners to address this problem. Therefore, replicated field studies were conducted during the 2014 and 2015 lettuce season in the Salinas Valley comparing the efficacy of automated thinners with manual thinning. During both seasons each treatment plot consisted of 5-10 randomly chosen sub-plots from which data were collected. Parameters measured were plant, weed and double (two closely spaced plants) counts, all done by taking data prior and after thinning, and plant spacing measurements performed after thinning. Time taken for the initial thinning process and the double/weed removal pass in each treatment plots were recorded. The average lettuce thinning time was 3 to 4 times quicker with the automated system than with the manual system. Although the automated system tended to leave more doubles than the manual system, the time required for removal of the doubles was similar between the two systems. Spacing of plants within rows was also similar between the two systems. In terms of weed removal, the automated system was as efficient as the manual system. Therefore, automated thinning holds great potential to aid lettuce growers in the Salinas Valley.

Title of Paper: Distribution of nanoparticles in food and effects on behavioral responses and biology of *Solenopsis xyloni* (Hymenoptera: Formicidae) colonies	
Authors: Julie Pedraza, Yunyun Chen, Hong Liang & Jorge M. González	
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Affiliation: California State University, Fresno	
Address: 2415 E. San Ramon Ave, M/S AS72, Fresno, CA 93740-8033	
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ABSTRACT:

Solenopsis xyloni , commonly known as the Southern Fire Ant (SFA), is native to southern US and is an important urban and agricultural pest. SFA is an aggressive ant that causes crop damage, and possesses venom that causes human bite victims to suffer symptoms ranging from irritation to nausea. SFA builds colonies deep under the soil surface, and members of every colony, forage for hemipteran honeydew, sweet foods, seeds, seedlings, and other insects. This study was conducted to understand SFA feeding behavior and biology when exposed to presence of nanoparticles (NPs) in food sources. A first set of trials involved feeding SFA colonies with 10% honey-water (10HW) infused with nanoparticles. A second set of trials involved feeding SFA with mealworms [*Tenebro molitor* (Coleoptera: Tenebrionidae)] previously fed with 10HW+NPs and tested positive for NP's ingestion which were encapsulated inside the coelom. After tomographic observation no NPs were found inside SFA bodies from both trials.

Title of Paper: Duration of weed-free periods in organic Romaine lettuce: effect on crop yield and quality

Author: Sarah Parry, Ryan Cox, Larissa Larocca de Souza, and Anil Shrestha

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ABSTRACT

Field studies were conducted in fall 2014 and spring 2015 at Fresno, CA to determine the effect of the duration of weed-free periods on crop yield and quality of transplanted organic Romaine lettuce (*Lactuca sativa* L.). The crop was grown for 8 weeks with 8 different weed-free periods [0 (no weed control), 1, 2, 3, 4, 5, 6, weeks and weed-free entire 8 weeks]. Weeding was done manually with hand hoes and time taken to weed each plot was recorded. All standard organically-acceptable production practices were followed. Data were collected on total and marketable yield, hand weeding costs, weed density, weed biomass, crop quality rating at harvest, and anthocyanin and organic acids (chlorogenic acid, ferulic acid, and protocatechuic acid). Total stand counts, disease incidence, anthocyanin and organic acid composition of the leaves were not affected by the durations of weed-free period. The critical weed-free duration for lettuce yield and quality was estimated as four weeks after transplant. Weed biomass data also showed that there was no benefit in controlling weeds beyond four weeks after lettuce transplant. The major weed species differed between the seasons. It can be concluded that a weed-free duration of four weeks after transplanting will be sufficient to produce organic Romaine lettuce without compromising yield or crop quality.

Tolerance of sorghum (*Sorghum bicolor* L. Moench) varieties to soil salinity at an early growth stage

Omar Robles[1], Larissa Larocca de Souza[1], Vitor Stella[1],
Jeffery Dahlberg[2], Steve Wright[3], and Anil Shrestha[1]
[1]California State University, Fresno, CA; [2]University of California, Kearney Agricultural Research and Extension Center, Parlier, CA; [3]University of California Cooperative Extension, Tulare, CA

Sorghum is being explored in California as a water-use efficient crop. However, much of the areas suitable for sorghum in the Central Valley are high in soil salinity. Although sorghum is classified as medium-tolerant crop to soil salinity, its tolerance at early-growth stages need to be determined. An experiment was conducted in 2015 at Fresno, CA to determine the effect of early salt-stress on a selected forage (cv. SS405) and a grain (cv. NK5418) sorghum variety. Seeds were planted in 3 gal pots containing locally-collected field soil. The pots were kept outdoors. Once the seedlings emerged, they were thinned to one plant/pot and irrigated with 300 ml of either 0, 5, 10, 15, or 20 ds/m sodium chloride solutions on alternate days from 2 weeks after emergence (WAE) to 6 WAE. Plant growth parameters were measured every week and the plants were harvested at 7 WAE and their dry weights were recorded. The experiment was conducted twice using a randomized complete block design with four replications. Salt stress had similar effects on the aboveground biomass of both sorghum varieties. Salt concentration up to 5 dS/m did not reduce the aboveground biomass. However, biomass was reduced by 25% and 50% at approximately 7 and 18.5 dS/m, respectively. Stomatal conductance was reduced at salt concentrations greater than 15 ds/m. Therefore, sorghum seems to be moderately-sensitive to soil salinity at an early growth stage.

Title of Paper: Effect of Irrigation Regimes on the Soil Movement and Nematicidal Efficacy of Fluopyram for Grape Production

Authors: Annabel Rodriguez, Sharon Benes, Alfonso Cabrera, Louis Holloway, Sonet Van Zyl

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ABSTRACT:

Plant-parasitic nematodes impact many perennial crops throughout California. As the phasing out of methyl bromide continues, finding nematicidal alternatives to help manage nematode populations is important. A new contact nematicide, fluopyram, has shown promise in managing populations in soils through drip applications. Knowing the best time to inject during a normal irrigation cycle is crucial to obtaining an effective concentration of the nematicide within the root zone for optimal control. In the first trial, fluopyram was injected through drip irrigation onto bare soil at different intervals within a 24-hour irrigation cycle to evaluate its movement in the soil. The second trial consisted of injecting fluopyram at the same intervals within an irrigation cycle as previously used, but in a vineyard setting. Results from the first trial indicated no significant difference in the concentration of fluopyram among treatments and depths, although there was a non-significant trend towards higher concentrations of the nematicide in the top two feet of soil. Applications conducted in a nematode-infested vineyard showed no significant decreases in *Meloidogyne arenaria* and *Mesocriconema xenoplax* nematode populations when compared to the control, but a significant difference among treated and untreated plots at 150 days post-application was found for *M. arenaria* only. Suppression of *M. arenaria* populations could have an impact on the amount of inoculum present for the next season. No significant differences in yield were observed, although treatments with injections earlier in the irrigation cycle had lower fruit weight, potentially due to the longer flush periods, which might have moved the fluopyram deeper in this sandy loam soil, thus reducing the efficacy in managing nematode populations.

Title of Paper:	Effects of Lygus lineolaris nymph feeding on anatomy of cotton squares in relation to EPG-monitored feeding
Authors:	1 Eeva Sharma, 3 Felix Cervantes , 2 Elaine Backus and 1 John Bushoven,
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ABSTRACT:

Lygus lineolaris (Palisot de Beauvois) (Hemiptera: Miridae) is considered the most important insect pest affecting cotton, Gossypium spp., in the US, especially in the eastern and mid-southern states. Nearly 45.5% of U.S. acres of cotton were infested by Lygus spp. in 2012, with an individual lygus bug potentially capable of destroying up to 23,400 cotton squares per hectare. Both immature and adult stages cause significant economic damage to cotton. However, fifth instar nymphs are more damaging than third instar nymphs and adults. The objective of this research was to better understand the cause of nymphal lygus damage by identifying internal anatomical changes to cotton squares over a regular timecourse after standardized probing by L. lineolaris fifth instars, as quantified by electropenetrography (EPG). In this experiment, a standardized four hours of L. lineolaris probing was repeatedly applied to multiple cotton squares. The samples were held for varying time periods of 0, 4, 12, and 24 hrs. The tissue samples were then prepared for light microscopy to examine anatomical changes. Some of the changes observed in the plant tissue caused by lygus feeding were plasmolysis, cell disintegration, and discoloration of the tissues. There are tannin deposits in the squares as a response to insect feeding. There are also anatomical differences noticed among the various timecourse treatments.

Title of Paper**: Evaluating Crop Water Requirement for Sugarbeet under Drip Irrigation**

Authors: Touyee Thao, Florence Cassel S., Dave Goorahoo, Jim Ayars, and Shawn Ashkan

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ABSTRACT:

Important changes in irrigation management and crop production have occurred over the past decade throughout the state of California. In the Central Valley, many growers have transitioned from low-value crops produced under flood irrigation to higher value crops grown with low-volume irrigation systems, including drip. More recently, this trend has also been observed for row crops, such as sugarbeets, a relatively salt-tolerant crop, and has been mostly attributed to the current drought that has severely affected the availability of water resources in the region. Overall, water conservation has become a top priority in California and has required producers to adopt management practices that optimize irrigation and water use efficiency. One approach to conserve water consists in optimizing irrigation scheduling through the development of new crop water requirement (CWR) estimates that better reflect the current agricultural and irrigation management practices. The most accurate and precise method to determine CWR involves the use weighing lysimeters to derive evapotranspiration (ET) and crop coefficient (Kc) estimates. Thus, the objectives of our study were to develop ET and Kc estimates for sugarbeets (*Beta vulgaris*) grown under drip irrigation using the lysimeter facility available at the University of California Westside Research and Extension Center. Results from our 2014-2015 lysimeter study, conducted on a clay loam soil, suggested that peak ET for sugarbeet was around 8 mm/day, while midseason Kc was 1.25. This Kc value was close to that reported in FAO-56. A strong correlation was also observed between crop Kc and fractional ground cover (Fc), with an r2 = 0.90.

Effect of soil salinity and moisture stress on sorghum [*Sorghum bicolor* (L.) Moench] seed germination

Yue Wu[1], Ryan Cox[1], Larissa Larocca de Souza[1], Jeffery Dahlberg[2], Steve Wright[3], and Anil Shrestha[1]
[1]California State University, Fresno, CA; [2]University of California, Kearney Agricultural Research and Extension Center, Parlier, CA;
[3]University of California Cooperative Extension, Tulare, CA.

Sorghum is being explored as a water-use efficient crop in California. However, much of the areas suitable for sorghum in the Central Valley have high soil salinity and are prone to moisture stress. Sorghum is considered drought-tolerant and medium-tolerant to soil salinity; however, the effect of these stresses at seed germination needs to be determined. Two separate experiments were conducted at Fresno, CA to determine the effect of salt and moisture stress on seed germination of a forage (cv. SS405) and a grain (cv. NK5418) sorghum variety using solutions of salt (NaCl) concentrations ranging from 0 to 200mM and water potentials ranging from 0 to −5.56 MPa. Petri dishes containing the seeds in the different solutions were placed in growth chambers set at 30 ± 5°C, 12 hr daylength. Germination was monitored for two weeks. The experiments were replicated five times and repeated. The forage and grain varieties responded differently to the salt and moisture stresses. Grain sorghum germination was reduced by 20% even at the highest NaCl level, whereas forage sorghum germination was reduced by 50% at 180 mM. Moisture stress reduced the germination of the forage and grain sorghum varieties by 50% at approximately -2.5 MPa and -1.5 MPa, respectively. Therefore, grain sorghum was more tolerant to salt stress than moisture stress, whereas forage sorghum was more tolerant to moisture stress than salt stress. These studies suggest that the mechanism of tolerance to these stresses may be different in the two sorghum varieties. Although the varieties were considerably tolerant to salinity and moisture stress, variety recommendations may need to differ for different soil conditions.

NOTES

NOTES

California Chapter – American Society of Agronomy
2016 Plant and Soil Conference Evaluation

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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	5
Conference provided useful information	1	2	3	4	5
Conference provided good contacts	1	2	3	4	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.

____

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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:____

____

____

Improvement of Yield Per Acre by Managing Canopy Size and Close Spacing Planting of Hass and Lamb Hass Avocados

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California produces about 90% of the nation's avocado (*Persea americana*) crop and San Diego County grows about 50% of all the avocados grown in the state. Avocado trees are native to subtropical climates where rainfall is abundant so it is important to keep trees well irrigated to produce fruit and leach out salts from their sensitive root zone. Currently the cost of water in San Diego County is approximately $1,400/ac. ft. and higher in the more elevated pumping districts. This further impacts growers who are already struggling to make profit. Increasing water costs which are expected to reach $2,000/ac. ft. by the year 2020 is of great concern. To adapt, growers need to dramatically increase yield per acre using the same amount of water or less. This can be achieved with high density spacing plantings. As an alternative to planting at the traditional spacing of 20' x 20,' trees for this project were planted at 10' x 10' spacing. In previous studies it has been suggested that since the trees are being kept small, the amount of water and land requirement might be less. A block of 72 Hass and 72 lamb Hass avocados, both on Dusa rootstalks were pruned two years after planting with two different methods (traditional and Bender) twice within the year and trees were kept under eight-foot in height. Yield was collected on the third year after planting for both varieties. Results indicated that there was a significant difference between varieties in yield. The Hass variety, the current industry standard, continues to thrive even in a high density planting setting as it out yielded lamb Hass. However, in general both varieties yielded more than the average trees in a conventional planting at a younger age. There was also a significant difference between the pruning types at P= 0.0523, however both pruning types had a similar effect on both varieties as there was no interaction between the variety and the pruning type. Pruning methods still need to be further evaluated to gain the information that is needed to maximize production for California growers. Even though high density planting is not a new concept in California and appears to be successful at increasing yield per acre, additional years of data are still needed.

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Plant and Soil Conference
February 2 – 3, 2016
Wyndham , Visalia
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POSTER SUBMISSION FORM

Title of Paper: Life cycle of fall- and spring-planted biotypes of *Conyza* sp. described in growing degree days
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ABSTRACT: : A two-year study was conducted at Fresno, CA to compare the growth and development of fall- and spring-planted glyphosate-resistant (GR) and glyphosate-susceptible (GS) horseweed (*Conyza canadensis*) and hairy fleabane (*C. bonariensis*). The time taken to reach various phenological stages (rosette, bolting, initial appearance of flower bud, initial flowering, and initial seeding) by the plants was recorded in days after transplanting and converted to growing degree days (GDDs). Dry mass of the plants at initial seed set was also recorded. Results showed that, the GDDs required to reach various phenological stages was different between the fall- and spring-planted hairy fleabane. The fall-planted hairy fleabane plants required more GDDs to set seed than the spring-planted ones. However, there was no difference between the GR and the GS hairy fleabane for the number of GDDs required to reach the various phonological stages. In contrast, both the fall- and spring-planted horseweed required similar GDDs to reach the various phenological stages. Furthermore, the GR horseweed plants required fewer GDDs to reach the various phenological stages than the GS plants. Planting date had no effect on final aboveground hairy fleabane biomass but fall-planted horseweed amassed more dry matter than the spring-planted individuals. Studies have reported that postemergence herbicides control these species better when applied at or before the rosette stage. This study suggests that these species should be controlled by mid-November for fall-emerging and early-April for spring-emerging populations of both species.

FOR STUDENT POSTER SUBMISSIONS:
I verify that __Katrina Steinhauer________________ completed this project as part of course work at my institution.

Signature of major professor __ Anil Shrestha ____

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POSTER SUBMISSION FORM

Title of Paper: Competition between a glyphosate-resistant and a glyphosate–susceptible biotype of junglerice (*Echinochloa colona*)

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ABSTRACT: Junglerice (*Echinochloa colona*) is a problematic weed in annual and perennial cropping systems as well as non-crop areas of California. This problem has been further aggravated by the discovery of glyphosate-resistant (GR) biotypes in the Central Valley. It is not known if the GR type of junglerice has any fitness penalty and is less competitive than the glyphosate-susceptible type. Knowledge of the competitive ability of these two biotypes of junglerice could be helpful in predicting their population dynamics. Therefore, a pot-study was conducted in summer 2015 in Fresno to compare the competitive ability of GR and GS junglerice. In each pot, the GR and GS plants were planted at different ratios (4:0, 3:1, 2:2, 1:3, and 0:4 of GR and GS plants) in a replacement series experiment style. The plants were grown for 6 weeks. At the early flowering stage, the plants were individually harvested and dry biomass was recorded. Results showed that the total aboveground biomass was greater in the GS than in the GR type. However, the number of flower heads was greater in the GR than in the GS type. This indicated that the biomass allocation patterns to the reproductive structures and total seed production could be different in the GS and the GR junglerice. The GS junglerice was more competitie and produced more biomass than the GR plants at all densities indicating that this particular GS biotype was more competitive than the GR biotype. However, this finding, cannot be generalized for all GR and GS biotypes of junglerice in California. The study will be repeated in 2016.

FOR STUDENT POSTER SUBMISSIONS:
I verify that __ Pahoua Yang ________________ completed this project as part of course work at my institution.

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