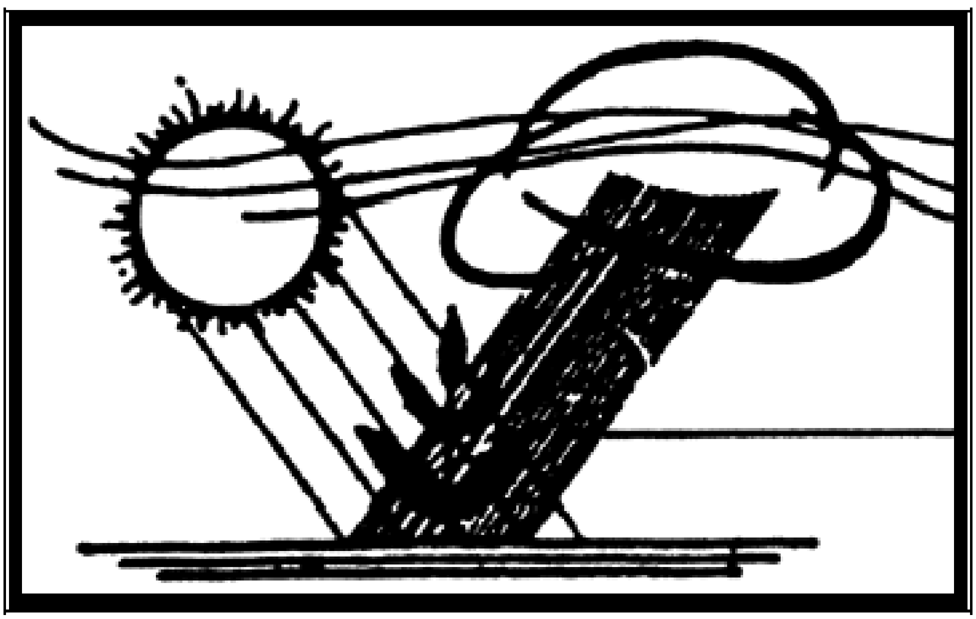
CONFERENCE PROCEEDINGS

2006

California Plant and Soil Conference

Realities of Modern Agriculture



California Chapter of the American Society of Agronomy

Co-sponsored by the California Plant Health Association

February 7 & 8, 2006

Visalia Holiday Inn
9000 W. Airport Dr
Visalia, CA

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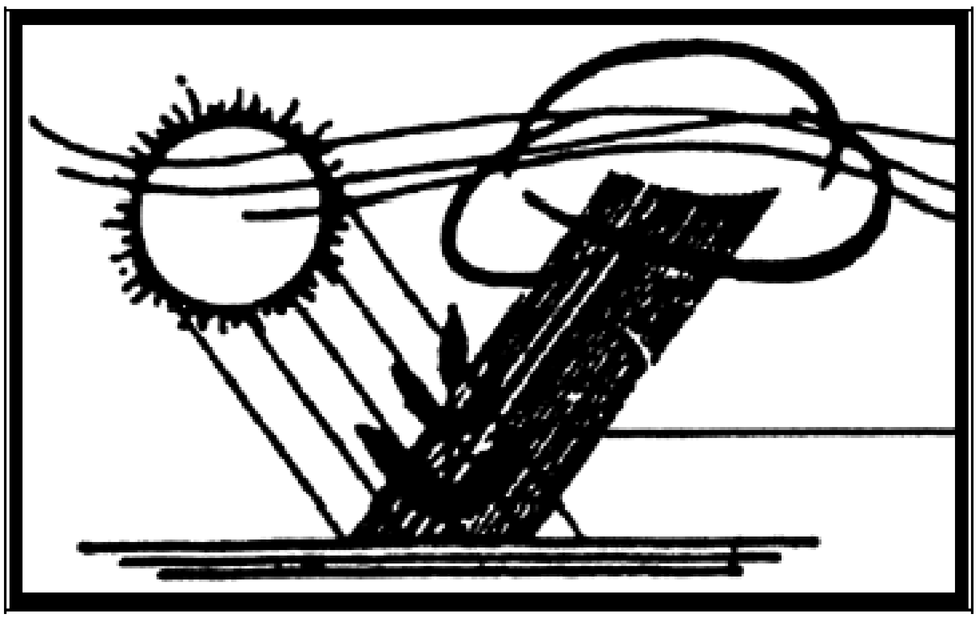

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CALIFORNIA PLANT & SOIL CONFERENCE
TUESDAY, FEBRUARY 7, 2006

REALITIES OF MODERN AGRICULTURE

10:00 **General Session Introduction** – Session Chair & Chapter President –Bruce Roberts, CSU Fresno

10:10 **The Future of California Agriculture in a Global Context -** Mechel Paggi, Director, Center for Agriculture Business California State University Fresno

10:40 **Agriculture Water: Factors Affecting Future Use -** David Zoldoske, Director, Center for Water Technology California State University Fresno

11:10 **Farm Land Protection Efforts in the Central Valley -** Maxwell Norton, Program Director – Agricultural Productivity and Farm Advisor, UC Cooperative Extension Merced Co.

11:40 Discussion

12:00 **Western Plant Health Association Luncheon Speaker: Ken Cassman, University of Nebraska**
"Global Agriculture by Intelligent Design"

CONCURRENT SESSIONS (PM)

I. Innovations and Important Issues in Pest Management

1:30 Introduction - Session Chairs: **Allan Fulton,** UCCE,; **Thomas Babb,** CA Dept Pest. Reg.

1:40 **Overview of technology for pest control and plant protection** – Ken Giles, Biological and Agricultural Engineering Department, UC Davis

2:00 **Adapting Variable Rate Technology to California Agriculture – One Dealer's Perspective** – Michael Larkin, Manager/Agronomist, Precision Agri-Lab, Western Farm Service

2:20 **Using Variable Rate Technology in cotton to reduce production inputs and increase yields** – Brock Taylor, Agronomist, Brock Taylor Consulting

2:40 Discussion **3:00 BREAK**

3:20 **Advances in tree fruit pest management** - Walt Bentley, UC Kearney Agricultural Center

3:40 **Refined management of late-season insect pests of cotton for mitigation of VOC concerns and protection of lint quality** – Larry Godfrey, Entomology Department, UC Davis

4:00 **Distribution and relative tolerance of glyphosate resistant ryegrass in California** – Tom Lanini, Department of Plant Sciences, UC Davis

4:20 Discussion

4:30 **ADJOURN**

II. Irrigation and Nutrient Management – Permanent Crops

1:30 Introduction – Session Chairs: **Joe Fabry ,** Fabry Ag Consulting**; Mary Bianchi,** UCCE

1:40 **Field Management and Monitoring of Almond Irrigation in Kern County** – Blake Sanden, UCCE Kern County

2:00 **Canopy Development and Physiological Responses of Almond to Deficit Irrigation and Nitrogen Management** – Bruce Lampinen, Department of Plant Sciences, UC Davis

2:20 **Irrigation Management of Early Ripening Peach Varieties** – R. Scott Johnson, Department of Plant Sciences UC Davis

2:40 Discussion **3:00 BREAK**

3:20 **Irrigation of Vineyards** – Larry Williams, Dept. of Viticulture UC Davis

3:40 **Irrigation Water Management in Groundwater Protection Areas** – Larry Schwankl, Land, Air, Water Resources UC Davis

4:00 **Development of Lime Recommendations for California Soils** – Robert Miller, Colorado State University Soil and Crop Sciences Department

4:20 Discussion

4:30 **ADJOURN**

ADJOURN to a Wine and Cheese Reception *in the Poster Room.*
A complimentary drink coupon is included in your registration packet.

WEDNESDAY, FEBRUARY 8, 2006
CONCURRENT SESSIONS (AM)

III. Irrigation & Nutrient Management – Annual Crops

8:30 **Introduction** – Session Chairs: **Tim Hartz** and **Will Horwath**, UC Davis

8:40 **Irrigation management of pepper** – Jim Ayars, USDA-ARS

9:00 **Updating crop coefficients for processing tomato** – Blaine Hanson, Dept. Land, Air & Water Res., UC Davis

9:20 **Drip irrigation of processing tomato – a grower's perspective** – Nathan Heeringa, J.G. BoswellCo.

9:40 Discussion **10:00 BREAK**

10:20 **Deficit irrigation of alfalfa** – Dan Putnam, Department of Plant Sciences, UC Davis

10:40 **Improving water-run N application in furrow- and border check field** – Stu Pettygrove, Dept. Land, Air & Water Res., UC Davis

11:00 **Nitrogen nutrition of cotto**n – Felix Fritschi, USDA-ARS

11:20 Discussion

IV. Site Selection & Development for Trees and Vines

8:30 **Introduction** – Session Chairs: **Ben Nydam**, Dellavalle Labs; **Dave Woodruff**, Woodruff Ag Consulting

8:40 **New Tools for Permanent Crop Site Selection** - Digital Soil Survey – Kerry Arroues, USDA – NRCS

9:00 **Site Selection Concerns -Agronomic to Permanent Crops** – Bob Beede, UCCE Kings County

9:20 **Soil and Water Quality for Trees and Vines** – Blake Sanden, UCCE Kern County, Bakersfield

9:40 Discussion **10:00 BREAK**

10:20 **Rootstock Selection for Vines –** Jennifer Hashim-Buckey**,** UCCE Kern County, Bakersfield

10:40 **Canopy Light Management for Orchard Planning** – Kevin Day, UCCE Tulare County

11:00 **Nematodes and Fumigation for Trees and Vines** – Becky Westerdahl, UCCE UC Davis

11:20 Discussion

12:00 **ANNUAL CHAPTER BUSINESS MEETING LUNCHEON**:
Presentation of Honorees, scholarship awards and election of new officers

CONCURRENT SESSIONS (PM)

V. Water Quality & Management

1:30 **Introduction** – Session Chairs: **Al Vargas,** California Department of Food & Agriculture

1:40 **Is the Glass Half Empty or Half Full - Findings of the Irrigated Lands Water Waiver Quality Monitoring -** Michael Johnson, University of California Davis

2:00 **To be announced** - Jean E. Moran, Lawrence Livermore National Laboratory

2:20 **CSI in the Lower San Joaquin River Water Quality Investigations** - Charles Kratzer, U.S. Geological Survey

2:40 **A Better way to Protect Groundwater** - John Troiano, California Department of Pesticide Regulation

3:00 Discussion

3:20 ADJOURN

VI. Managing Nutrients From Dairy Effluent

1:30 **Introduction** – Session Chair: **Charles Krauter**, CSU Fresno

1:40 **Using Nutrient Management to Improve Groundwater Quality Under Dairies: Case Studies -** Marsha Campbell Mathews, UCCE, Stanislaus Co.

2:00 **Optimizing Organic Fertilizer Applications -** David Crohn, University of California, Riverside

2:20 **Atmospheric Ammonia Emissions From Application of Dairy Lagoon Effluent -** Dave Goorahoo, CSU Fresno

2:40 **Alternative Methods of Treatment for Dairy Effluent and their Effect on Crop Nutrition –** C. Krauter, CSU Fresno

3:00 Discussion

3:20 ADJOURN

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Poster Abstracts

Poster Submission

California Chapter of American Society of Agronomy

Past Presidents

Year	President
1972	Duanne S. Mikkelson
1973	Iver Johnson
1974	Parker E. Pratt
1975	Malcolm H. McVickar
1975	Oscar E. Lorenz
1976	Donald L. Smith
1977	R. Merton Love
1978	Stephen T. Cockerham
1979	Roy L. Branson
1980	George R. Hawkes
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1982	Carl Spiva
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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 Zoldoske
2003	Casey Walsh Cady
2004	Ronald Brase
2005	Bruce Roberts

California Chapter of American Society of Agronomy

Past Honorees

Year	Honoree	Year	Honoree
1973	J. Earl Coke		
1974	W.B. Camp	1997	Jolly Batcheller
1975	Milton D. Miller		Hubert B. Cooper, Jr.
	Ichiro “Ike” Kawaguchi		Joseph Smith
1976	Malcom H. McVickar	1998	Bill Isom
	Perry R. Stout		George Johannessen
1977	Henry A. Jones	1999	Bill Fisher
1978	Warren E. Schoonover		Bob Ball
1979	R. Earl Storie		Owen Rice
1980	Bertil A. Krantz	2000	Don Grimes
1981	R. L. “Lucky” Luckhardt		Claude Phene
1982	R. Merton Love		A.E. “Al” Ludwick
1983	Paul F. Knowles	2001	Cal Qualset
	Iver Johnson		James R. Rhoades
1984	Hans Jenny		Carl Spiva
	George R. Hawkes	2002	Emmanuel Esptein
1985	Albert Ulrich		Vince Petrucci
1986	Robert M. Hagan		Ken Tanji
1987	Oscar A. Lorenz	2003	Vashek Cervinka
1988	Duane S. Mikkelsen		Richard Rominger
1989	Donald Smith		W. A. Williams
	F. Jack Hills	2004	Harry Agamalian
1990	Parker F. Pratt		Jim Brownell
1991	Francis E. Broadbent		Fred Starrh
	Robert D. Whiting	2005	Wayne Biehler
	Eduardo Apodaca		Mike Reisenauer
1992	Robert S. Ayers		Charles Schaller
	Richard M. Thorup	**2006**	**John Letey, Jr.**
1993	Howard L. Carnahan		**Joseph B. Summers**
	Tom W. Embelton		
	John L. Merriam		
1994	George V. Ferry		
	John H. Turner		
	James T. Thorup		
1995	Leslie K. Stromberg		
	Jack Stone		
1996	Henry Voss		
	Audy Bell		

California Chapter
American Society of Agronomy

2005 Chapter Board Members

Executive Committee

President Bruce Roberts, Plant Science Dept. CSU Fresno
First Vice President William Horwath, Dept. of Land, Air & Water Resources, UC Davis
Second Vice President Ben Nydam, Dellavalle Laboratory, Inc.
Secretary-Treasurer Tom Babb, CA Dept. Pesticide Regulations
Past President Ronald Brase, California AgQuest Consulting, Inc.

Governing Board Members

One-year term	James Ayars, USDA-ARS Joe Fabry, Fabry Ag Consulting Tim Hartz, CE Vegetable Crops Specialist
Two-year term	Mary Bianchi, UCCE San Luis Obispo County Allan Fulton, UCCE, Tehama County Jeffrey Wong, , Cal Poly State University
Three-year term	Charles Krauter, CSU Fresno Al Vargas, CA Dept. Food & AG Dave Woodruff, Woodruff Ag Consulting
Advisor	Casey Walsh Cady, California Dept of Food and Agriculture

2006 Honorees

John Letey, Jr.

Joseph B. Summers

John Letey, Jr.

Professor Emeritus, Department of Environmental Science, University of California, Riverside

Dr. John Letey has had a long and distinguished career in the service of California agriculture. Dr. Letey arrived at the University of California Riverside (UCR) in 1961 after a short stint as a Bruin (UCLA) and upon receiving a doctorate in Soil Physics from the University of Illinois in 1959. Dr. Letey remained at UCR achieving title of Distinguished Professor, Emeritus. Dr. Letey served as major professor to 25 doctoral students and mentor to numerous others. In addition to his teaching assignments in soil physics and water resources, Dr. Letey was instrumental in developing one of the first environmental science undergraduate programs in the nation. Dr. Letey chaired the Department of Soils and Environmental Sciences at UCR from 1975 to 1980.

Dr. Letey has distinguished himself as a scholar as he has authored or co-authored more than 300 technical publications. Dr. Letey's research has been in the forefront of California's soil and water resource management issues where he has conducted basic and applied research. His research accomplishments have advanced the basic understanding of soil and water resource processes and provided for improved resource management and protection. Dr. Letey's research interest can be categorized into: 1) irrigation, salinity, drainage and plant-water relationships; 2) water repellency and surfactants; 3) polymers in irrigation management; 4) soil oxygen; 5) transport of pesticides; 6) nitrogen cycle and nitrogen fertilizer reactions; 7) basic transport phenomenon; and 8) economic analysis. Dr. Letey's approach to his research has been driven by the need to provide integrated management of all crop production components in order to achieve high yields, water quality protection, and efficient utilization of resources.

Dr. Letey has provided valuable leadership and service in the advancement of soil and water management and protection at the state, national, and international level. At the state level, Dr. Letey has served on numerous advisory committees. He has provided his expertise on nitrate and nutrient management, non-point source pollution control, salinity and drainage management, and drinking water protection. At the national level, Dr. Letey has participated on numerous external review panels and as a consultant to other states and universities. Dr. Letey also was a member of the National Research Council, Water Science and Technology Board

Dr. Letey has participated in numerous international agriculture development projects for the United Nations Food and Agriculture Organizations, the US Agency for International Development, and the Israel-Egypt Joint Project on Agriculture. These projects have taken Dr. Letey to India, Bulgaria and throughout the Middle East where he has provided his expertise on water conservation and reuse, and salinity management. Dr. Letey has participated in numerous international forums including for the National Academy of Sciences, the National Research Council, the People to People Soil Science Delegation to China, and to the International Union of Soil Science. Dr. Letey has been an invited speaker to a multitude of national and international forums, including four presentations to the California Chapter of the American Society of Agronomy, Plant and Soil Conference.

Dr. Letey has served the University of California as Director of the Centers for Water and Wildland Resources and Director of the Water Resources Center. He also served as director of the

John Letey, Jr. (continued)

Salinity and Drainage Task Force and state coordinator for the U.S. Department of Agriculture's Water Quality Initiative and was the Director of the UC Kearney Foundation of Soil Science.

For his distinguished service and scholarly accomplishments, Dr. Letey has received numerous recognitions. Most recently Dr. Letey received the 2005 Soil Science Distinguished Service Award from the Soil Science Society of America. He also received the Gamma Sigma Delta Award for Distinguished Service to Agriculture in 1996 and was recently honored by his alma mater Colorado State University. Dr. Letey was recognized in 1970 by the American Society of Agronomy for outstanding research and received the Soil Science Award. Dr. Letey is a fellow of the Soil Science Society of America, the American Society of Agronomy, and the American Association for Advancement of Science.

For his distinguished service, his scholarly contributions and leadership, the California Chapter of the American Society of Agronomy honors Dr. Letey.

Joseph B. Summers

Joseph B. Summers served in Europe as a bomber crewmember in the U.S. Army Air Corp. After the war, he returned to his home state of Iowa and earned his BS in Engineering at the University of Iowa in 1948. He began his career with the Bureau of Reclamation in Denver Colorado. While there, he earned his masters degree at Colorado University. Mr. Summers then joined Chicago's Harza Engineering Company.

Modesto Irrigation Company then lured him to California, hiring him as an assistant engineer. Joseph B. Summers has been directly affiliated with agriculture in the southern San Joaquin Valley from the early 1960's. In 1962, Mr. Summers started his own company in Hanford. The Tulare Lake Drainage District retained him in 1962 to determine the agricultural drainage needs of the area, together with a plan to construct a collection and disposal system for the lands of the old Tulare Lake. These highly productive lands were in jeopardy from saline water rising to the level of the root zone.

In 1962, the Tulare Lake Basin Water Storage District and Empire Westside Irrigation District were interested in obtaining water from the soon to be construction State Water Project (SWP). The California Aqueduct, conveying water down the west side of the Valley from the Sacramento-San Joaquin Delta, would allow the districts to deliver SWP water to their respective lands. Summers was retained to negotiate a water supply contract from the State of California and to design a conveyance facility from the new aqueduct. This supplemental water supply has resulted in over 2.5 million-acre feet of water not pumped from the groundwater basin. Summers has chaired and served on several committees of the State Water Contractors, Inc. His experience and knowledge of the SWP has saved both districts costs by promoting increased efficiencies by the Department of Water Resources, the operator of the SWP

In 1990, Summers was selected as chairman of the Program Coordination Committee to oversee the $100 million water conservation plan being implemented between the Metropolitan Water District of Southern California and the Imperial Irrigation District. This project was completed in 1999 under the budgeted amount and exceeded the target volume for water to be conserved. Summers was selected as chairman of two Coordination Committees in 2003 to oversee the construction of concrete lining to reduce seepage in both the All American and Coachella Canals in Southern California. The two projects will conserve in excess of 100,000-acre feet of the water.

Summers has influenced agricultural water projects and water facilities design throughout California through his work with many water districts and on an international level with his involvement in a number of projects through the World Bank. His ability to not only design a project but also to explain its importance and relevancy to regulators and legislators has been invaluable to agriculture.

2006 Scholarship Recipient and Essay

Essay question:

What do you see as a critical challenge to sustaining California agriculture and how should that challenge be addressed?

Scholarship Committee:

Casey Walsh Cady
James Ayars
Mary Bianchi
Jeff Wong

Scholarship Program First Place Essay

Bryanna Fissori, California State University, Chico

"My interest is in the future because I am going to spend the rest of my life there."
\- *Charles F. Kettering*

Without a doubt California's most precious commodity is not almonds, rice or even dairy products, it is water. Water is crucial to the sustainability of California agriculture. The difficulty of maintaining an adequate and affordable supply stems from the fact that it is being distributed between three major sectors throughout the state consisting of agriculture, urban and environmental use.

We are seeing a continual increase of farmers, especially in the north, fallowing their land and selling their water rights to urban areas instead of producing a crop. Many growers are finding a higher return on this commodity than the ones they were previously producing. As the population in California continues to grow, it is likely that this trend will accelerate, leaving the state with fewer and fewer suppliers of food and other agricultural commodities.

Increasing water storage is crucial to the sustainability of California agriculture. There are programs such as the CalFed/Delta Bay program which is designed to provide funding to research the possibility of storage but without a knowledgeable base of water consumers placing pressure on the government to provide results, this could be a very drawn out process. In the meantime increased efficiency in water use through technological advances in irrigation systems will assist in maintaining the current status.

To combat this issue and acquire storage and other provisions necessary to create a sustainable water supply, agriculturalists must stay informed on crucial legislation and policy regarding the state's water concerns. The state's capacity for agricultural sustainability is currently riding on the rain and it is imperative that agriculturalists do their part to come up with a solution before it is too late.

Scholarship Program Second Place Essay

James Johnson, California State University, Fresno

Water Allocation and Quality

As California water issues begin to rise the most pressing concern to sustaining California agriculture is the need for quality water and proper allocation of it. With the growing population, the efficiency of water usage in agriculture has become increasingly important. In order to be more efficient, drip irrigation should be readily incorporated into crops where it is a sustainable measure. This would allow better water efficiency and less cost to the grower. Water should also be reused whenever possible for use on crops where pure water isn't as important and also for use in wetlands for water fowl. The movement toward more efficient use of water will not only help conserve the most precious resource in the world but it will also allow for sustaining current crop yields at a lower cost.

The quality of water is also of great importance as without quality water neither agriculture nor people can flourish. The leeching of chemicals into the water table through inefficient use of fertilizers and herbicides can create major problems as that contaminated water could potentially become drinking water for some person. This leeching of chemicals is primarily caused by improper use of fertilizers by growers. There is only a certain amount of nutrients that can be taken up by a plant during a growing season and overuse of fertilizer can be ultimately lead to a great deal of leeching that could cause potential contamination problems. Drip irrigation reduces mineralization and would most likely lessen the risk of contaminating the water table. However, proper usage of chemicals should be advocated to growers more avidly in order to press the issue that one should not contaminate their own water.

This is merely two points of many that involve the water issue in California. Yet, the allocation of water in California is of grave importance in a growing society in order to sustain the agricultural industry. Likewise, the need for quality water in the future is also quite important for sustaining both the population and agriculture. Knowledge is the most effective way to combat any problem and therefore the most realistic way to address these challenges is through statewide awareness of the problems and possible solutions can be implemented.

Session I

Innovations and Important Issues in Pest Management

Session Chairs:

Allen Fulton, UCCE, Tehama County

Thomas Babb, CA Dept Pest. Reg.

Adapting Variable Rate Technology to California Agriculture—One Dealer's Perspective

Michael D. Larkin, Agronomist/Manager, Western Farm Service/Precision Agri-Lab,

24730 Avenue 13, Madera, CA 93637

Phone (559) 661-6386 x103, FAX (559) 661-6135, mlarkin@agriumretail.com

Introduction

Western Farm Service offers growers agricultural inputs and innovative services through more than 100 staffed facilities in California, Arizona, Washington, Oregon, and Idaho. Our centralized technology center, Precision Agri-Lab, located in Madera, CA is a soil and plant laboratory providing advanced agronomic support to customers and sales personnel in California, Oregon and Arizona. Services include soil, plant, water, and fertilizer analyses, crop monitoring programs, plant nutrient and amendment recommendations, GPS mapping services, remote weather data collection, disease modeling and prediction, and soil moisture monitoring services. Precision Agri-Lab also serves as the mapping center for all variable rate applications, provides grid soil sampling services, and facilitates the use of satellite and aerial imagery.

Variable rate technology remains at the forefront of our precision agriculture efforts today. As a company, we are committed to bringing the best products, the best people, and the best service to our customers. It is our belief precision agriculture will continue to evolve as growers become more comfortable with the technology offerings in the marketplace.

Variable Rate Technology

Simply stated, the application of crop inputs at different rates within an individual application job is variable rate technology. The crop input may be a nutrient, amendment, pesticide, plant growth regulator, seeding rate, etc. The application rate is based on a recommendation which addresses the likelihood of a positive response, after having completed some means of assessing field variability. Growers have practiced variable rate technology for decades using a "seat of the pants" approach. Within the last several years, the use of GPS units and automated controller systems has improved our ability to precisely apply crop inputs.

Assessing Field Variability with Remote Sensing

While we do offer aerial or satellite imagery options to our growers, we are conservative in our expectations for the benefits remote sensing offers. Our experience suggests imagery can provide an indication of relative variability within and among fields. It often does not, however, provide an immediate indication of the cause for variability. Investigation of the cause for variability still requires in-field scouting and/or sampling. Our pest control advisors and field consultants are generally found within and among fields in their daily routine. They are often already aware, as are the growers, such variability is present. Thus, the image has not really provided new information, but it may help to determine the extent of the problem, and may help to target future scouting or sampling locations.

One area where imagery has merit is for variable rate recommendations of plant growth regulators and defoliants, particularly in cotton production. Our experience during the previous two years suggests reduced inputs of plant growth regulators and defoliants are likely to occur when recommendations are based on crop vigor or crop senescence as determined through remote sensing. The challenge remains in providing imagery and services where the economic incentives remain positive for the producer, dealer, and image provider.

Using remote sensing for developing variable rate nutrient recommendations has not found favor with us. Doing so would presume the limiting factor is identical for areas of the image which appear similar, when in fact the limiting factors may be different. We place greater confidence in sampling. Although not presented in this paper, we have observed fields in which we did both grid soil sampling and aerial or satellite imagery. We then separated the fields into management zones based on the imagery. We observed the same magnitude of variability of some soil test parameters within management zones as we did among management zones. Where it is evident the principal limiting factor is most likely to be ubiquitous, as is the case in some of our salt-affected soils, then aerial or satellite imagery has an excellent fit for developing variable rate amendment recommendations.

Assessing Field Variability with Grid Soil Sampling

Our preferred method for creating variable rate recommendations for plant nutrients is based on grid soil sampling and soil analysis. We currently recommend 1.0 to 5.0 acre grid sizes, with 2.5 acres being the most common and preferred grid size. Please note the distinction between variable rate nutrient and variable rate amendment applications in the following discussion.

Our preference for grid soil sampling to derive variable rate nutrient recommendations is based in large part on analysis of our soils database. Two other methods of note include using soil texture or type (such as from a soil survey or soil texture analysis) and EC mapping (such as from a Veris EC unit) as a way of delineating management zones for reduced sampling and soil analysis expense. We have found such strategies are not reliable for prediction of nutrient needs in most of the soils within our service area.

Table 1 shows the correlation coefficient matrix for soil test parameters analyzed from soil samples collected from our grid-sampled fields during 2000 to 2003. The database includes approximately 12,500 samples which represent roughly 30,000 acres in various locations throughout California. Saturation percentage (SP) is used to estimate soil texture with the following guidelines: SP of <20 = sands, 20-35 = sandy loams, 35-50 = silt loams to loams, 50-65 = clay loams, and >65 = clays or organic soils. Soil pH is measured from the saturated paste. Soil ECe, Ca, Mg, Na, and B are measured from a saturated paste extract. Exchangeable sodium percentage (ESP) is calculated by a standard equation from the Ca, Mg, and Na analysis. Soil NO3-N is from a 1M KCl extract, PO4-P is from the Olsen sodium bicarbonate method, K is an ammonium acetate extraction, SO4-S is a 8mM calcium phosphate monobasic extraction, and Cu, Fe, Mn and Zn all come from a 0.5M DTPA extract.

Working on the assumption that SP may be a reliable indicator of soil texture, the data indicate relatively weak correlations exist between SP and other soil test parameters. The best correlations of SP to other soil test parameters are SP to Cu with *r*-value of 0.43, and to K with *r*-value of 0.40; the r^2 would only be about 0.20 suggesting only 20% of the variability in soil test Cu and K levels can be explained by measuring SP.

Table 1. Correlation coefficients (*r*) of soil test parameters from approximately 12,500 grid soil samples collected in California during 2000 to 2003.

	SP	pH	ECe	Ca	Mg	Na	ESP	NO3-N	PO4-P	K	SO4-S	B	Cu	Fe	Mn	Zn
SP	1.00															
pH	0.20	1.00														
ECe	0.11	0.21	1.00													
Ca	0.20	0.13	0.65	1.00												
Mg	0.19	0.11	0.74	0.80	1.00											
Na	0.06	0.18	0.93	0.39	0.53	1.00										
ESP	0.00	0.34	0.67	0.16	0.27	0.69	1.00									
NO3-N	0.17	0.09	0.31	0.44	0.35	0.12	0.13	1.00								
PO4-P	0.13	-0.09	0.00	0.07	0.03	-0.03	-0.10	0.24	1.00							
K	0.40	0.17	0.28	0.19	0.14	0.23	0.34	0.25	0.21	1.00						
SO4-S	0.21	0.12	0.87	0.58	0.65	0.88	0.73	0.07	-0.01	0.21	1.00					
B	0.14	0.19	0.35	0.25	0.25	0.28	0.36	0.14	0.03	0.28	0.27	1.00				
Cu	0.43	-0.18	-0.03	0.01	0.00	-0.03	-0.11	0.09	0.26	0.21	0.06	0.00	1.00			
Fe	0.06	-0.52	-0.08	-0.11	0.00	-0.05	-0.08	-0.06	0.12	-0.19	0.02	-0.16	0.29	1.00		
Mn	-0.01	-0.49	-0.04	-0.03	0.02	-0.03	-0.11	0.11	0.20	-0.02	-0.02	-0.04	0.30	0.47	1.00	
Zn	-0.15	-0.22	-0.11	-0.07	-0.10	-0.08	-0.15	-0.02	0.25	-0.02	-0.04	-0.06	0.38	0.05	0.18	1.00

Relatively strong correlations (those with *r*-values > 0.70) are found in ECe to Mg, ECe to Na, ECe to SO4-S, Na to SO4-S, and ESP to SO4-S. In the arid west where soils are not generally highly leached and are typically calcareous, the base cations of Ca, Mg, and Na often greatly influence the chemical characteristics of the soil. Weak correlations of SP or ECe to primary nutrients (N, P, K) and micronutrients (B, Cu, Fe, Mn, Zn) erode our confidence in using soil texture or ECe to derive variable rate nutrient recommendations.

The relatively strong correlations of ECe to Mg, Na, SO4-S, and ESP do provide some potential for variable rate amendment applications such as elemental sulfur, gypsum, or sulfuric acid. Thus, when the principal limiting factors are known to be saline, sodic, or saline-sodic conditions, then use of ECe as a means of characterizing variability may have merit. However, if there were any interest in pursuing variable rate nutrient applications, then our recommendation would be to go ahead with the grid soil sampling which would include both nutrient and amendment recommendations.

Some may question whether similar relationships exist in the correlations of soil test parameters in fields which were not grid soil sampled. Although the data is not shown, the *r*-values in our conventionally sampled soils database (>50,000 samples) reveal similar relationships and *r*-values as seen in Table 1.

Further investigation as to whether stronger correlations exist within fields rather than among fields was also performed. Tables 2 and 3 show the distribution as a percentage of fields where the *r*-values of SP (Table 2) or ECe (Table 3) to other soil test parameters were positively strongly correlated (*r* > 0.75), positively moderately correlated (*r* = 0.50 to 0.75), weakly correlated (*r* = 0.50 to –0.50), negatively moderately correlated (*r* = -0.50 to –0.75), and negatively strongly correlated (*r* < -0.75).

The high percentage of fields where the *r*-value is between 0.50 and –0.50 suggests the within field correlation of SP or ECe to other soil test parameters is weak. Most notable exceptions to this are correlations of ECe to Ca, Mg, SO4-S, and Na (*r* >0.75, and percentage of fields falling in this category >67%). This reinforces our belief ECe or soil texture as measured by SP are poor predictors of nutrient need. We feel the most suitable indicator of nutrient need is best described by proximity to sampling location and actual soil analysis. We recognize there are inherent risks in these assumptions, but we hold more confidence in actually sampling the soil to develop variable rate recommendations than pursuing other technologies. In short, the more samples that characterize a field, the greater degree of confidence in the recommendations.

Table 2. Distribution of correlation coefficient (*r*) of saturation percentage (SP) versus other soil analysis parameters.

SP vs.	*r* >0.75	*r* = 0.75 to 0.50	*r* = 0.50 to –0.50	*r* = -0.50 to –0.75	*r* <-0.75
	---% of Fields*				
NO_3-N	2.2	13.2	83.2	1.1	0.4
PO_4-P	2.6	10.6	83.5	2.9	0.4
K	24.9	26.4	47.3	1.5	0.0
Ca	1.5	13.6	80.4	4.5	0.0
Mg	1.9	14.7	81.1	2.3	0.0
SO_4-S	6.9	20.8	71.1	0.8	0.0
B	3.8	14.7	77.0	4.2	0.4
Cu	29.4	23.8	46.0	0.8	0.0
Fe	7.9	20.0	68.3	3.4	0.4
Mn	3.0	15.5	77.0	3.8	0.8
Zn	3.8	11.3	80.8	3.4	0.8
pH	3.4	8.7	81.9	4.9	1.1
ECe	3.3	15.8	78.0	2.9	0.0
Na	3.4	14.7	79.6	1.9	0.4
ESP	5.1	10.6	81.2	2.4	0.8

* Data from 273 grid soil sampled fields representing 7,972 samples. Average field size was 68.3 acres.

Table 3. Distribution of correlation coefficient (*r*) of electrical conductivity of saturated paste extract (ECe) versus other soil analysis parameters.

ECe vs.	*r* >0.75	*r* = 0.75 to 0.50	*r* = 0.50 to –0.50	*r* = -0.50 to –0.75	*r* <-0.75
	---% of Fields*				
NO_3-N	34.1	29.3	35.9	0.7	0.0
PO_4-P	3.7	9.9	85.3	1.1	0.0
K	5.1	20.5	73.3	1.1	0.0
Ca	85.7	5.7	7.9	0.8	0.0
Mg	86.0	4.5	9.1	0.4	0.0
SO_4-S	67.3	19.2	13.1	0.4	0.0
B	26.0	26.4	47.2	0.4	0.0
Cu	2.6	10.9	82.3	4.2	0.0
Fe	1.5	5.7	86.8	5.7	0.4
Mn	7.9	17.4	71.7	3.0	0.0
Zn	2.3	10.2	84.5	2.3	0.8
Na	73.2	15.5	11.3	0.0	0.0
ESP	29.0	18.4	45.9	5.1	1.6

* Data from 273 grid soil sampled fields representing 7,972 samples. Average field size was 68.3 acres.

Future of Variable Rate Technology

From an agronomic standpoint, variable rate technology makes sense. Economically, we find it difficult to prove or disprove whether it is beneficial. There are generally increased investments in time, equipment, and services, while inputs of nutrients, chemicals, and amendments, etc. may be less, steady, or more compared to conventional applications. With today's equipment, and technology, variable rate application can be accomplished satisfactorily. The real challenge is deciding which input to put where, and at what rate in order to achieve the expectations of the customer.

New Advances in Arthropod Pest Management in Stone Fruits

Walt Bentley, UCIPM Entomologist, Kearney Agriculture Center
9240 South Riverbend, Parlier, CA 93648
Phone (559) 646-6527, FAX (559) 646-6593, walt@uckac.edu

Introduction

There are approximately 122,000 acres of peaches and nectarines currently grown in 6 western states including California, Colorado, Washington, Oregon, Utah, and Idaho. Of this total, California harvests 75,782 acres of peaches and 36,500 acres of nectarines.

Eighteen pests are commonly found damaging peach in the Western United States (Pickel et al 2005). The four key arthropod pest problems of peach include Oriental fruit moth (OFM), peach twig borer (PTB), San Jose scale (SJS), and green peach aphid (GPA). Of these, OFM, PTB, and SJS are invasive pest, being brought into to the United States on planting material. Green peach aphid is known worldwide but does not form the sexual stage in the major peach growing areas of California and is not found infesting peaches in the San Joaquin Valley. In the remaining five western peach growing states GPA is a key pest. Other common pests in the west include omnivorous leafroller (OLR), forktailed bush katydid (FTBK), western tarnished plant bug (WTPB), webspinning spider mites, European red mite (ERM), and flatheaded wood borer (FHWB). The western US is not plagued by pests such as plum curculio and Japanese beetle. These two pests are key problems in the eastern US.

Early Approach to Pest Management

Until recently, the management of peach pests relied upon a variety of broad-spectrum insecticides, at least since the discovery and of DDT by Dr. Paul Muller in 1940 (Pfadt, 1971). Insecticide use in peaches progressed from DDT and endosulfan to parathion, carbaryl, azinphomethyl, phosmet, permethrin and others. The result of this reliance on broadspectrum pesticides was the widespread development of webspinning spider mites as a serious pest problems (Hoyt and Caltagiorone, 1969) and the elimination of biological control in the orchard ecosystem.

Oriental fruit moth, currently the most devastating pest in peach production, did not become established in the west until the 1940's. In the Eastern United States infestations were widespread by 1930. The first OFM found in California was in Orange County on September 30, 1942 (Finney, G. L., S. E. Flanders, and H. S. Smith, 1947). It did not become established in the San Joaquin Valley until 1954. Oriental fruit moth became established in the states of Colorado, Washington, Oregon and Utah by 1945 (Allen, H. W. 1958). This coincided with the availability of a wide range of organophosphate and carbamate insecticides. Oriental fruit moth quickly became the key pests requiring repeated sprays annually (Bowen et al, 1973, Hoyt and Caltagiorone, 1969). These sprays quickly led to severe outbreaks of both two-spotted and Pacific mite and eventual insecticide resistance development by OFM.

Peach twig borer, a pest similar in biology and damage to OFM, was also managed with broad-spectrum insecticides. The primary sprays being a dormant application that included an organophosphate or pyrethroid insecticide. The repeated OFM sprays (3 to 5 depending upon harvest date) also controlled PTB during the growing season.

Horticultural mineral oil plus an organophosphate spray applied during the dormant period has also been the primary control of the third key pest, San Jose scale. This very same spray helps manage green peach aphid where it is problematic. Often, these same organophosphates along with carbamates were used during the spring and winter for SJS and aphid control. With the elimination of the western predator mite, *Galandromous occidentalis*, repeated acaracides were required for management.

Innovations in Pest Management

Within the last decade western peach growers have been able to change their approach to managing pest problems. They have implemented a truly integrated management program. The development of mating disruption for Oriental fruit moth in the late 1980's was the single most important break through. This single management technique has reduced sprays for OFM from 3 to 5 per year to 0 or1. Another important development was the synthesis of selective insecticides for peach twig borer omnivorous leafroller and katydid, and the renewed use of horticultural mineral oil for San Jose scale and European red mite. A 6 year study of peach and nectarine farmers in the San Joaquin Valley demonstrated that a program of mating disruption for OFM, horticultural mineral oil use for SJS, ERM, and European fruit lecanium scale, and bloom time sprays of selective insect growth regulators, spinosad, or *Bacillus thuringiensis*, can manage pests as effectively as a more broad spectrum approach (Bentley et al, 2004). Additionally, the cost of this reduced risk program is no different than the standard approach having been used from 1950-1990. This is an important change. Within the last decade surface water contamination by organophosphate pesticides has been documented in the west (Holmes, R., V. de Vlaming, and C. Foe). This contamination has resulted in toxicity to aquatic invertebrates and is of regulatory significance. In California "all waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in aquatic life" (Central Valley Basin Plan of The Central Valley Regional Water Quality Control Board).

The movement away from broad spectrum dormant sprays will help farmers mitigate the issue of surface water contamination. Also, this reduced risk approach allows for biological control to play a major part in the integrated pest management program. *Macrocentrus ancylivorus* Rohr, a parasitoid of OFM and PTB, is commonly found in California peach orchards. Parasitism of OFM in orchards where no broad-spectrum insecticides are used has reached 95% by late August (Bentley, 2005). This level of parasitism greatly reduces the population in subsequent years and allows for a more effective mating disruption program. Another key predator in the peach system is the gray field ant, *Formica aerata,* demonstrated to reduce PTB abundance in peach orchards (Daane and Dlott, 1998)

The IPM approach used in California has not simply traded one group of insecticides for another. But, for pests such as OFM and PTB, a preventative program is still used. Each spring, after the first OFM is trapped, placement of mating disruption dispensers is routinely done. Newly developed dispensers provide effective disruption for 150 to 180 days. Although many peach farmers do make a second hanging in August, some have had adequate control with a single hanging. During the bloom and post bloom period, as fungicides are applied, insecticides such as *Bacillus thuringiensis*, methoxyfenozide or diflubenzuron are applied for PTB.

Monitoring for PTB, OFM and OLR is done with pheromone baited sticky traps. These traps are checked on a weekly basis to determine if there is a breakdown in mating disruption (OFM) or to determine phenology of pests (PTB and OLR). Counting wilted peach shoots at the end of the first and second generation of OFM is a method of detecting the efficacy of mating disruption. If an average, per tree, of more than 3 wilted shoots are found, supplemental treatment with an appropriate insecticide is necessary (Pickel et al, 2005).

There are monitoring plans and treatment thresholds for SJS and ERM (Pickel et al, 2005). For example, a threshold of 5% of spurs infested with SJS indicates a need for a dormant oil application. Infestation of 20% of the sampled spurs requires the inclusion of an insect growth regulator such as pyriproxifen or buprofezin. The spurs are sampled in January or February. Fruit harvested in May or June does not require the dormant spray unless wood death is noted. If a peach farmer does spray for SJS they may include a product such as spinosad or diflubenzuron for PTB and forgo the bloom spray for this pest. This approach has led to the establishment of the SJS parasitoids, *Encarsia perniciosus* and *Aphytis vandenboshi* that provide approximately 30% pest reduction (Bentley, 2003).

Sampling peach leaves for webspinning spider mites can guide farmers for the need to treat this pest. A presence/absence monitoring plan is used by peach farmers to determine the need for acaracide application (Strand, 1999). This plan takes into account the abundance of predators in relation to spider mites.

Implementing IPM

Integrated Pest Management for arthropod pests in peaches can now be truly implemented in California peach production. The cost of such an approach has not differed from the conventional standard approach used in the 1980's and early 1990's (Bentley et al, 2003). This is good for the peach grower, the consumer and the environment.

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Refined Management of Late-Season Insect Pests of Cotton for Mitigation of VOC Concerns and Protection of Lint Quality

Larry D. Godfrey, Extension Specialist, Dept. of Entomology
One Shields Ave., University of California, Davis 95616
Phone (530) 752-0473, FAX (530) 752-1537, ldgodfrey@ucdavis.edu

Introduction

Cotton aphid, *Aphis gossypii*, and silverleaf whitefly, *Bemisia argentifolii*, populations are significant annual threats to cotton production in the San Joaquin Valley. Both pests can reduce cotton yields; however, the potential to contaminate cotton lint, creating a condition called "sticky cotton", has been the primary concern in recent years. Aphid populations have been a challenge to cotton integrated pest management in the San Joaquin Valley for ~15 years. Ten years of successful research by research and extension personnel and timely delivery for these results to clientele created a sound management program in the late 1990's (Godfrey et al., 2000). However, the high level of scrutiny placed on sticky cotton by the cotton industry after the 2001 season, and the magnified importance of late-season cotton aphid infestations, have "strained" this program. The recent regulatory concerns over volatile organic compounds (VOCs) and the role of cotton in this phenomenon have the potential to further complicate the management of cotton aphids. Lorsban 4E is commonly used to control cotton aphids, especially during the August and September period when other materials are less effective through the aerial application route and this is a key product in the VOC concerns. Through this research, cotton aphid management plans on cotton were revisited and additionally refined. Concomitant with the increased importance of cotton aphids has been the continued range expansion and build-up of silverleaf whitefly (also known as sweet potato whitefly strain B) populations in the SJV (Godfrey et al., 1995). Important research on sampling, damage potential, and management of *Bemisia* whiteflies has been conducted in Arizona (Oliveira et al., 2001). This research has formed the backbone of our present management scheme in California. However, significant differences in whitefly infestation patterns, biology, crop landscapes, environmental conditions, and cotton species (upland cotton versus pima cotton) created the need to adapt and modify the management program.

Procedures

Studies were designed to create a knowledge base to optimize pest management strategies for insect pests of cotton during the critical late-season period. Integrated pest management relies on concise information and delivery of these data in a grower-friendly format. Specific studies were conducted to fortify data gaps in our present cotton IPM scenario. "Silver bullets" that could revolutionize the present system were not available so small incremental advances were sought. "Letting the guard down" on sticky cotton was not an option for the cotton industry. Late-season aphid and SLWF populations were particularly damaging in 2001 and the cotton industry successfully responded to this threat. Since 2001, when mills complained about the quality of SJV lint, there has been an increased concern over cotton lint quality and cotton producers and PCAs have developed a near zero-tolerance for late-season cotton aphids as well as whiteflies. In many ways, management is analogous to vegetable production where quality and aesthetics are of utmost importance.

The impacts of sticky cotton are difficult to quantify; price deductions for contaminated lint can be given and the system for doing this is evolving. However, the primary economic damage is that a production region gains the reputation of producing and marketing cotton that is sticky. This creates less demand for that cotton and the brokers and mills purchase this cotton less aggressively, therefore the price declines - counteracting this reduced demand is a long-term process. A severe SLWF infestation in AZ in the early and mid-1990's resulted in price reductions of 5-15%.

Sticky cotton is particularly problematic for pima cotton (two species of cotton are grown in the SJV [Acala/upland and Pima]); Pima cotton produces a finer lint, demands a premium price, and has a different ginning process which magnifies the importance of honeydew contamination. Both Acala and Pima varieties are at risk but the latter tends to be most vulnerable to late-season infestations. Pima cotton requires a longer growing season and fields are often the last harvested providing the last attractive cotton habitat in an area. In recent years, the acreage of pima cotton has increased dramatically relative to acala cotton. Overall, several gaps existed in the knowledge-base on IPM in pima cotton.

Several objectives were addressed in these studies during 2004 and 2005 including 1.) examining the efficacy of experimental insecticides for cotton aphid and whitefly control, 2.) examining the effectiveness of alternative formulations of chlorpyrifos (to reduce the reliance on Lorsban® 4E) for cotton aphid control, 3.) investigating the utility of remote sensing for detection of cotton aphid infestations, and 4.) defining the economic threshold for cotton aphids and whiteflies for the prevention of sticky cotton in acala and pima cotton.

Results and Conclusions

Experimental Insecticides and Alternative Formulations: Cultural control measures (i.e., planting date, nitrogen use rate, etc.) and biological control (predators and parasitoids) play important roles in aphid management especially during the early- and mid-season periods. However, use of insecticides is critically important during the late-season period to protect the exposed cotton lint. Given the propensity of aphids and whiteflies to develop resistance to insecticides and the possible loss of active ingredients due to regulatory actions, development of new products is critical. Presently, aphid management relies on insecticides in the neonicotinoid and organophosphate chemical classes with carbamate insecticides also contributing. Over-reliance on neonicotinoid insecticides has the potential to hasten the development of resistance and this is a possibility if restrictions from VOC concerns are placed on organophosphate insecticides. Small plot studies with ground applications were conducted to evaluate product efficacy; aphid populations were quantified at several intervals following application. One experimental insecticide representing a new class of chemistry (flonicamid in the pyridinecarboxamide class) and one registered, but not widely used, product (pymetrozine [Fulfill®] in the triazine class), were tested against the registered standards. In 2004, studies were conducted during the mid-season period. Both flonicamid and pymetrozine showed potential for control of cotton aphids in cotton. Efficacy was similar to that of registered standards such as Lorsban 4E and Assail 70WP. It was also interesting to note that Lock-On®, a chlorpyrifos formulation with a low-volatile polymer carrier, did not provide the level of aphid control seen with Lorsban 4E. Additional studies were conducted in 2005 on acala and pima cotton during the mid- and late-season periods.

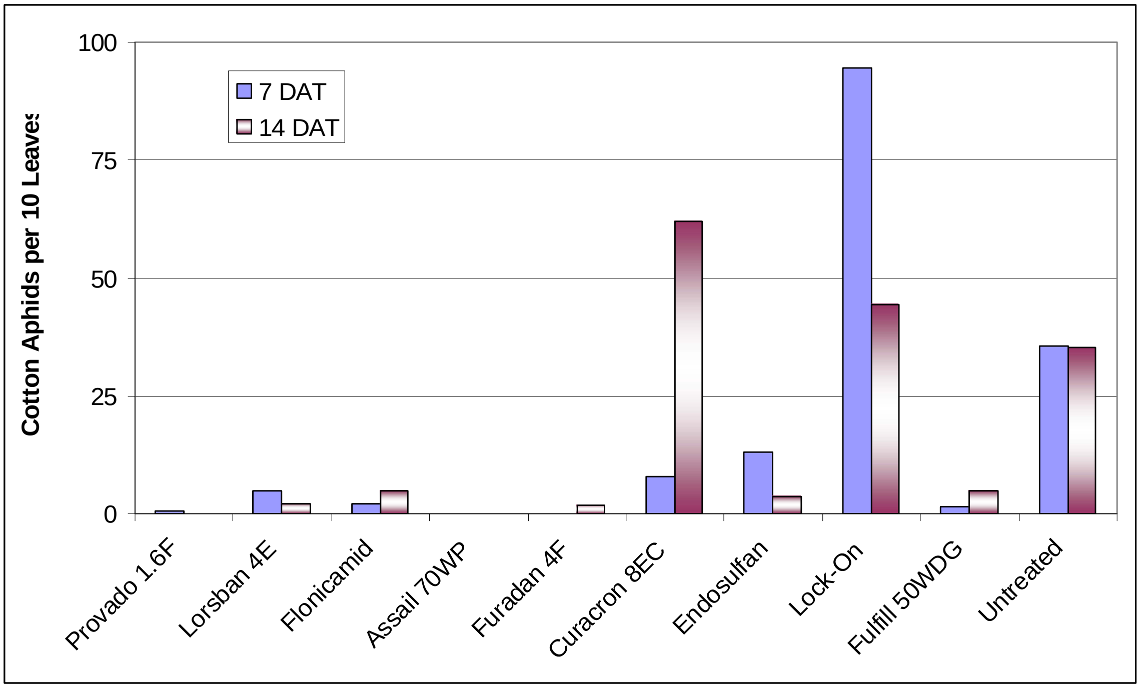

Figure 1. Efficacy of selected insecticides against cotton aphids at 7 and 14 days after treatment, 2004.

<u>Remote Sensing for Detection of Cotton Aphid Infestations:</u> Multispectral and hyperspectral analysis from remote sensing, a precision tool in development, can detect differences in crop health. This information can be coupled with observations on the ground for ground-truthing of arthropod populations and other plant stress factors. This allows the information seen in the image to be associated with biological factors in the field. Precision agricultural methods have the potential to positively impact cotton IPM in the SJV. If the area where pests are located within fields can be detected, pesticide applications can potentially be reduced both in frequency and in amount. Spider mite and cotton aphid infestations in the SJV tend to be heterogeneous, with some areas of high infestation and some areas of negligible infestations in fields. However, the currently available ground sampling methods make it impossible to detect all infestations within the large fields of the SJV- typically 80 to 190 acres. Arthropod management decisions are currently made on an inter-field basis rather than an intra-field basis.

Field experiments were conducted in 2003 and 2004 to investigate the potential for remote sensing to detect cotton plants with early infestations of cotton aphid (Reisig et al. 2005). Additionally, we wanted to see if plant stress from aphid feeding could be differentiated from stress from another common leaf-feeding arthropod, i.e., spider mites. Differential populations of aphids and mites were established in field plots using selective and disruptive pesticides. Hyperspectral and multispectral airplane imagery were collected in 2003; hyperspectral imagery using a portable spectrometer and multispectral satellite imagery were collected in 2004. Plots in 2003 with mite damage (mite infestations above treatment threshold levels) were found to have lower average reflectance using the green band in the multispectral imagery. In the narrow band at ~579 nm, uninfested cotton was found to have higher average reflectance levels than mite-infested and aphid-infested cotton using the hyperspectral imagery in 2003. Using the portable spectrometer in 2004, it was found that average reflectance levels tended to decrease as aphid numbers increased. Additionally, using the multispectral satellite image in 2004, it was found that aphids at economic threshold levels could be detected using a canopy index and near infrared images. Therefore, it appears that remote sensing has potential for IPM applications in SJV cotton, although more research needs to be done to test and implement these uses under grower field conditions.

Late-Season Threshold for Cotton Aphids and Whiteflies: One of the keys to effectively managing late-season honeydew-producing insects is knowledge of the relationship between population levels and the amount of lint stickiness. This threshold value is critical for scheduling appropriate management actions, including insecticide applications. Rosenheim et al. (1995) suggested a threshold of 10-15 aphids per leaf following boll opening in California and Slosser et al. (2002) found the threshold ranged from 11 to 50 aphids per leaf in west Texas cotton. Naranjo et al. (1998) found significant relationships between silverleaf whitefly populations and lint yield but relationships with honeydew deposition were lacking. In studies conducted in 2002, results showed that the threshold for prevention of sticky cotton was 5 to 10 aphids per 5^{th} main stem node leaf. In 2003, aphid levels of 5 per leaf resulted in sticky cotton; however, this population of aphids was confounded with a low population of silverleaf whiteflies which also contributed to the stickiness. These mixed populations of sucking insects are becoming the norm for the SJV as opposed to single species infestations. Studies in 2004 supported the 5 aphids per leaf threshold for minimizing the occurrence of sticky cotton. All this previous research was conducted on acala cotton; in 2005 studies were extended to Pima cotton. Significant populations of aphids were present in both the acala and the Pima cotton plots. Results on cotton stickiness are still being determined.

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Distribution and Relative Tolerance of Glyphosate Resistant Ryegrass in California

W. Thomas Lanini, Extension Weed Ecologist, University of California, Davis
One Shields Ave, Department of Plant Sciences, Davis, CA 95616
Phone (530) 752-4476, FAX (530) 752-4604, wtlanini@ucdavis.edu

Introduction

Ryegrass (*Lolium* spp.) is a winter annual, common throughout California. In 1998, two orchard sites were identified as possibly having glyphosate resistant ryegrass populations. These populations were confirmed as being resistant to glyphosate (Simarmata et al. 2003). At least one orchard in the San Joaquin Valley has also been reported to contain glyphosate resistant ryegrass (R. Vargas, personal communication). The species of ryegrass, although reported to be rigid ryegrass (*Lolium rigidum*) (http://www.weedscience.org/in.asp), it appears to be *L. multiflorum* or possibly a hybrid of *L. rigidum* and L. multiflorum.

Although it has only been confirmed in two or three orchards, many other non-confirmed reports have indicated that glyphosate resistant ryegrass may be more common in California than originally reported. If resistance to glyphosate is confirmed, alternative weed management programs would need to be developed. The objective of this study was to screen ryegrass populations collected throughout California for resistance to glyphosate and to determine the level of resistance among populations.

Materials and Methods

1. Seed Collection

Seed from mature annual ryegrass was collected in May, July, and August, 2004, from roadsides and agricultural fields and orchards throughout the Sacramento and San Joaquin Valleys (Table 1). A description of each collection site was noted, including collection date, and the GPS coordinates. At each site, seed from at least 15 plants was collected and combined into a single sample. Attempts were made to collect at least 1000 mature seed for each sample site. A total of 60 sites ryegrass sites were sampled in 2004. Seed was cleaned and dry seed stored at room temperature (70°F) until use. At least four months of dry storage was required to overcome dormancy and begin the experiments.

2. Preliminary sensitivity experiment

Seed from a known susceptible ryegrass population were planted into pots and grown in the greenhouse. Pots, 4-inch diameter X 4-inch deep, were filled with UC modified soil mix http://greenhouse.ucdavis.edu/materials/nutrients_soil.htm), and at least 10 seed planted 0.25 to 0.5 inches deep. Pots were placed in a temperature controlled greenhouse, 75°F day and 55°F night, with supplemental lighting (12 hr day length). Plants were thinned to 2 to 3 plants per pot at one week after emergence and allowed to grow until 4-6 inches in height. Once plants reached the desired height, they were treated with 8 glyphosate rates: 0, 0.031, 0.062, 0.125, 0.25, 0.50, 1.0, and 2.0 lbs acid equivalent (ae)/ac. Four replicate pots per treatment were used. Glyphosate applications were made using a track sprayer, with a final spray volume of 16 gal/acre. Distilled water was used for all applications, in order to avoid confounding effects of hard water. Twenty one to 25 days after treatment, plants were harvested and fresh weight determined. Percent control was calculated as the fresh weight of the treated plant divided by the fresh weight of the untreated plant. The rate that resulted in a 50% reduction in fresh weight (I_{50}) was calculated.

3. Screening experiment

Seed from each individual ryegrass population was planted into 12-inch X 18-inch flats to provide at least 20 plants in each flat. Application of glyphosate was made to each flat at 0.062 lbs ae/ac, the I_{50} rate determined in the preliminary sensitivity experiment. Plants were grown in the same greenhouse, under similar conditions as used in the preliminary sensitivity experiment. Ryegrass was cut at ground level and shoot fresh weight was measured for each individual flat at 21 days after treatment. Samples were then placed in a forced air dryer (120°F) and dried, and weighed. The distribution of responses within and between populations was compared.

4. Rate response experiment

In addition to comparing all populations at a low application rate, we also wanted to determine the rate of glyphosate necessary to kill all ryegrass from a population. Following cutting for biomass measurement, ryegrass was able to produce new shoot growth. Once plants reached 6 inches in height, they were once again treated with glyphosate, but at double the previous rate – 0.125 lbs ae/ac. At 21 days after treatment, plants were again cut at ground level for biomass measurement as done in the screening experiment. This was repeated with glyphosate rate doubling [0.25, 0.75 (triple rate), 1.5, 3.1, 6.1, and 12.2 lbs ae/ac] at each successive treatment, until all plants in a flat were killed.

Results and Discussion

Seed were collected by driving until a mature ryegrass was seen, stopping and collecting a sample. Thus, many samples were collected on the roadside, but in all cases adjacent to agricultural fields. Ryegrass was a common along roadsides and in fields in the Sacramento Valley. While driving in the San Joaquin Valley, ryegrass was less common on roadsides and fields, particularly further south in the Valley.

Treating the 60 ryegrass populations with glyphosate at 0.062 lbs/ac resulted in minimal growth reductions in all the populations (data not shown). The susceptible population was a population collected about 20 years ago from a location with no known glyphosate use. Thus, all the ryegrass populations appeared resistant relative to the susceptible ryegrass.

Of the 60 ryegrass populations evaluated, only five populations were killed by the recommended glyphosate rate of 0.75 lb/a (Table 1). At double the recommended rate of glyphosate (1.5 lbs/ac), less than 15% of the sampled ryegrass populations were killed. The observation that many populations are resistant to glyphosate is not surprising, since seed samples were collected from areas where it is likely they would have been treated with glyphosate, in many cases repeatedly, and thus only resistant plants would remain. Ten populations have not been completely killed by over 12 lbs of glyphosate per acre, and a few populations show less than 50% control from the 12.2 lb/ac rate, indicating a very high level of resistance.

The ryegrass populations in the northern Counties, near the locations of the original observations of resistance, required a high rate of glyphosate for control. It is likely that most populations in California contain some glyphosate resistant individuals and that once susceptible individuals are removed by treatment with glyphosate, resistant individuals breed with other resistant individuals, creating a highly resistant population.

The abundance of glyphosate resistant ryegrass along roadsides has likely allowed the rapid spread throughout the state, as mud picked up in tires could carry the seed. The high level of glyphosate resistance in roadside ryegrass may be a reflection of repeated use of glyphosate by road crews, particularly in programs where residual herbicides are not used.

The data on glyphosate resistant ryegrass distribution and rate sensitivity will serve as a baseline, allowing other populations to be tested and compared in the future. Now that glyphosate resistant ryegrass has been confirmed in many areas of California, alternative management options will need to be implemented.

Table 1. Site description and coordinates for annual ryegrass seed collected in 2004 (60 sites), going from south to north, and the rate of glyphosate[1] (lbs/acre) needed to kill ryegrass.

Site description	County	Date collected	North Coordinate	West Coordinate	Glyphosate rate (lbs ae/acre) required for 100% ryegrass control
Roadside	Fresno	Aug-2004	36°35.277	119°29.693	1.5
Roadside - Aromas	Monterey	Aug-2004	36°52.669	121°38.234	3.1
Almonds Ave 18 1/2	Madera	1-Jul-04	37°01.106	120°16.165	6.1
Cotton Gin yard	Madera	9-Jul-04	37°02.531	120°35.504	12.2 +
Roadside Hwy 165	Merced	9-Jul-04	37°08.804	120°49.451	3.1
Roadside Hwy 59	Merced	9-Jul-04	37°14.296	120°29.275	3.1
Almond orchard	Merced	1-Jul-04	37°14.443	120°22.747	6.1
Almond orchard	Merced	1-Jul-04	37°15.503	120°22.787	3.1
Almond orchard	Merced	9-Jul-04	37°22.9726	120°53.176	3.1
Roadside	Stanislaus	9-Jul-04	37°25.193	120°59.100	0.75
Almond orchard	Stanislaus	1-Jul-04	37°32.198	121°14.313	3.1
Roadside near Keyes	Stanislaus	9-Jul-04	37°33.151	120°55.774	0.75
Next to RR tracks	San Joaquin	9-Jul-04	37°51.601	121°13.184	3.1
Abandoned orchard	San Joaquin	8-Jul-04	37°54.803	121°40.686	0.75
Tomato field	San Joaquin	8-Jul-04	37°55.743	121°23.844	1.5
Vacant lot near Rd 8 in Stockton	San Joaquin	9-Jul-04	38°04.102	121°14.715	3.1
Edge of corn field	San Joaquin	8-Jul-04	38°04.177	121°44.163	3.1
Vineyard near Stockton	San Joaquin	8-Jul-04	38°06.439	121°23.449	0.75
Roadside near Pear orchard	Solano	8-Jul-04	38°09.246	121°40.730	1.5
Hwy 113 & Jepson Prairie	Solano	7-Jul-04	38°16.991	121°49.431	3.1
Roadside	Solano	7-Jul-04	38°20.194	121°48.291	0.75
Hwy 99 and Grant Line rd	Sacramento	9-Jul-04	38°22.657	121°21.860	3.1
Roadside Pedrick rd.	Solano	11-Jul-04	38°24.545	121°48.276	3.1

Roadside near Pedrick road	Solano	8-Jul-04	38°28.904	121°48.326	3.1
Roadside Rd 98	Yolo	12-Jul-04	38°32.565	121°48.188	12.2+
Roadside north or Winters	Yolo	12-Jul-04	38°32.836	121°58.265	6.1
Roadside near Winters	Yolo	12-Jul-04	38°32.894	121°53.074	12.2+
Roadside	Yolo	2-Jul-04	38°33.722	121°57.023	6.1
Roadside near Turkovich Farm	Yolo	2-Jul-04	38°34.834	121°56.045	12.2+
Roadside	Yolo	2-Jul-04	38°36.518	121°58.275	3.1
Roadside	Yolo	2-Jul-04	38°37.188	121°46.159	3.1
Roadside	Yolo	2-Jul-04	38°37.214	121°57.012	3.1
Roadside	Yolo	12-Jul-04	38°38.106	122°00.488	6.1
Roadside Capay Valley	Yolo	12-Jul-04	38°42.346	122°03.791	3.1
Almond orchard County Line rd	Yolo	12-Jul-04	38°55.550	122°00.706	12.2
Almond orchard	Colusa	14May04	38°55.934	122°03.641	3.1
Roadside	Colusa	12-Jul-04	38°57.095	122°22.874	3.1
Almond orchard	Colusa	14May04	38°57.296	122°03.643	3.1
Roadside	Colusa	12-Jul-04	39°04.969	122°04.737	12.2+
Roadside south of Willows	Colusa	12-Jul-04	39°06.356	122°09.111	3.1
Walnut orchard	Sutter	11-Jul-04	39°06.598	121°40.296	3.1
Roadside near Willows	Colusa	12-Jul-04	39°07.189	122°13.445	6.1
Roadside	Colusa	Aug.2004	39°11.944	122°00.487	6.1
Roadside	Colusa	Aug.2004	39°12.616	122°02.278	6.1
Abandoned orchard	Sutter	11-Jul-04	39°15.011	121°40.326	3.1
Roadside	Colusa	Aug.2004	39°15.32590	122°03.34777	12.2+
Roadside with rice all around	Butte	11-Jul-04	39°29.584	121°50.547	3.1
Roadside	Butte	20May04	39°34.844	121°56.044	3.1
Prune orchard	Butte	11-Jul-04	39°35.994	121°51.436	6.1
Almond orchard	Butte	11-Jul-04	39°36.804	121°51.463	3.1
Corn field	Glenn	Aug.2004	39°39.209	122°00.059	6.1
Roadside next to almond orchard	Glenn	11-Jul-04	39°41.081	121°52.745	12.2+
Young almond orchard	Glenn	11-Jul-04	39°42.541	122°04.460	6.1
Walnut orchard	Glenn	11-Jul-04	39°44.092	121°57.741	12.2+
Prune orchard	Glenn	11-Jul-04	39°47.382	122°04.009	12.2+
Roadside	Glenn	11-Jul-04	39°48.253	122°04.001	3.1
Prune orchard	Tehama	11-Jul-04	39°49.545	122°07.375	12.2+
Prune orchard near Corning	Glenn	11-Jul-04	39°49.555	122°08.028	6.1
Roadside	Glenn	11-Jul-04	39°51.435	122°09.185	3.1
Olive orchard near Corning	Tehama	11-Jul-04	39°54.850	122°07.530	3.1

[1] The glyphosate rate listed on the Roundup WeatherMax label for control of ryegrass is 0.75 lb ae/acre.

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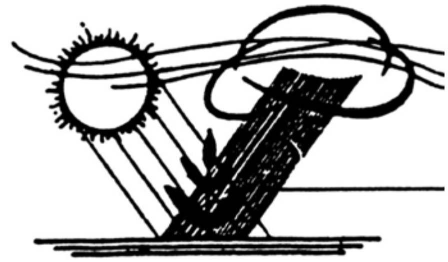
Session II

Irrigation and Nutrient Management – Permanent Crops

Session Chairs:

Joe Fabry, Fabry Ag Consulting

Mary Bianchi, UCCE San Luis Obispo County



Canopy Development and Physiological Responses of Almond to Deficit Irrigation and Nitrogen Management

Bruce D. Lampinen and Samuel G. Metcalf,
Dept. of Plant Sciences, University of California, One Shields Avenue, Davis, CA 95616
Phone (530) 752-2588, bdlampinen@ucdavis.edu

Yield from tree crops is generally closely related to canopy light interception. Because of this, irrigation management can potentially play an important role in productivity during the years when trees in an almond orchard have not yet filled in their allotted space. By providing young almond trees with adequate (but not excessive) water during the early years of orchard development, canopy light interception can be maximized leading to potential for increased early yields, providing that other factors are not limiting.

However, there are potential tradeoffs in using high levels of water and nitrogen to push an orchard into early productivity. As the trees mature, they may become overcrowded resulting in a need for substantial and regular pruning or mechanical hedging, either of which will likely lead to decreased yield potential. Defects such as open kernels and mold are directly related to irrigation levels (unpublished data by author) and hull rot can also be increased by irrigation (Teviotdale et.al., 1994). In addition, food safety is an increasing concern for almond growers and susceptibility of almond kernels to microbial infection was found to be higher in kernels from irrigated compared to dryland farmed almond trees (Schirra and Agabbio,1989).

Tree size, and potentially productivity may be regulated by deficit irrigation. Midday stem water potential was found to be closely related to overall tree growth in young almonds after 2 years of deficit irrigation treatments (Shackel et. al., 1998). A reduction in yields resulting from deficit irrigation regimes has been largely attributed to decreased canopy development (Torrecillas et.al., 1989). Uriu et al. (1970) found that deficit irrigation early in the season had a larger impact on slowing trunk circumference growth than deficit irrigation later in the season. In addition, they found that deficit irrigation reduced trunk circumference growth more than crop load. Ongoing research by the authors also suggests that deficit irrigated trees may be able to produce higher yields at a given level of canopy light interception than fully irrigated trees.

Therefore, the possibility arises that some level of deficit irrigation and/or deficit nitrogen management can be used to achieve the desired level of canopy coverage in a reasonable amount of time while setting up a canopy system that can be more easily managed over time.

Optimal deficit irrigation regime

An ongoing irrigation and nitrogen experiment in almond suggests that it might be possible to control final tree size with deficit irrigation and/or nitrogen management during the tree development phase. The study is currently being conducted on microsprinkler irrigated Nonpareil almonds that were in their fifth leaf at the start of the experiment in the spring of 2001. The moderate water treatments were irrigated when midday stem water potential reached about -12 bars while the moderate nitrogen treatments applied nitrogen when July leaf nitrogen levels fell below 2.2%.

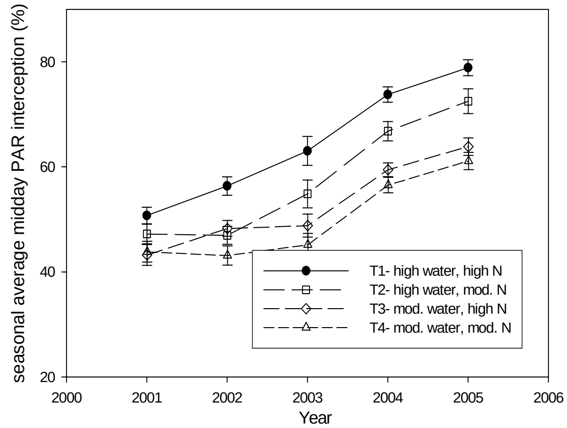


Fig. 1. Seasonal average midday canopy light interception by year for control and deficit treatments.

Both moderate water and moderate nitrogen treatments impacted canopy development. Figure 1 shows the seasonal average midday canopy light interception by treatment. Midday canopy light interception was measured using a light bar and taking 100 measurements in a grid pattern between the tree rows at the time the sun is directly overhead (plus or minus ½ hour). A deficit irrigation regime that resulted in a seasonal average midday stem water potential of 2 bars lower than that for a fully irrigated control resulted in a two year delay in reaching a similar level of canopy development (moderate water treatments in Fig. 1). A moderate nitrogen treatment (T2; July leaf nitrogen level of 1.8 to 2 % compared to 2.2% in the control) resulted in a one year delay in canopy development (Fig. 1). However, it is interesting to note that the seasonal average midday canopy light interception appears to be leveling off in all four treatments in 2005 (Fig. 1). If this trend continues, it would suggest that by planting the trees in the deficit treatments slightly closer together, it might have been possible to have an orchard with a more easily managed tree size that would require minimal or no pruning while still producing comparable yields. The trees in the high water/high nitrogen treatment are beginning to be overcrowded and mechanical hedging of the orchard will begin this winter. Although the deficit treatments will be minimally impacted by this hedging, the high water/high nitrogen treatment will have a fair amount of canopy removed by the hedging. Since all hedging and pruning trials to date have shown

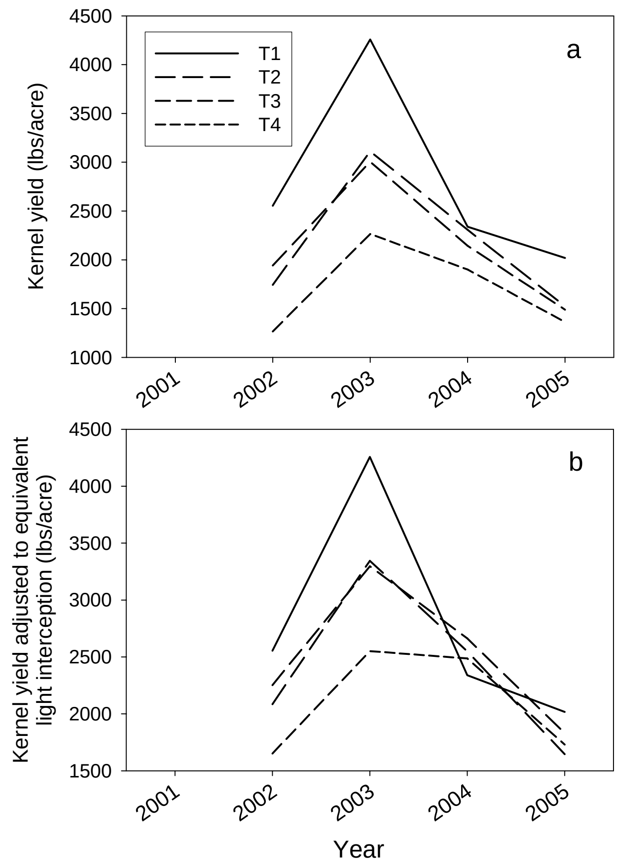


Fig. 2. Plot of a) kernel yield by year and b) kernel yield adjusted to equivalent light interecption. T1 is high water, high nitrogen, T2 is high water, moderate nitrogen, T3 is moderate water, high nitrogen and T4 is moderate water, moderate nitrogen.

reductions in yield with hedging (particularly when hedging results in large cuts), it is expected that this will be the case here, particularly in the high water/high nitrogen treatment.

Yields have been highest for the high water/high nitrogen treatment in all years and were significantly higher than all of the deficit treatments in 2002, 2003 and 2005 (Fig. 2a). However, because the deficit irrigated trees grew more slowly, it might have been possible to plant the trees closer together and get higher yields. If yields for the deficits are adjusted to equivalent levels of midday light interception to the control treatment, the yields for all treatments were similar in 2004 and 2005 (Fig. 2b). This suggests that the yields are being limited by canopy development and that by planting trees closer together, yields for deficits might have been similar to control yields.

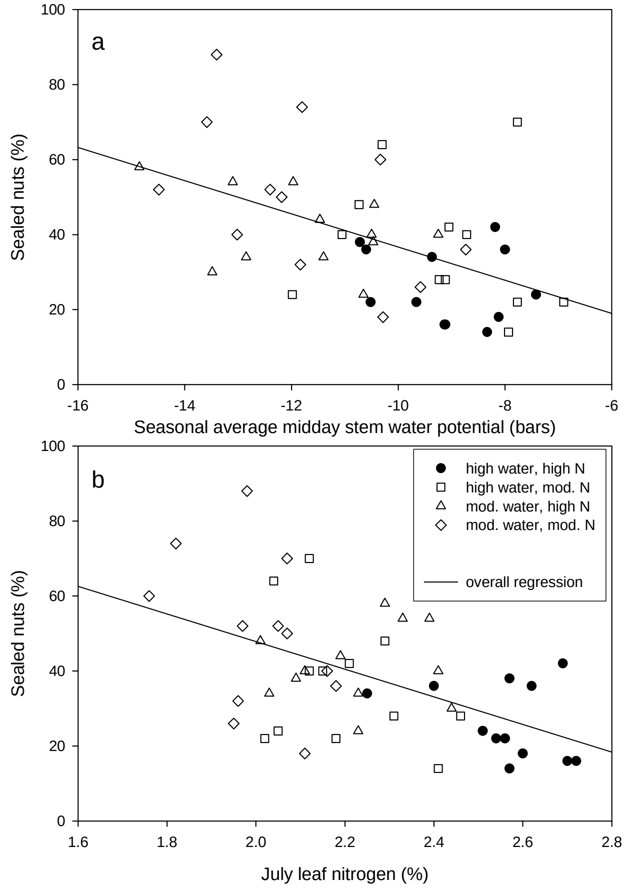


Fig. 3. Percentage of sealed nuts versus a) seasonal average midday stem water potential and b) July leaf nitrogen levels.

The percentage of sealed shells decreased about 4% for every one bar decrease in seasonal average water potential (Fig. 3a). Likewise, the percentage of sealed nuts decreased about 4% for every 0.1% drop in leaf nitrogen level (Fig. 3b). More sealed nuts are associated with less worm damage and decreased potential for microbial contamination in almond suggesting pushing plants with excessive nitrogen may lead to increased potential for worm damage as well as microbial contamination.

Conclusions

Previous and ongoing work has shown that negative impacts of mild to moderate deficit irrigation on yield in almond is primarily due to reduction in canopy volume. Therefore, deficit irrigation and/or nitrogen management strategies that are used to control canopy size in more dense plantings or those that are imposed after the desired canopy volume is reached may be more likely to result in effective canopy size control with less chance for negative impacts on yields. However, it should be noted that deficit treatments would need to be controlled based on midday stem water potential since it is difficult to know the actual level of deficit imposed on the trees with deficit treatments based on soil moisture and/or evapotranspiration.

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Irrigation Management of Early Ripening Peach Varieties

R. Scott Johnson, Extension Specialist, UC Kearney Agricultural Center
9240 S. Riverbend Avenue, Parlier, CA 93648
Phone (559) 646-6547, FAX (559) 646-6593, sjohnson@uckac.edu

Rebecca C. Phene, Staff Research Associate, UC Kearney Agricultural Center,
9240 S. Riverbend Avenue, Parlier, CA 93648
Phone (559) 646-6521, FAX (559) 646-6593, bcp@uckac.edu

Introduction

Peaches and nectarines grown for the fresh market in California are harvested anywhere from April through October. The variety picture is constantly changing as new selections are introduced through several very active breeding programs. In the past, early varieties (harvested before mid June) have generally been small in size and prone to rapid softening. However, over the past few decades breeders have been able to significantly improve the quality of these early varieties. Therefore, they have become quite popular in recent years and now make up a substantial portion of the market.

Early peach and nectarine varieties are distinctly different from later varieties in a number of ways (DeJong et al., 1987) and thus need to be managed differently. First, fruit growth proceeds at a faster rate right from the beginning. In fact, at bloom the pistil is already larger, suggesting this difference starts sometime before, perhaps even as early as the previous year when flower parts were differentiating in the bud. After bloom, the fruit grows steadily up to harvest, as compared to the double sigmoid growth curve of mid and late season peaches. Even with steady growth, it is difficult to attain large fruit sizes required by the market of today. Thus, a number of techniques are employed to maximize fruit size potential. Trees are thinned early (sometimes even blossom thinned) and heavily, and practices such as girdling (Day and DeJong, 1990) are imposed. With some early varieties, there also seems to be a tendency to produce more doubles and other fruit defects. Therefore, a more careful hand thinning procedure is required.

There is also quite a difference in vegetative growth. Almost all peach and nectarine varieties start growing very vigorously in the spring. However, the presence of fruit tends to slow down vegetative growth in mid and late season varieties. In contrast, once early fruit have been harvested, vegetative growth continues at a rapid rate. Thus, it may be necessary to employ certain cultural practices, such as summer pruning, to prevent the negative consequences of excess vegetative growth. Furthermore, the fruiting wood on early varieties tends to be more fruitful (increased flower density and fruit set), so only a minimal amount of vegetative growth is necessary to produce a normal crop.

Postharvest Water Stress

One approach growers have used to reduce vegetative growth in early varieties is to withhold water after harvest. Since peak ET occurs in mid summer, there is the opportunity for substantial water savings by employing this technique. However, there are also a number of problems that can arise, so care must be taken. Too often, growers just neglect these early varieties once the fruit is harvested. They are too busy dealing with the harvest of other varieties, so these early orchards become a much lower priority. However, there are certain strategies that work better than others and also some tools to help implement these strategies. Therefore, with a minimum amount of work, a grower can minimize the negative effects of water stress and still reduce vegetative growth.

If water stress becomes too severe in a peach tree, defoliation, shoot dieback, scaffold sunburn and gumming from the trunk can occur (Proebsting and Middleton, 1980). Such trees are more prone to attack by pests such as mites and trunk boring insects. Fruit quality problems can also increase with water stress that occurred during the previous season. We now know of at least four disorders that are increased by water stress. These include fruit doubles (2 fruit fused together), deep sutures (deep cleft in the suture), split pits and smaller fruit size (Handley and Johnson, 2000; Johnson et al., 1992; Naor et al., 2005; Patten et al., 1989). Recent research suggests the timing of postharvest water stress may determine which of these disorders is most severe. Thus, mid summer stress will cause more doubles and split pits, while early fall stress will lead to more deep sutures and smaller fruit size. Therefore, a management strategy is needed to minimize the most serious problems. There is also a tool, the measurement of stem water potential, which can help determine severity of the stress.

Stem Water Potential

Researchers have tried several different methods of measuring the degree of water stress in plants. Although there is some controversy, many have agreed that the most reliable and consistent tool is stem water potential as measured with a pressure chamber (Garnier and Berger, 1985; McCutchan and Shackel, 1992). In our experience it has certainly been quite consistent among years and varieties in peach and nectarine orchards. We have developed a rule of thumb for well-watered orchards in the San Joaquin Valley: the stem water potential reading (in bars) is generally equal to the negative value of the month of the year during the summer. For example, in May the reading is about -5 bars and in August it is about -8 bars. This relationship stays very constant from year to year and provides a baseline to which we can compare water stressed orchards. Furthermore, we have concluded (as have others in other countries) that a reading of -20 bars represents a threshold of stress below which serious damage can occur (Naor et al., 2005). Therefore, there is both an upper and lower limit that can help indicate the degree of water stress a given orchard is experiencing. We have found the average stem water potential reading during the summer correlates well with such parameters as total vegetative growth and percentage of double fruits.

Postharvest Irrigation Strategies

The best strategy for minimizing fruit quality problems in the following year is to keep the stem water potential as close to the well-watered baseline as possible. Of course, this doesn't save irrigation water or reduce vegetative growth. If either of these is an important objective of the postharvest irrigation program, there are strategies to accomplish this. Often fruit quality parameters are sacrificed in the process, but certain strategies will tend to minimize the negative effects. However, we have found that almost any increase in water stress will lead to a greater probability of some type of negative effect.

Before discussing the more promising strategies, it is worth mentioning the least promising one. Continuing with full irrigation until early August and then cutting off irrigation completely is probably the worst way to save water. First, the trees often have extensive leaf area by early August and thus high water use. By cutting off the water completely, rapid stress can develop and the stem water potential can drop below -20 bars quickly. We have seen extensive defoliation in the center of the tree and dieback of shoots. Furthermore, the next year, this treatment tends to have a large number of deep sutures and somewhat smaller fruit size.

One promising strategy is to cut irrigation to about 50% of tree demands for the whole postharvest period. Stress develops quite slowly and in our experience the SWP has never dropped below -20 bars. However, in a more shallow or sandy soil this might not be the case and careful monitoring is advisable. Obviously, this strategy might need to be modified under different soil, weather and tree vigor conditions. This strategy can also increase deep sutures, but generally not to the extent of the treatment mentioned above. We have also combined this strategy with a mechanical topping treatment right after harvest. Some regrowth occurs from the pruning cuts, but not nearly as much as the fully irrigated control trees. In general the trees looked healthy and not overly vigorous by the end of the season.

What we have considered the best strategy is one of reduced irrigation from after harvest until early August, and then full irrigation until at least mid September. In our experiments we have used 25% of full ET during the initial stage which has kept the SWP from exceeding -20 bars. Once again, this level of irrigation may need to be modified for different soils, weather conditions or tree vigor. The fruit quality parameter most affected by this treatment is double fruits. However, if thinning crews are properly trained, double fruits can be largely eliminated at thinning time. On the other hand, there are some varieties with a great propensity for fruit doubling. If this problem is too extensive, yields will be reduced even with careful hand thinning. Another fruit quality problem that showed up in one experiment was that of split pits. The treatment that caused an increase in this disorder had no irrigation during June and July which caused the SWP to drop below -20 bars. This again points out the importance of careful monitoring to make sure SWP stays within the limits mentioned above.

We have tested this strategy in several different experiments, including three separate varieties and, in one case, under flood irrigation (Handley and Johnson, 2000; Johnson et al., 1992; Larson et al., 1988). In general, the results have been encouraging. Often, the percentage of double fruits has been no different than the fully irrigated control. Vegetative growth has also been reduced, especially if mechanical topping was performed right after harvest.

In conclusion, different strategies of imposing postharvest water stress can have quite different results. We have found the best strategy to be one of imposing moderate stress right after harvest for about 2 months and then restoring full irrigation during the late summer period.

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Irrigation of Vineyards:
Establishment of Crop Coefficients for Use in California Vineyards

Larry E. Williams, Professor, Department of Viticulture and Enology
and
Kearney Agricultural Center
9240 S. Riverbend Ave. Parlier, CA 93648
Phone (559-646-6500, williams@uckac.edu

Introduction

The many different trellis and training systems utilized to produce grapes are dependent upon the final grape product (wine, raisins or table (fresh) grapes) and harvest method among other factors. Row spacings in vineyards can vary from a little more than 3 feet to 12 feet due to the size of equipment used or the type of trellis erected. Therefore, the amount of canopy cover within a single vineyard can be small or approach 100% due to the trellis and row spacing configuration. After full canopy has been achieved, the amount of canopy cover within California vineyards can range from less than 30% for a VSP (Vertical Shoot Positioned) trellis on a 10 foot row spacing to greater than 90% for an overhead arbor type trellis system used for raisin and table grape production (L.E. Williams, unpublished data). The above would indicate that the standard seasonal crop coefficients for grapevines that have been previously published (Allen et al., 1998; Synder et al., 1989) and those recently developed (Williams et al., 2003a; 2003b) would not be appropriate for all vineyard trellis and row spacing situations.

A recent study demonstrated that the amount of shade cast on the ground beneath a grapevine canopy at solar noon was more highly correlated with grapevine water use and the crop coefficient than leaf area or leaf area index (LAI) (Williams and Ayars, 2005b). In another study it was shown that the seasonal crop coefficient did not decrease until late in the growing season (end of October) if the vines had a functional canopy and they were continually irrigated at 100% of crop evapotranspiration (Williams and Ayars, 2005a).

This study was conducted to establish seasonal crop coefficients (K_c) for various trellis/training systems in vineyards throughout the state of California. It was assumed that the relationship found by Williams and Ayars (2005b), relating percent shaded area and the seasonal crop coefficient, could be used to estimate the crop coefficients to determine full vine water use of vines in these vineyards. Once the vines' canopies were fully developed, the K_c would remain constant until the end of October.

Materials and Methods

Numerous times during the 2000 and 2001 growing seasons the amount of shade cast on the ground 30 minutes on either side of solar noon was determined for various trellis/training systems in vineyards throughout California. Row directions in these vineyards varied from almost true north/south to true east/west. The shaded area was determined as described by Williams and Ayars (2005b). Shaded area was then converted to percent shaded area by dividing shaded area by total area allotted per vine in the vineyard and that value multiplied by 100. The percent shaded area was converted to a crop coefficient using the regression equation obtained from the relationship between percent shaded area and the crop coefficient for Thompson Seedless grapevines grown in the lysimeter (Williams and Ayars, 2005b). The relationship between the crop coefficient (K_c) and percent shaded area was: K_c = percent shaded area x 0.017.

Shaded area was determined by taking an image of the area beneath the vines with a digital camera (Sony Mavica FD-91). The camera was held at a height of ~ 4 feet or lower, depending upon the distance of the canopy from the soil surface, and 10 feet from the row. A known rectangular area encompassing all the shade of each vine, to be used as the reference area, was outlined with flagging tape attached to small wooden stakes driven into the soil. The image of the area beneath the canopy was downloaded to a computer and cropped to include only the outlined area. The reference area and shade within the reference area was digitized with Sigma Scan Pro Version 5 (Aspire Software International, Leesburg, VA.). Since the images were only taken on cloudless days, there were clear differences in color between the shade and that of the soil. The color image was converted to gray scale and an intensity threshold was used to digitize the area of the entire image (reference area) and a new intensity threshold was used to digitize the area that was shaded. The amount of pixels comprising the shade was divided by those of the reference's to obtain the fraction of shade within the known area. Once the shoots of the vines were within 1.5 feet of the soil surface it was not possible to use the digital camera to measure shade. A wooden grid (with 6 $inch^2$ squares) was used thereafter and the percent shade within each square determined. Total area was the product of the number of squares with shade and the fraction of shade within each square. The shaded area determined with the wooden grid and the digital camera were compared several times early in the growing-season and were found to be within 3 to 6% of one another.

Results

The amount of shade a particular trellis/training system was dependent upon the width of the canopy (data not given). The amount of shade cast on the ground per unit row length was similar for a single trellis type regardless of where the vines were grown when the image was taken around solar noon (Figure 1). In addition, for all but the VSP trellis system, the amount of shade cast on the ground was similar regardless of row direction. Small differences among locations in shaded area were due to differences in hedging the shoots by the individual owner.

The estimated maximum K_c for a particular trellis/training system increased as the canopy increased when an 11-foot row spacing was used for the calculation (Table 1). The greatest K_c and highest water use were those for the gable trellis. Its maximum shaded area was greater than 90% while that for the VSP on 11-foot row spacings was lowest. As the row spacing for the VSP trellis decreased from 11 feet to 8 feet, water use increased.

Discussion

The use of crop coefficients in estimating ET_c ($ET_c = ET_o$ x K_c) is widely accepted (Allen et al., 1998). The K_c is dependent upon crop type and management practices, i.e. those practices that may influence the rate of canopy development and the ultimate canopy size or the amount of ground cover (Allen et al., 1998). Several authors have related the K_c to various measures of crop development such as leaf area (Williams et al., 2003b), LAI and percent ground cover (Heilman et al., 1982) and in most cases they were linearly related for different crops. It was recently demonstrated that the K_c of peach trees (*Prunus persica* (L.) Batsch) was a linear function of the fraction of light intercepted by the canopy at midday (Ayars et al., 2003) or the amount of shade cast on the ground beneath the canopy at solar noon (Williams and Ayars, 2005b). Williams and Ayars (2005b) found that the K_c was also more highly correlated with percent shaded area than with actual leaf area per vine or calculated LAI. In that study it was also shown that water use and the K_c increased when the canopy's curtains were raised, without a concomitant increase in the amount of leaf area per vine, indicating that it was the amount of leaf area exposed to sunlight (also referred to by others as effective or exposed leaf area) and not the total amount of leaf per vine that determines water use.

Differences in trellis types and row spacing, both of which could affect the fraction or percent ground cover, are not presently accounted for in current publications listing crop coefficients for vineyards. The amount of shaded area measured in this study is representative of the seasonal canopy development in each vineyard and the ultimate canopy size. Its conversion to seasonal crop coefficients would therefore reflect changes in canopy development and ultimate size. Current studies on the water relations of vines irrigated with various fractions of estimated ET_c for a particular trellis/training system would support this assumption. I've shown that vines irrigated at estimated full ET_c (using the K_cs given in this paper) or greater have midday leaf water potentials greater than –1.0 MPa (data not given), values which have been measured on vines that are well watered (Williams and Trout, 2005). Vines irrigated with water amounts less than estimated full ET_c have midday leaf water potential values that are more negative.

Conclusions

From a practical standpoint, managers could estimate their own individual vineyard K_c, if the trellis differs from that given here, simply by measuring the width of the shade cast upon the ground throughout the season and using the relationship between percent shaded area and the K_c from that given in this paper. This would provide estimates of grapevine water use at 100% of ET_c and irrigations could be scheduled based upon this value. I have found that grapevines used for raisin and table grape production can be deficit irrigated at 80% of ET_c without a loss of yield while maximizing berry size. One could also deficit irrigate wine grapes at less than 60% of ET_c to reduce berry size and possibly increase fruit quality. However, I have found that deficit irrigating vineyards at less than 70% of ET_c will reduce yields, the absolute decrease dependent upon location.

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Table 1. Equations to calculate seasonal crop coefficients (K_c) as a function of degree-days (base 10˚C) from March 15 for vineyards with various trellis types or training systems and 11-foot row spacings. The K_c was estimated as described in the Materials and Methods section. Seasonal water use (March 15 to October 31) for the 2002-growing season of vineyards using the same trellis/training systems is also given. Reference ET data was obtained from the CIMIS weather station at the Kearney Ag Center using 2002 data.

Trellis Type/ Training System	Seasonal K_c Equation[a] (for 11-foot row spacing)	2002-Seasonal Water Use mm (inches)
Gable Trellis	$1.53/(1 + e^{(-(x - 550/250)})$	1324 (52.1)
Lysimeter (2 ft. cross-arm)	$0.96/(1 + e^{(-(x - 373/169)})$	907 (35.7)
Quadrilateral Cordons	$0.93/(1 + e^{(-(x - 300/175)})$	912 (35.9)
California Sprawl Canopy	$0.82/(1 + e^{(-(x - 275/150)})$	819 (32.2)
Lyre, Wye or V Trellis	$0.79/(1 + e^{(-(x - 300/150)})$	779 (30.7)
Vertical Shoot Positioned (VSP)	$0.47/(1 + e^{(-(x - 525/301)})$	552 (21.7)
VSP (w/8 ft. row spacing)	$0.65/(1 + e^{(-(x - 525/301)})$[b]	759 (29.9)

[a] The numerical value of e = 2.71828 and x = degree-days (base temperature of 10˚C) from March 15. The degree-days used were those from the 2002-growing season. Degree-days in Fahrenheit (base of 50˚F) cannot be used in the equations.
[b] Note: this is for a VSP trellis on 8-foot row spacing.

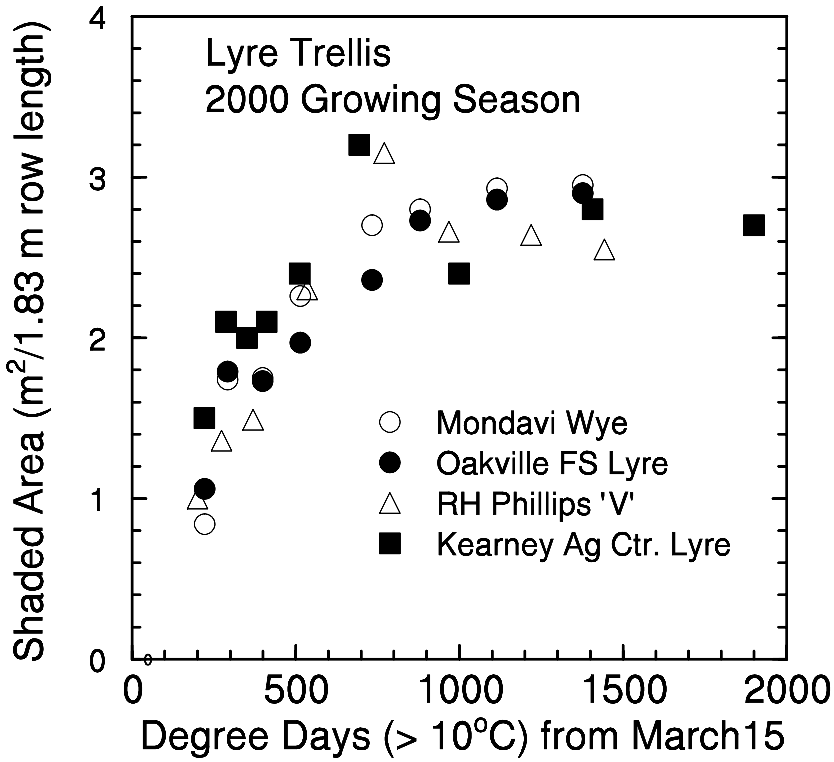


Figure 1. The amount of shade measured beneath grapevines in vineyards using trellis systems similar to a Lyre, Wye or 'V'. Data were collected at the Robert Mondavi Vineyards in Napa Valley, the Department of Viticulture and Enology Field Station near Oakville, the R.H. Phillips Vineyards near Dunnigan Hills and the Kearney Agricultural Center. Row direction for two of the vineyards was approximately north/south (Oakville FS lyre and RH Phillips 'V') while two were approximately east/west (Mondavi Wye and Kearney Ag Ctr. Lyre). Shade is expressed per 1.83 m (6 feet) of row length.

IRRIGATION WATER MANAGEMENT IN GROUNDWATER PROTECTION AREAS

Larry Schwankl, Irrigation Specialist
UC Kearney Ag Center
9240 S. Riverbend Ave., Parlier, CA 93648
(559) 646-6569, schwankl@uckac.edu

Terry Prichard, Water Management Specialist,
Cooperative Extension San Joaquin County
420 South Wilson Way, Stockton CA, 95205
(209) 468-2086, tlprichard@ucdvis.edu

Blaine Hanson, Irrigation and Drainage Specialist
LAWR – UCDavis
One Shields Ave., Davis, CA 95616
(530) 752-1130, brhanson@ucdavis.edu.

SUMMARY

An innovative aspect of the recent Groundwater Protection Area (GWPA) regulations is that instead of eliminating the use of pesticides found in groundwater below vulnerable areas, their use is allowed if certain improved management practices are followed. These practices, which include a number of irrigation water management techniques, have been determined to minimize the risk of the pesticide moving to groundwater.

Under previous pesticide regulations, Pesticide Management Zones (PMZs) were created in areas where pesticides were found in groundwater as a result of legal agricultural use. In 2003, based on increasing evidence of more widespread pesticide contamination of groundwater, the California Dept. of Pesticide Regulation (DPR) changed the criteria for identifying vulnerable areas, and changed the name of these vulnerable areas from Pesticide Management Zones (PMZs) to Groundwater Protection Areas (GWPAs). The GWPA regulations apply only if both of the following criteria fit the proposed pesticide application: 1. The pesticide to be applied is designated as a groundwater hazard, AND 2. The proposed application site is designated as being in a GWPA zone, either as a Leaching GWPA or as a Runoff GWPA. Use of the regulated pesticides in Runoff GWPAs has a stated list of management techniques, one of which must be practiced in order to use the regulated pesticide. In Leaching GWPAs, the primary management requirement is that an irrigation efficiency of applying no more than 133% of the crop net irrigation requirement at each irrigation for 6 months following the pesticide application be met. Achieving this level of irrigation efficiency is discussed. More information on complying with the GWPA regulations can be found at the GWPA Compliance web site (gwpa.uckac.edu).

INTRODUCTION

Under previous pesticide regulations, Pesticide Management Zones (PMZs) were created in areas where pesticides were found in groundwater as a result of legal agricultural use. Pesticide Management Zones were 1 square mile sections of land in which one or more pesticides were found in groundwater, and identified as being vulnerable to groundwater contamination.

In 2003, based on increasing evidence of more widespread pesticide contamination of groundwater, the CA Dept. of Pesticide Regulation (DPR) changed the criteria for identifying vulnerable areas, and changed the name of these vulnerable areas from Pesticide Management Zones (PMZs) to Groundwater Protection Areas (GWPAs). The purpose of the changes was to prevent new areas from becoming contaminated and to avoid increasing the contamination of groundwater in areas already contaminated.

All areas designated as PMZs were re-designated as GWPAs. Additional areas have been identified as GWPAs based on soils and depth to groundwater data. These criteria were developed from statistical analysis of over 15 years of well sampling data compiled by DPR.

WHO DO GWPA REGULATIONS AFFECT?

The GWPA regulations apply only if <u>both</u> of the following criteria fit the proposed pesticide application:

1. The pesticide to be applied is designated as a groundwater hazard. The current list (called the 6800(a) list is Title 3 of the California Code of Regulations) of regulated pesticides contain any of the following active ingredients:
    - Atrazine (Aatrex)
    - Bentazon (Basagran)
    - Bromocil (Hyvar, Krovar)
    - Diuron except products with less than 7% diuron that are applied to foliage (Karmex, Krovar)
    - Norflurazon (Solicam, Predict, Zorial)
    - Prometon (Pramitol)
    - Simazine (Princep)

<u>AND</u>

2. The proposed application site is designated as being in a GWPA zone, either as a Leaching GWPA or as a Runoff GWPA.

GWPA ZONES

Groundwater Protection Areas (GWPAs) are geographically defined areas that are vulnerable to pesticide contamination either by leaching or runoff. GWPAs include all existing pesticide management zones (PMZs), plus other areas based on specified soil types, and a <u>depth to groundwater of 70 ft or less</u>.

Leaching GWPAs are defined as sections of land where pesticide residues move from the soil surface through the soil matrix with percolating water to groundwater. Leaching GWPAs are located in areas with lighter-textures soils and relatively rapid infiltration rates.

Runoff GWPAs are defined as sections of land where pesticide residues are carried in runoff water to more direct routes to groundwater such as dry or drainage wells, poorly sealed production wells, or soil cracks or to areas where leaching can occur. Runoff GWPAs are located in areas with hardpan layers and/or low infiltration rates.

DPR has prepared maps for each county, showing the sections designated as Leaching GWPAs and the sections designated Runoff GWPAs. The maps are available on the following website: http://www.cdpr.ca.gov/docs/empm/gwp_prog/gwpamaps.htm

Additionally, the sections designated as Leaching GWPAs and the sections designated Runoff GWPAs are listed by county on the following website: http://www.cdpr.ca.gov/docs/gwp/gwpa_lists.htm.

A number of the County Agricultural Commissioner offices have further refined the GWPA zone mapping for their County. It is recommended that you check with your local Ag Commissioner office if you are uncertain whether you're in a GWPA.

Runoff GWPA

If it is determined that the area on which a regulated pesticide is to be applied is in a Runoff GWPA, the regulations give growers the flexibility to choose from a menu of management practices that best fit their situation. For more information on these management practices, see the Groundwater Protection Areas section of the GWPA Compliance web site (gwpa.uckac.edu)

Leaching GWPA

Leaching GWPAs contain coarse soils with relatively rapid infiltration rates. Pesticides containing active ingredients that are regulated to protect groundwater may be applied by a permitted applicator if *any one* of the following mitigation measures can be met:

(a) **No irrigation.** No irrigation water is applied for six months.
(b) **No contact with irrigation water**. Pesticides are applied to the planting bed or the berm above the level of the irrigation water in the furrow or basin so there is no contact with the irrigation water.
(c) **Irrigation Management**. The irrigations are managed so that, for each irrigation applied for 6 months after the pesticide is applied, the net amount of water applied divided by the net irrigation requirement is 1.33 or less.

Note:
(1) The net irrigation requirement is the amount of water needed to bring the soil in the crop root zone to field capacity at the time of irrigation. It can be determined by direct measurements of soil moisture, such as by using tensiometers, or indirect measurements of soil moisture, such as by estimating evapotranspiration that has accumulated since the last irrigation.

In addition, if the above management practices are not feasible, growers, registrants, and others can request that DPR approve other, effective management practices that may be more suitable to their cultural practices or farming techniques while those practices are being adopted into regulation.

IRRIGATION WATER MANAGEMENT

As noted above, one of the management compliance options of the Leaching GWPA regulations is to irrigate no more than 133% of the crop water needs during a 6-month period after pesticide applications. In order to achieve this, a manager must know *How Much Water to Apply* and he must *Apply the Correct Amount of Water*.

How Much Water to Apply

Estimating the crop water use since the last irrigation is the easiest way of determining the net irrigation requirement. Crop water use estimates, often referred to as crop evapotraspiration (ET), can be estimated by using historical ET records or they can be measured (real-time ET). The network for measuring evapotranspiration in California is the California Management Information System (CIMIS), operated by the CA Dept. of Water Resources. Information on scheduling irrigations using real-time ET is available at www.cimis.water.ca.gov.

Using historical ET estimates is a very good method of determining irrigation requirements. Using historical ET allows a manager to plan ahead the timing and amounts of irrigation. Weather conditions deviating from the average can be adjusted for. An effective irrigation strategy is to plan ahead and irrigate using historical ET and then compare the historical ET estimates to CIMIS real-time ET values. If too much or too little irrigation water was applied, corrections can be made at the next irrigation event.

Tables of historical ET estimates for a number of crops and CA locations are available in the Net Irrigation Requirement section of the GWPA Compliance web site at gwpa.uckac.edu. Crop evapotranspiration estimates are also available form numerous other sources. Be sure that the information is for the crop you're interested in and not just for a "reference" crop.

The GWPA Regulations also allow using soil moisture monitoring techniques to determine the amount of required irrigation water. Quantifying soil moisture content is sometimes a more difficult method of determining the irrigation amount. Additional information on soil moisture monitoring can be found in the Net Irrigation Requirements section of the GWPA Compliance web site (gwpa.uckac.edu).

Applying the Correct Amount of Water

The first important step in applying the correct amount of water is to measure the amount of applied water. Quantifying the amount of applied water is often a difficult task in agricultural systems. Flow meters, such as a propeller meter, are accurate and easy to use but are limited to situations where water is flowing through pipelines or tubing. Measuring flow rate in open channel conditions, such as canals or ditches, is more difficult and less accurate.

An extensive coverage of measuring applied water is in the Net Irrigation Application section of the GWPA Compliance web site (gwpa.uckac.edu). In that section, you are able to choose the water measurement information for the irrigation system you use. For example, if you use border strip irrigation with alfalfa valves, download the file "Flood / Border Irrigation – Valve Discharging into Border".

If you find that the measured applied irrigation water is greater than 133% of the net irrigation requirement, improvements must be made in irrigation water management (IWM).

The Improving Irrigation Practices section of the GWPA Compliance web site (gwpa.uckac.edu) covers in detail potential IWM improvements.

IWM improvement techniques which may be effective in both furrow and flood irrigation systems include: (1) using shorter field lengths, (2) ensuring field slopes are uniform, and (3) use of tailwater return systems. Shorter field lengths (1/4 mile or less) are often the most effective method of improving water application uniformity and allowing a small application depth to be applied. Unfortunately, shorter field lengths are more labor-intensive to irrigate, take land out of production for roads, tailwater ditches, etc., and may require increased investment in pipelines.

Maintaining a uniform field slope requires regular land planning and periodic (every few years) land leveling. Breaks in field slope, resulting from routine land preparation, can cause water to slow or stop moving down the field during irrigation, reducing irrigation uniformity and efficiency.

Tailwater return systems collect the tailwater runoff from borders and reuse the water for irrigation. Tailwater return systems require a tailwater pond and a pump / pipeline or other system to allow the return water to be reused. Simply leaving the water in the pond until it infiltrates is not improving the irrigation efficiency and may lead to groundwater contamination problems.

IWM techniques specific to furrow irrigation include using furrow torpedoes and surge irrigation. Furrow torpedoes are weighted cylinders (think scuba tank filled with concrete) which are dragged in the furrow to smooth the furrow. They are most effective when used after cultivation and they allow water to advance across the field more rapidly.

Surge irrigation entails turning irrigation water on and off as it flows down the furrow. When properly done, using surge irrigation can advance the water across the field using less water, cut down on deep percolation losses, and reduce tailwater runoff.

Flood irrigation specific IWM techniques include increasing the border flow rate, causing the water to advance down the border more quickly, shortening the irrigation time, and often resulting in less total water needed to irrigate the border. The more quickly advancing water often requires more careful management, especially in the timing of irrigation set times. If the water is not turned off at the correct time, increased water amounts may "pile up" at the border end, resulting in increased scalding, weeds, and disease problems.

Sprinkler irrigation systems not meeting the 133% net irrigation requirement need to be evaluated to determine their application rate and application uniformity. To attain high application uniformity the sprinklers must be spaced appropriately and the system pressure should not vary significantly (not more than 20%). Application rates can be modified by changing sprinkler nozzle size, but care should be taken in doing this because of its impact on pressure losses and application uniformity.

Microirrigation systems not meeting the 133% net irrigation standard likely suffer from irrigation non-uniformity caused by poor system design and/or emitter clogging problems. Microirrigation systems should have uniform pressure throughout the system. The exception may be microirrigation systems with pressure-compensating (PC) drippers or microsprinklers which maintain a constant discharge across a range of pressures. Incorrectly sized lateral tubing or pipelines may cause uneven microirrigation system pressures. Correcting this problem is expensive since new hardware must often be purchased.

Clogging of drip emitters or microsprinklers can also cause irrigation non-uniformity. Prevention of clogging is often a routine maintenance issue. Good filtration systems, system flushing, and chemical treatment when necessary can solve most clogging problems.

Development of Lime Recommendations for California Soils

Robert O. Miller, Soil and Crop Sciences Department,
Colorado State University, Fort Collins, CO 80523
Ph: 970-686-5702; Fax: 970-491-0564; E-mail: rmiller@lamar.colostate.edu

Dr. Janice Kotuby-Amacher, USU Analytical Laboratory,
Utah State University, Logan, UT 84322-4830
Ph: 435-797-2217, Fax: 435-797-2117. E-mail: jkotuby@mendel.usu.edu

Nat Dellavalle, Dellavalle Laboratories;
1910 W. McKinley, Ste. 110, Fresno, CA. 93728-1298
Ph: 559-223-6129, Fax: 559-268-8174, E-mail: soillab@aol.com

Chad Bethel, Precision Agri-Labs,
24730 Ave 13 Madera, CA 93637
Ph: 559-661-6386, Fax: 559-661-6135, E-mail: cflab@lightspeed.net

Introduction

Increasingly acid soils have been noted on soils of northern and central California by field agronomists and soil testing laboratories. These soils tend to be moderate to highly weathered or poorly buffered and/or acidified through ammonium based nitrogen fertilizers. Acidity levels below a pH of 5.60 are sufficient to impact crop growth and quality, dependent on crop species and cultivar. Current lime recommendations for California utilize the SMP buffer method and are based on calibration models developed in the eastern United States on soils of distinctly different parent material, growing conditions and cropping systems. In 2002 a project was initiated to evaluate lime requirement calibration models for California soils selected from the San Joaquin Valley, North Coast and Sacramento Valleys of California. Soils were selected from vineyard, tree crop, forage and row crop areas, where low pH values have been noted by commercial testing laboratories and agricultural consultants.

Methods

One-hundred twenty soils were collected in 2002 and 2003 representing 19 counties of central and northern California. Soils were analyzed for: saturated paste moisture content; pH saturated paste method; saturated paste EC; pH (1:1) H_2O method; pH (1:1) 0.01 M $CaCl_2$ method; KCl extractable Al and texture in triplicate. Soil lime methods based buffer pH included: SMP buffer pH (Sims 1995,); a modified SMP method (50% strength) Adams Evans buffer pH Mehlich buffer pH (Mehlich, et al, 1976); and Woodruff Buffer pH (Sims, 1996). All soils were evaluated for exchangeable acidity based on a modified incubation with calcium hydroxide

(Adams, 1962) based on 5 days. In 2004 an additional 22 acid validation soils were collected from across California.

Results and Discussion

Of the soils collected results indicated fourteen soils had a pH (1:1) 0.01 M $CaCl_2$ (i.e. salt pH) less than 4.00, thirty-nine of the soils were between 4.50 to 5.00, forty-two had a pH in the range of 5.00 to 6.00 and three with a pH between 6.00 and 6.30. Results for soil KCl extractable Al, an indicator of strongly acid soils, indicated five soils had Al values exceeding 100 mg kg^{-1} and twenty-six soils in the range of 20 - 100 mg/kg Al. Extractable Al concentrations increased dramatically with decreasing pH. Al concentration became significant (> 2.0 mg kg^{-1}) for soils with a pH 0.01 M $CaCl_2$ below 4.80. For the saturated paste pH method this is a value of 5.10 and for pH (1:1) H_2O a value of 5.60.

Soil saturated paste moisture content ranged from 19.8 - 69.3% indicating the soils evaluated ranged from loamy sand to clay in texture with the median CEC of 6.3 cmol kg^{-1}. 5-Day lime incubation values ranged from 210 to 10,590 lbs ac^{-1} with a median of 1380 lbs ac^{-1} $CaCO_3$. Thirty soils had a 5-Day incubation lime rate of less than 1000 lbs ac^{-1} and seventeen with a rate exceeding 4000 lbs ac^{-1} .

A plot of 5-day lime incubation rate ($CaCO_3$ lbs ac^{-1}) with pH (1:1) 0.01 M $CaCl_2$ indicates a unique area plot, (See Figure 1). With decreasing salt pH there is an increase in 5-day incubation lime rate. A plot of isolines of saturated paste moisture shows that "general" ranges of lime rates for a given pH can be further identified by the saturated paste moisture content. As an example a soil with 24% saturated paste moisture and a salt pH of 5.00 would have a lime application rate of 1400 lbs ac^{-1}, while a soil with an identical pH and 40% saturated paste moisture content would have a lime application rate of 3000 lbs ac^{-1}. These isolines for separating 5-day lime incubation rates are only approximate as some soils (as indicated in the legend) fall outside the isolines demarcating general boundaries. Nonetheless, eighty-one of the ninety-eight soils fall with in the boundary areas, indicating that saturated paste moisture can be used as a co-variable in estimating lime requirement as determined by a 5-Day incubation.

Results for the SMP buffer method ranged from pH 5.45 to 7.45, with a median of 6.89. Based on reported SMP lime recommendation (Sims, 1996), the threshold SMP buffer pH for which no lime is required was 6.95. Using this SMP recommendation model for estimating lime, 46% of the California soils evaluated had no lime requirement.

During 2003 and 2004 an additional twenty-two soils were collected from for validating the principle models developed in the initial phase of the project. The validation soil pH (1:1) 0.01 M $CaCl_2$ values ranged from 3.19 to 5.75 with a median 4.42. Soil saturated paste moisture and CEC ranges were identical to the original ninety-eight soil database. KCl extractable Al indicated five soils had Al values exceeding 100 mg kg^{-1}, eight soils in the range of 20 - 100 mg/kg Al, and eight soils with 1.0 - 20 mg kg^{-1} Al. 5-Day lime incubation lime rates ranged from 480 to 26,600 lbs ac^{-1} with a median of 1940 lbs ac^{-1} $CaCO_3$. The Relationship between the 5-Day incubation and Mehlich lime rate for all soils evaluated is shown in Figure 2.

Figure 1. Relationship of pH (1:1) 0.01 M $CaCl_2$ and 5-Day incubation lime rate, ninety-eight California soils.

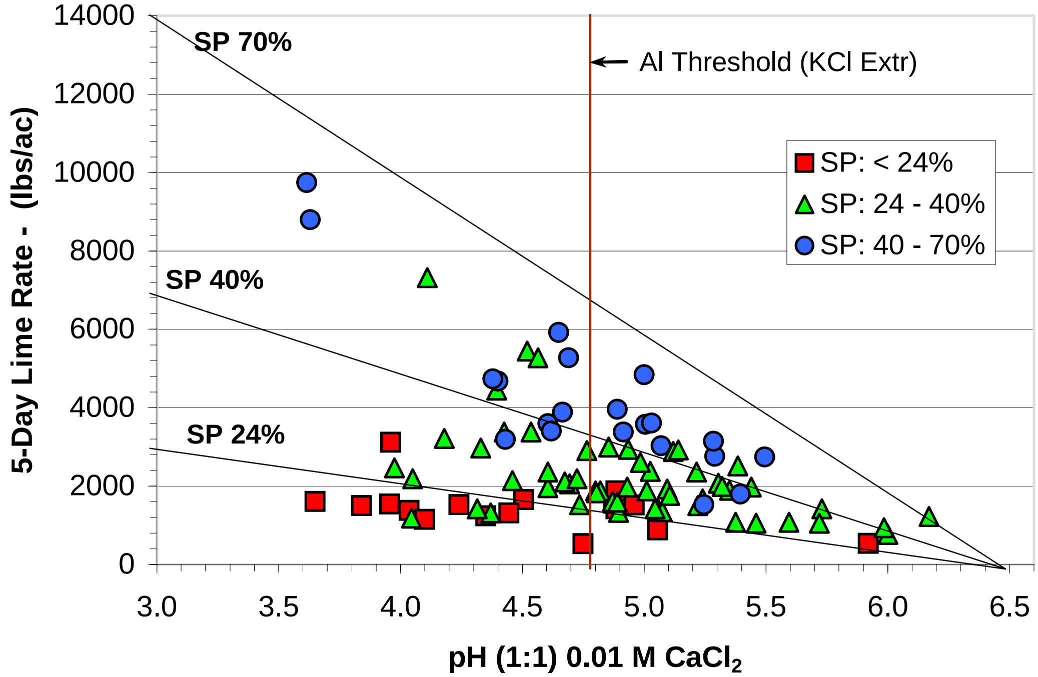
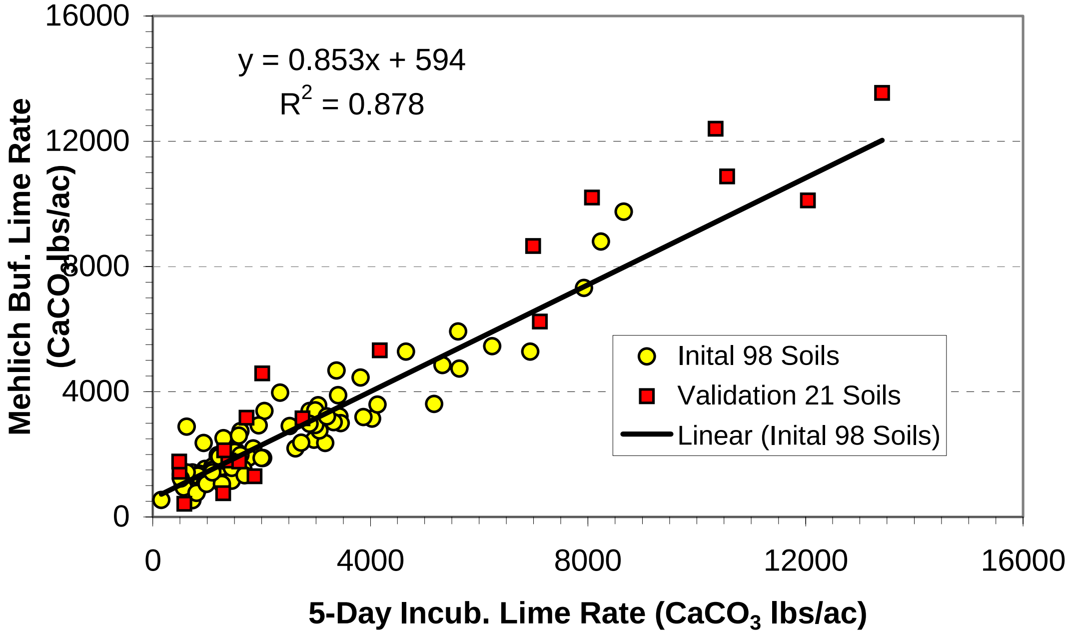


Figure 2. Comparison of Mehlich buffer lime recommendation and 5 Day Lime Incubation rate for one hundred twenty California soils.



y = 0.853x + 594
R^2 = 0.878
Inital 98 Soils
Validation 21 Soils
Linear (Inital 98 Soils)
Mehlich Buf. Lime Rate ($CaCO_3$ lbs/ac)
5-Day Incub. Lime Rate ($CaCO_3$ lbs/ac)
0
4000
8000
12000
16000

Summary and Conclusions

Two models were selected for predicting lime requirements for California soils. Suggested lime rates were based on neutralization of soil acidity to a pH of 7.00 to a depth of 6 inches using 100% $CaCO_3$. The actual lime application rate would require adjustment as typical agricultural lime ranges from 60% - 80% Calcium Carbonate Equivalent (CCE). The first was based on soil pH (1:1) 0.01 M $CaCl_2$ and saturated paste moisture (application rate based on 5-Day incubation lime rate). The (1:1) 0.01 M $CaCl_2$ pH method could be easily implemented California agricultural testing laboratories as soil saturated paste is a routine analysis method.

The 2nd model for estimating lime rate for California soils was based on the Mehlich buffer pH method. This model explained 87% of the variability in 5-Day incubation results. It has the advantage that only one additional soil test is needed and provides for the estimate of exchangeable acidity. The equation for exchangeable acidity (AC) and determining lime application rate from the Mehlich buffer are as follows:

EQ2: AC = (6.60 - Mehlich Buf pH) x 4

EQ3: Lime Rate lbs ac^{-1} = ((0.10 x (AC^2))+AC) x (2000 x 0.446)

In general there was very good agreement between the two models and the 5-Day incubation. The relative difference between the two models for a majority of the soils was generally within the lime rate error of estimation, which for these methods is approximately 240 lbs ac^{-1} of 100% $CaCO_3$. Soils with high KCl extractable Aluminum (Al > 100 mg kg^{-1}) were the exception with the Mehlich buffer indicating a much higher lime rate, similar to the amount listed for the 5-Day incubation method.

Acknowledgment

Thanks goes to the staff, consultants and management of Western Farm Services, Dellavalle Laboratory, UCCE, A&L Western and Sunland Labs for their assistance in securing soils for this project. Special thanks to Byron Vaughan, Laboratory Director, MDS Harris Laboratory, Lincoln, Nebraska for his assistance in providing the 5 Day Incubation analysis results.

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Session III

Irrigation & Nutrient Management – Annual Crops

Session Chairs:

Tim Hartz, Plant Sciences, UC Davis

Will Horwath, LAWR, UC Davis

Water Requirements of Irrigated Bell Peppers

Tom Trout, USDA/ARS, Water Management Research
9611 S. Riverbend Avenue, Parlier, CA 93648
Phone (559) 596-2852, FAX (559) 596-2851, ttrout@fresno.ars.usda.gov

James Ayars, USDA/ARS, Water Management Research Laboratory,
9611 S. Riverbend Avenue, Parlier, CA 93648
Phone (559) 596-2875, FAX (559) 596-2885, jayars@fresno.ars.usda.gov

Introduction

As the world population increases, there will an increased demand for food and for water to improve the environment and to sustain manufacturing. However, the water supply is fixed and the water to meet these needs and demands will have to come from the industry that uses approximately 80% of the available water supply, irrigated agriculture. Irrigation efficiency world wide is poor and modest improvements in irrigation management may yield much of the required water. In California, the options are limited because irrigation efficiency is not as poor as in the remainder of the world and the potential for increased water supply from agriculture is limited.

Drainage from irrigated agriculture contributed to the environmental crisis at the Kesterson reservoir that has led to retirement of nearly 40,500 ha of land on the west side of the San Joaquin Valley (SJV). In addition to the land retirement, the Central Valley Project Improvement act has reduced the total water supply available to the westside of the SJV by 900 million cubic meters. This has resulted in a shift in cropping from long season high water requirement crops (tomato, cotton) to short season vegetable crops (lettuce, pepper, broccoli, onion). This has also resulted in a shift in irrigation systems from surface irrigation to pressurized systems i.e. sprinkler and microirrigation. There is very little information describing the crop water requirements for vegetable crops grown in this region using sprinkler and microirrigation. This paper reports the results of a field study that determined the crop water requirements for a bell pepper crop grown on the Westside of the SJV using drip and furrow irrigation.

Materials and Methods

Three different irrigation systems were installed at the West Side Research and Extension Center in order to evaluate and compare various irrigation methods commonly used to grow vegetable crops on the west side. These include: 1) a furrow irrigation system, 2) a surface drip irrigation system, and 3) a subsurface drip irrigation system with drip laterals installed 30 cm deep. Water was applied with each system at four different irrigation levels in order to determine the best application amount for obtaining maximum yield. Amounts of applied water were equal to 50, 75, 100 or 125% of the crop evapotranspiration rate determined from water losses in a well watered crop lysimeter. Overall, there were 12 irrigation treatments (3 irrigation systems X 4 irrigation levels) arranged at the site in a split-plot experimental design with four replicate plots per treatment. Each plot is 90 m long and consists of four crop beds spaced 1 m from center to center; outside beds serve as borders between treatments.

An irrigation control system applied all drip irrigations automatically in response to lysimeter water use (see Phene et al. 1989 for details). The lysimeter (which has drip tubing installed 30 cm deep) and all drip irrigation treatments in the field were watered after 2 mm of crop evapotranspiration has been measured by the lysimeter. This resulted in several applications each day to match peak water use. Furrow irrigated plots were watered weekly based on the water use over the previous 7 days.

Bell peppers (var Barron) were planted on April 25, 2005 as transplants with a planting density of 17,000 plants/ac (23.5 cm in row spacing by 1 m row spacing). Harvest was in July and early August. Plants were grown following normal cultural practices, which included pre-plant and irrigation applied nutrients. Sprinkler irrigation was used to establish seedlings.

The amount of water applied to each treatment was recorded automatically using electronic flow meters installed in the irrigation manifold. Crop evapotranspiration was measured with a lysimeter and with a Bowen Ratio system installed in the pepper field. A second Bowen Ratio system was installed in the grass field next to the pepper field. Crop Et measured by the Bowen Ratio system in the peppers was divided by the grass Et measured by the Bowen Ratio system in the grass field to calculate daily kc values (Allen, et al 1998). Peppers were harvested 3 times from a 9 m section of the center 2 rows of each treatment. The peppers were sorted into green and red market peppers and culls.

Discussion and Results

The applied water for each of the treatments is summarized in Table 1. The Et measured by the crop lysimeter was 504 mm and the data show that the target Et levels were met for the drip systems and approximately 5% higher in the furrow systems.

Table 1. Applied irrigation water (mm) on bell pepper irrigation trial at WSREC in 2005.

	Irrigation levels			
Irrigation Methods	50%ET	75%ET	100%ET	125%ET
Furrow	271	398	529	661
Surface Drip	253	378	504	626
Sub Surface Drip	251	379	500	626

The daily evapotranspiration (ET) for the crop and the grass reference are plotted in Figure 1. The data show that there was approximately 8 to 10 mm of water lost per day in the grass and pepper crop during July and August with the pepper crop ET being higher than the grass. These data were used to calculate the bell pepper crop coefficient shown in figure 2. The K_c in July and August was between 1 and 1.2 for the pepper crop. This was an average across all the treatments.

The yield results for the 2005 experiment are summarized in Table 2. The data show that the subsurface drip had the highest yields at the 75% ET treatment but was not significantly different from the surface drip at the other irrigation levels. Furrow irrigation yields were less than either SD or SSD at both 100% and 125% ET levels. At the 50% level there was no significant difference across the system type. Comparing the mean values of the water treatments, the data show that the yields for the 50% treatments are less and the mean yield for the 125% water treatment was statistically greater than the intermediate treatments. The water use efficiency data were generally highest for the SSD treatments with the exception being the 125% treatment

Table 2. Pepper market yield (Mg ha^{-1}) at WSREC experimental site during 2005 growing season.

	Irrigation levels				
Irrigation Methods	50%ET	75%ET	100%ET	125%ET	Mean
Furrow	21.3 ef	26.2 df	22.6 def	26.7 d	24.2 b
Surface Drip	19.2 f	26.8 d	34.5 c	44.8 a	31.2 ab
Sub Surface Drip	22.7 def	34.8 c	39.2 bc	40.6 ab	34.4 a
Mean	21.0 c	29.4 b	32.1 b	37.4 a	30.6

LSD for irrigation methods at alpha 0.05 level = 7.6 Mg ha^{-1}
LSD for irrigation levels at alpha 0.05 level = 4.8 Mg ha^{-1}
LSD for interaction (M X L) at alpha 0.05 level = 5.2 Mg ha^{-1}

Table 3. Water use efficiency in Mg/ha/mm of applied water.

	Irrigation levels			
Irrigation Methods	50%ET	75%ET	100%ET	125%ET
Furrow	.079	.066	.043	.040
Surface Drip	.076	.071	.068	.072
Sub Surface Drip	.090	.092	.078	.065

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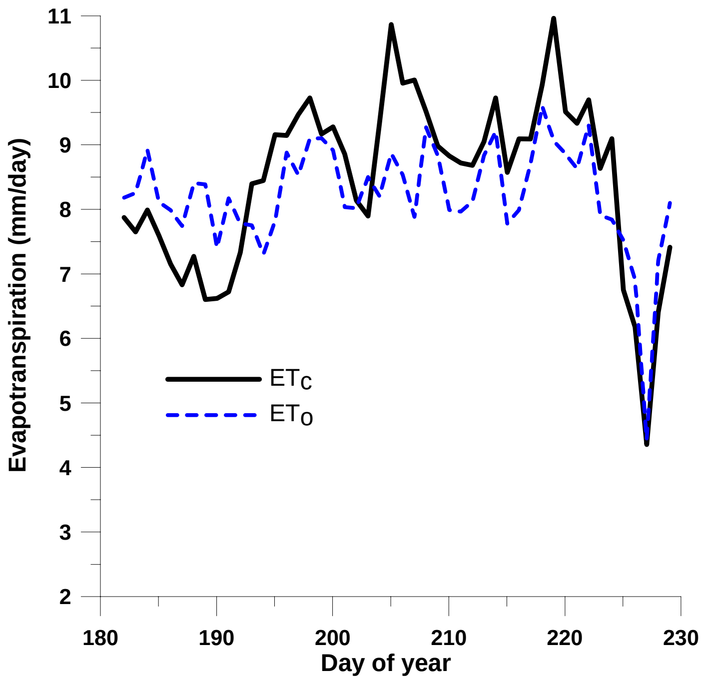

Figure 1. Daily evapotranspiration of grass (ET_o) and pepper (ET_c) at the West Side Research and Extension Center in July 1 to August 17, 2005 measured by the Bowen Ratio technique.

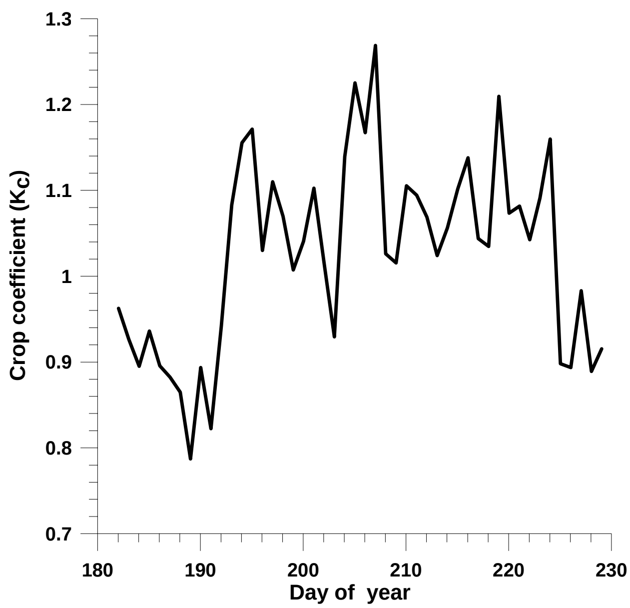

Figure 2. Pepper crop coefficient calculated using Bowen Ratio data from July 1 to August 17, 2005.

Evapotranspiration of Processing Tomatoes in Commercial Fields on the West Side of the San Joaquin Valley

Blaine Hanson, Dept. of Land, Air and Water Resources, University of California, Davis
One Shields Ave, Davis, CA 95616
Phone (530) 752-4639, FAX (530) 752-5262, brhanson@ucdavis.edu

Don May, Dept. of Land, Air and Water Resources, University of California, Davis
Phone (559) 884-6436, FAX (559) 884-2216, reidedo@sbcglobal.net

Introduction

The average state-wide crop yield of processing tomato per unit area increased from 23.7 t/ac for 1970 - 1974 to 36.3 t/ac for 2000 - 2004, a 53 percent yield increase (California Tomato Growers Association, Inc., 2004). During the 1970's, seasonal ET_c ranged from 25.1 inches to 28.1 inches with an average seasonal value of 25.4 inches (Fereres and Puech (1981).

ET_c is commonly estimated by multiplying a crop coefficient by a reference crop evapotranspiration (ET_o). Measured mid-season crop coefficients developed from experimental data ranged from 1.05 under subsurface drip irrigation (Phene et al., 1985) to 1.25 under sprinkler irrigation (Pruitt et al., 1972).

The long term yield increase coupled with the variability in crop coefficients determined from experimental data 20 to 35 years old raises questions about current ET_c requirements. This study evaluated ET_c and crop coefficients of processing tomato on the west side of the San Joaquin Valley in furrow-and drip-irrigated commercial fields under a wide range of cultural practices experienced by growers.

Materials and Methods

ET_c of processing tomato was determined from 2001 to 2004 using three furrow-irrigated and five drip-irrigated commercial fields located on the west side of the San Joaquin Valley near Five Points, CA. Sites were selected to obtain a wide range of cultural practices (Table 1). ET_c was determined with the Bowen Ratio Energy Balance Method (BREB). Other data collected were soil water potential (Watermark electrical resistance blocks), canopy coverage (infrared digital camera), yield and soluble solids (commercial grading station), and applied water.

Crop coefficients were calculated as the ratio of ET_c to $ET_{o.}$ ET_o was obtained from the California Irrigation Management Information System (CIMIS) station located at the University of California Westside Research and Extension Center, about 3 to 5 miles from the eight fields.

Results/Discussion

Examples of the daily crop evapotranspiration are in Fig. 1A. Initially, small ET_c occurred at H2003 (drip irrigation) for several days and then substantially increased due to the sprinkler-irrigated stand establishment. Thereafter, relatively small ET_c values occurred until about DOY120 (day of year), after which, ET_c increased rapidly with time until nearly DOY145. Between DOY145 and DOY190, little trend in ET_c occurred with time with an average mid-season value of 0.31 inches/day, but day-to-day variability was considerable. At D2003 (drip irrigation), initial values of ET_c were relatively small due to using the subsurface drip system for stand establishment. After DOY150, ET_c increased rapidly with time until about DOY180, when maximum values of ET_c occurred. Thereafter, little trend in ET_c with time occurred although smaller values were found for about a 10 day period near the end of the crop season. The average mid-season value was 0.27 inches/day for D2003.

Daily crop coefficients were plotted against days after planting (DAP). At H2003, daily crop coefficients were greater than 0.95 during the sprinkler-irrigated stand establishment (Fig. 1B). Also, high crop coefficients were found between DAP60 and DAP62 due to rainfall. At D2003, relatively small crop coefficients initially occurred with time due to the drip-irrigated stand establishment (Fig. 1B). Crop coefficients at both sites increased rapidly with time until the mid-season growth stage.

A summary of the crop coefficient behavior for all sites is:

- During the sprinkler irrigation at the start of the crop season, maximum crop coefficients ranged from 0.91 to 1.21 with an average maximum coefficient of 1.03.
- The average crop coefficient between sprinkler irrigation and 10% canopy coverage was 0.19.
- Crop coefficients at the start of the crop season were smaller than 0.3 for sites where subsurface drip irrigation was used for stand establishment.
- Crop coefficients remained relatively constant with time during the mid-season growth stage. Average mid-season crop coefficients varied from year to year with values ranging from 0.96 to 1.09. No statistical differences were found between the mid-season crop coefficients of the two irrigation methods for a given year, however, differences were significant between years.
- The daily crop coefficient data showed well-defined late season growth stages only for the 2002 drip system and the 2004 drip and furrow systems. No late season stages of decreasing ET_c with time were found for the other sites.

Canopy coverage plotted against DAP showed similar growth rates for the drip and furrow irrigated sites of 2001 and 2002 because of similar planting dates and similar planting types (data not shown). Canopy growth of H2003 (drip irrigation) lagged behind that of D2003 (drip irrigation) because of the very early planting date of H2003 (March 1) compared to that of D2003 (May 1). In 2004, growth rates differed between the two fields due to different planting dates and also due to stand establishment problems with the drip irrigated field.

A second-order polynomial equation described the relationship between canopy coverage (C) and crop coefficient (K_c) (Fig. 2A). A regression analysis resulted in the following equation:

$$K_c = 0.126 + (0.0172)(C) - (0.0000776)(C^2) \qquad (1)$$

The regression was highly significant with a coefficient of determination of 0.96.

Eq. 1 can be used to determine crop coefficients using canopy coverage data. However, this relationship may be inconvenient to use because of the time required to measure canopy coverage. Thus, a family of curves expressing crop coefficients with time of year was developed for different planting times using the canopy growth curves for those planting times and Eq. 1 (Fig. 2B).

Discussion

Seasonal crop ET_c ranged from 20.8 inches to 29.6 inches with an average of 25.5 inches (Table 2). The difference in the average ET_c between irrigation methods was not statistically significant (t-test, level of significance of 0.05). Applied water ranged from 22.9 inches to 40.1 inches (Table 2). The furrow irrigation amounts included surface runoff that was recovered and reused elsewhere on the farms. Crop yield ranged from 35.1 t/ac to 65.5 t/ac (Table 2). The difference in average yields between irrigation methods was not statistically significant. No correlation occurred between crop yield and ET_c, mainly due different varieties and site conditions used during the study. Water use efficiency (WUE), defined as the ratio of yield to ET_c, ranged from 1.29 (2002 furrow) tons/ac-in to 2.67 tons/ac-in (H2003). The average WUE was 1.52 tons/ac-in and 1.86 tons/ac-in for furrow and drip irrigation, respectively, but these values were not statistically different based on the t-test (level of significance = 0.05)

Conclusions

No differences in seasonal ET_c were found between irrigation methods. These seasonal ET_c's are similar to those reported by Fereres and Puech (1981). The 53% increase in yield between 1970 to 1974 and 2000 to 2004 has not increased the seasonal ET_c, but instead increased the average water use efficiency of processing tomato from 0.93 ton/ac-in to 1.32 tons/ac-in over the 35 year period.. Thus, for the same depth of water, much higher yields per acre are being obtained today compared to those of 35 years ago. Mid-season crop coefficients varied between years, but similar values were found between irrigation methods for a given year.

It is recommended that the relationship between canopy coverage and K_c along with ET_o data, or the family of curves in Fig. 2B, be used to schedule tomato irrigations to provide sufficient water to meet crop ET_c requirements.

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Table 1. Site characteristics of the eight sites consisting of planting date, bed spacing, planting type (T = transplants; D = direct-seeded), establishment methods (S = sprinkler; D = drip), plant rows per bed, crop season, and soil type (CL = clay loam).

	2001		2002		2003		2004	
	Furrow	Drip	Furrow	Drip	H2003 (Drip)	D2003 (Drip)	Furrow	Drip
Planting Date	Apr 16	Apr 18	Apr 8	Apr 2	Mar 1	May 1	Apr 25	May 25
Bed Spacing (inches)	66	66	60	60	60	66	66	66
Planting Type	T	T	D	D	D	T	T	T
Establishment	S	D	S	S	S	D	S	S
Row/bed	1	1	1	1	2	1	1	1
Crop Season (days)	121	128	133	147	138	109	125	133
Soil Type	CL	CL	CL	CL	CL	CL	CL	CL
Variety	BOS 3155 Heinz 9557	Heinz 9557 Heinz 9665 Heinz 9773	Heinz 9491	Heinz 9773 Peto-Hypeel 303	SUN 6117	Heinz 9557 Peto-Hypeel 303	Heinz 9780	Heinz 9492 Heinz 9665

Table 2. Seasonal ET_c, applied water, crop yield, soluble solids and water use efficiency (WUE) for 2001, 2002, 2003, and 2004.

	Seasonal ETc (in)	Applied Water (in)	Yield (tons/ac)	Soluble Solids (%)	WUE (tons/ac-in)
			2001		
Furrow	25.5	32.9	38.5	5.6	1.51
Drip	22.5	22.9	41.8	5.1	1.86
			2002		
Furrow	27.1	26.0	35.1	*	1.29
Drip	29.2	30.1	39.2	*	1.34
			2003		
H2003	24.5	31.6	65.5	4.7	2.67
D2003	20.8	35.2	40.7	5.6	1.96
			2004		
Furrow	29.6	40.1	52.0	5.2	1.76
Drip	24.8	24.6	36.2	*	1.45
Average					
Furrow	27.4	33.0	41.9		1.52
Drip	24.4	28.8	44.7		1.86
All sites	25.5	30.4	43.6		1.73
	n.s.	n.s.	n.s.		n.s.

* data not available

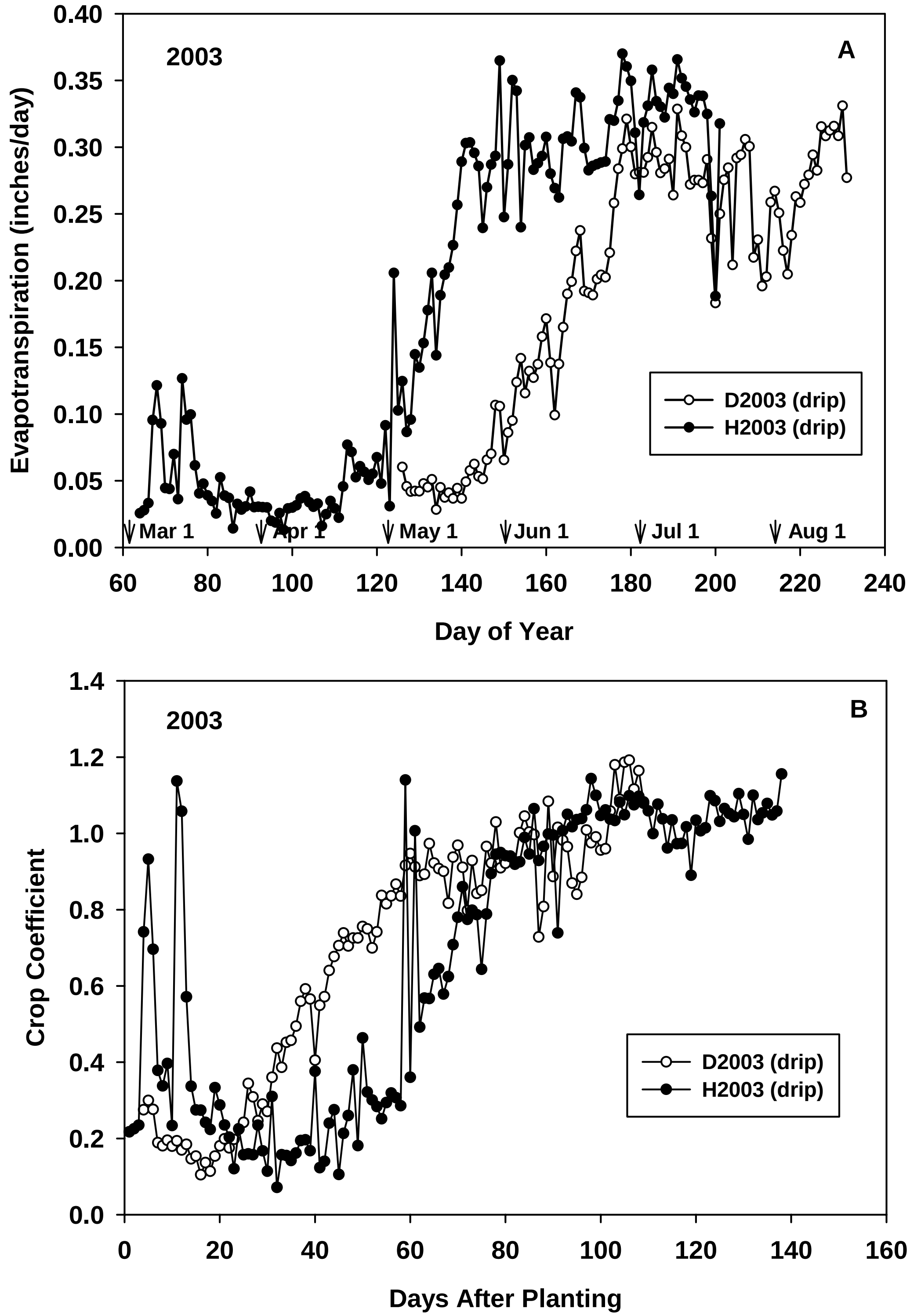

Figure 1. (A) daily crop evapotranspiration for the 2003 drip irrigated fields, and (B) daily crop coefficients for the 2003 drip irrigated fields.

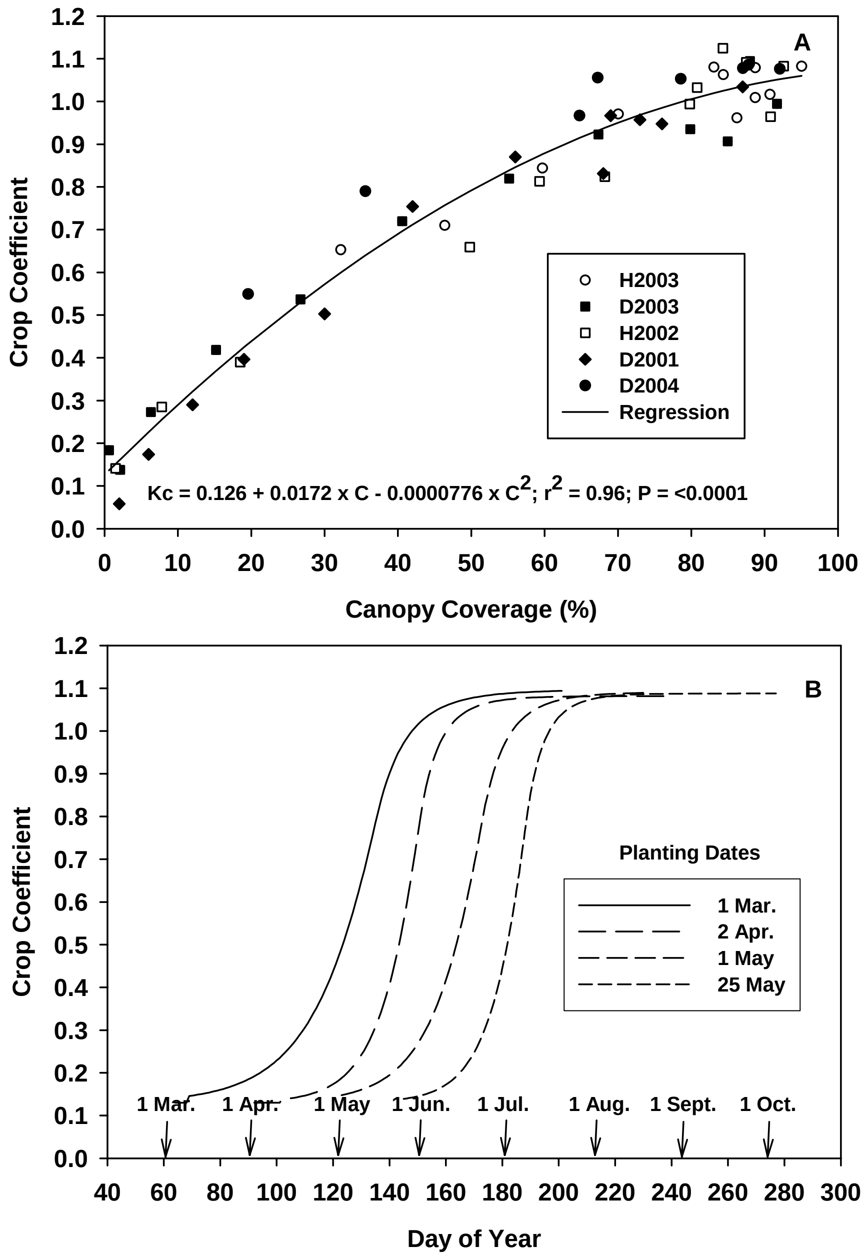

Figure 2. (A) Canopy coverage vs. crop coefficient, and (B) curves of crop coefficient vs. day of year for various planting times.

The Transition To Drip Irrigation With Processing Tomatoes

Nathan Heeringa, Tulare District Manager,
J. G. Boswell Company - P.O. Box 877 - Corcoran, CA 93212
Phone (559) 992-5011 - FAX (559) 992-3884 - nheeringa@jgboswell.com

Introduction

The transition into drip irrigation has helped the J. G. Boswell Company establish itself as a leader in producing high quality processing tomatoes. Lower commodity prices and decreased returns on the foundational crops of the Central San Joaquin Valley have resulted in a transition into new crops. Part of these crop changes for the J. G. Boswell Company has resulted in a significant increase in tomato production. Irrigation systems are a critical component of any crop, yet the transition into drip irrigation has made the production of processing tomatoes on the heavy flat soils of the Tulare Lake bottom a successful and profitable crop.

The irrigation of processing tomatoes is the single most important factor in producing a profitable crop in the Mediterranean-type climate of the San Joaquin Valley. Over the past decade, furrow irrigation has been the most common irrigation method. As the J. G. Boswell Company increased tomato production into the Tulare Lake bottom, vast research was conducted to optimize the furrow irrigation that tested siphon pipe size, length of run, bed and furrow shape, irrigation set timing, irrigation cut-off timing, alternate row irrigation and many other agronomic factors. While production improvements were being made with the use of siphon pipe irrigation, other irrigation methods were being researched that included sprinklers irrigation, linear irrigation systems and drip irrigation systems. Drip irrigation consistently provided significant improvements in tomato production with higher yields, quality and profitability. As we have transitioned into nearly 100 percent drip irrigation with processing tomatoes, we continue to research and improve drip irrigation to provide a highest quality and quantity of processing tomatoes.

Drip Irrigation Systems on Processing Tomatoes

Drip irrigation systems are continually changing and the options are nearly endless in choosing the best system for your production. A critical component in choosing a drip irrigation system for the J. G. Boswell Company was in designing a retrievable system. This type of system would allow the drip tape to be retrieved and reused year after year. It was essential to maximize the significant inputs of a drip irrigation system in the changing climate of farming in the Tulare Lake bottom. The highest economic return of the drip irrigation system is maximized on higher valued crops; however, crop rotation is still a vital element in maintaining soil health. A retrievable drip system reduced the risk of placing a large capital investment in the high-risk environment of a flood zone or the ever-changing cropping patterns and practices of today's agriculture market.

There are a number of components to consider when choosing a retrievable drip irrigation system. The handling of the tape greatly increases during its projected lifetime, so it must be easy to handle. Being able to easily identify the top of the tape and have the emitters facing the correct direction is useful as the tape often twists when it is reused. Quick and easy repair of the tape is an important factor in a retrievable system and the tape must have the correct tensile strength to prevent stretching. Tape thickness is another critical component to maximize the longevity of the tape. Pumping and filter stations must also be designed to handle the flexibility of a retrievable drip irrigation system.

The Effects of Drip Irrigation on the Agronomic Management of Processing Tomatoes

An increase in irrigation uniformity with drip irrigation has had a significant impact on improving the production of processing tomatoes. Within the Tulare Lake bottom, the average slope of a field is about 0.02% fall, or approximately one foot per mile fall. Within a furrow irrigation system a one-half inch (½") obstruction in the furrow can back up the water 400 feet. This can lead to very low levels of uniformity of irrigation that can result in saturated soil conditions that are easily infected with *Phytophthora* root rot. As wet conditions get wetter throughout the season, they can easily affect the sensitive water table conditions in the Tulare Lake bottom. Any decrease in irrigation uniformity will also reduce the uniformity of material applied through the irrigation system, including fertilizers and insecticides. The flat conditions in the Tulare Lake bottom that are often restrictive in furrow irrigation actually help maximize irrigation uniformity within a pressurized drip irrigation system. When water is uniformly applied to a very consistent soil type and conditions, the entire field can be managed to its fullest capacity.

Drip irrigation increases the flexibility in irrigation timing and the precision of applying the exact quantity of water desired. Continuing research is being conducted to determine the best methodology of irrigation scheduling in drip systems within the J. G. Boswell Company. Whether it is 'spoon feeding' multiple times per day or matching evapotranspiration on a weekly basis, the flexibility in management is infinitely higher with drip irrigation compared to furrow irrigation.

There are several key factors to remember when setting an irrigation schedule within drip irrigation. The limitations and risks of the drip system should be considered. If the maximum application rate within one week only matches the maximum forecasted evapotranspiration for that period, deficit irrigation is not a recommended practice. The amount of water applied can be maximized to the soil's water holding capacity to reduce the intervals between irrigation and maximize soil nutrients, but this comes with distinct risks. A long irrigation set, or large application of water, can result in a decrease in water use efficiency. Any reduction of water use efficiency can increase water cost and use, decrease the effectiveness of chemigation, leach nutrients and potentially raise the perched water table.

There are a number of critical stages during tomato production that a producer must consider when setting a drip irrigation schedule. During crop establishment, there is a distinct balance between the need of readily available moisture for the young crop and the need for field operations with heavy equipment. Drip has proven to be a great success in establishing a crop during adverse conditions, especially as daytime temperatures rise near 100° F. Special care must be considered during fruit development to prevent any soil moisture from reaching the soil surface. The management of mold within the tomato crop must include the management of canopy and surface moisture near exposed fruit. Drip irrigation allows the crop to be irrigated further into the season; however, the cut-off date for irrigation is still dependent on a variety of factors including soil type, crop health, harvest flexibility and the drip system logistics.

Conclusions

Drip irrigation has improved tomato crop production within the Tulare Lake bottom. Yields continue to increase with improvements in agronomic practices using drip irrigation. The increased irrigation efficiencies of drip tape have helped reduced the amount of applied water per unit of crop. Drip irrigation provides a more stable supply of tomatoes by addressing many of the risks throughout the season that include crop establishment, mold management and harvest conditions. Fertility applications and rates are being adjusted to meet these higher yields and the dynamics of the drip system. Drip irrigation is enhancing the value of many chemigated products with the increase in irrigation efficiencies and a more flexible irrigation scheduling method. The long-term effects of drip irrigation will continue to be researched. Drip irrigation increases the ability to manage a perched water table with increased water efficiency and provides a tool to manage root development above a perched water table. Drip irrigation also provides a tool to manage soil chemical properties within a regional zone. Changing the soil's pH or nutrient availability may be cost restrictive in a traditional irrigation method, yet drip irrigation provides a tool to address these issues in the prime root zone of the drip tape. The past few years of success and our optimism in improving the soil health have made drip irrigation a basis for tomato production on the Tulare Lake.

Field Studies on Deficit Irrigation of Alfalfa

Dan Putnam, Extension Forage Specialist, Department of Plant Sciences,
One Shields Ave., UC Davis 95616, 530-752-8982, dhputnam@ucdavis.edu

Steve Orloff, UCCE Farm Advisor, Siskiyou County
1655 S. Main Street, Yreka, CA 96097, 530-842-2711, sborloff@ucdavis.edu

Blaine Hanson, Extension Irrigation Specialist, Department of Land, Air, and Water Resources,
UC Davis, CA 05616, 530-752, brhanson@ucdavis.edu

Harry Carlson, UCCE Farm Advisor and Director, Intermountain Research and Extension Center
PO Box 850, Tulelake, CA 96134, 530-667-2719, hlcarlson@ucdavis.edu

Introduction

More irrigation water is applied to alfalfa than to any other crop in California. Department of Water Resources estimates indicate that 19.5 percent of all the irrigation water used in California goes toward alfalfa production. Because of its high water use, alfalfa is often in the crosshairs of regulators and environmentalists searching for new sources to satisfy the increasing urban demand and for environmental mitigation efforts. Although some have said so, it is not true that alfalfa is a "water waster". Alfalfa's high water use is attributable to its long growing season and the number of acres in the state, typically around a million acres, and its high yield. Compared with other agricultural commodities, alfalfa is one of the highest in water use efficiency (Loomis 1991, Putnam et al., 2001).

Nevertheless, agriculture, and alfalfa in particular is scrutinized when water supply is at issue. There are few win:win opportunities when dealing with contentious issues like water allocation. Simply stated, the demand is oftentimes greater than the supply—especially in drought years—and the entities involved to do not want to forfeit a portion of their allotment, especially when their livelihood depends on adequate supplies. Alfalfa's high water use, however, may provide some opportunities for temporary water transfers, if methods of deficit irrigation are agronomically acceptable, and orderly voluntary transfer mechanisms can be developed. If a production system were developed that reduce the amount of water applied to alfalfa, it could result in a considerable water savings, while maintaining forage production systems for the millions of farm animals in the state. The animal industries which provide a collective demand for alfalfa and forages is worth well over 6 billion dollars (dairy, beef, sheep, horses), so complete cessation of alfalfa or forage production would have major impacts on California's economy. This concept represents a 'middle path' which maintains forage production in the face of an almost certain future of droughts and excess demand for water.

Short-Term Voluntary Water Transfers.

Water transfers from agriculture are discussed by water agencies as the primary option for dealing with water shortages in drought years. However, fallowing of large acreages can have devastating and enduring consequences on the farm economy of an area and can negatively affect the well being of an entire community. Furthermore, fallowed fields are more susceptible to wind erosion and weed encroachment and are poor wildlife habitat compared with alfalfa fields. An alternative to complete fallowing is deficit or partial irrigation. Alfalfa is particularly well suited to this approach. As a species, *Medicago sativa* evolved in regions with seasonal rains and seasonal droughts, and alfalfa has genetic and morphological features that make it able to adapt to these conditions. Although forage yield is reduced by moisture stress, alfalfa plants survive by entering a "drought-induced dormancy" and recover once water is available. The concept then is to provide a mechanism so that interested alfalfa growers could voluntarily transfer a portion of their irrigation water (in summer and fall) for alternative uses, environmental or urban, in drought years and receive compensation.

Advantages to the Temporary Deficit Approach

There are several advantages to this approach. First and foremost, it maintains forage production and farm economic stability. Additionally, spring and early summer cuttings are often higher in yield and forage quality than late summer or fall cuttings. Yield per cutting normally trails off in fall as temperature and daylength decline. Therefore, a high percentage of the total seasonal production occurs before midsummer. If early harvest with full irrigation were allowed, a summer 'dry-down' would favour maximum spring/early summer yields, and transfer water during mid-late summer when yields and water-use efficiency is significantly lower. Seasonal water use is highest in midsummer and lower in spring and fall (Figure 1). However, Water-Use-Efficiency or the amount of crop per unit of water is greatest in spring (Figure 1). Such differences are greater in the Imperial Valley (Loomis and Wallinga, 1991). The goal is to maximize water use efficiency. This approach also takes advantage of the moisture stored in the soil from winter and spring rains. While this practice is logical in theory, field research was needed to evaluate the economic and agronomic viability of deficit irrigation of alfalfa for water conservation.

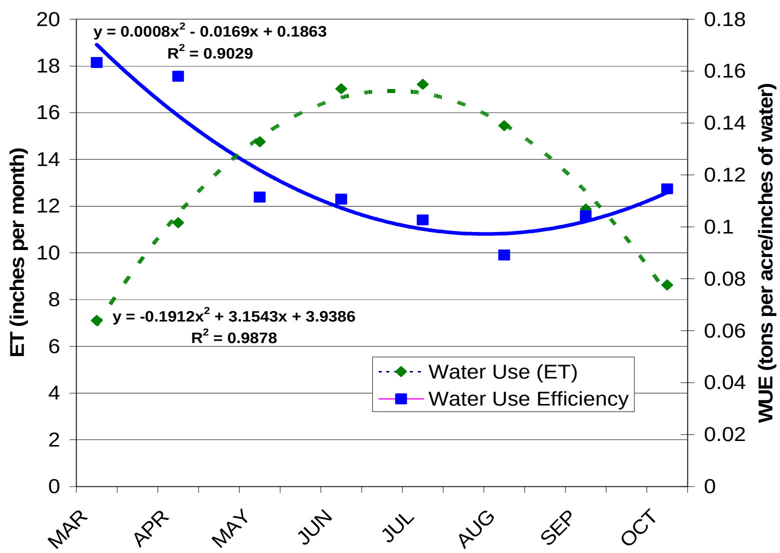

Figure 1. Changes in alfalfa water use (ET) and water use efficiency over the growing season, Davis, CA.

On-Farm Field Studies

Field trials were established in 2003-2005 in the Intermountain area (Klamath Basin and Scott Valley) and the Sacramento Valley of California to examine the impacts of deficit irrigation strategies. Two to three trials were conducted in producer fields in each region. These regions differ dramatically in climate, adapted varieties, and numbers of cuttings (3-4 for the Intermountain area, 6-7 for Sacramento Valley).

The Intermountain trials were conducted at locations with vastly different soil types representing some of the extremes in the intermountain area. The Klamath Basin sites were a fine sandy loam and a silt loam with high organic matter content. The Scott Valley sites are a Settlemeyer Loam and a Stoner gravely sandy loam. All intermountain locations were sprinkler irrigated. There were three irrigation treatments:

1. normal full-season irrigation

2. no irrigation after first cutting
3. no irrigation after second cutting

The Sacramento Valley trials were conducted on two growers' fields in Yolo County, both clay loam soils susceptible to cracking. Both sites were flood irrigated and the irrigation treatments were applied to entire border strips. Treatments were:

1) normal full-season irrigation,
2) irrigation cut-off in mid summer (July)
3) irrigation cut-off in mid summer (July) with resumption of irrigation in fall.

The Sacramento Valley sites represented significantly different production methods than the Intermountain sites. These are very heavy soils. The cracking nature of these Yolo clay loam and Capay series clay loams are important hydraulically, since the cracks increase surface area for infiltration.

Water Savings - Intermountain

Water savings with the deficit irrigation treatments varied considerably between sites depending on the growers' irrigation practices (Figure 2). Cutting irrigation off after 1st cutting (typically no irrigation after June 1st) resulted in a water savings of between 11 and 23 inches of water. When no irrigation was applied after 2nd cutting (usually equated to no irrigation after July 15) there was a water savings of between 6 and 18 inches. These amounts represent a considerable reduction in the total seasonal water application, as most alfalfa fields in the Intermountain area are only irrigated one or two times before first cutting.

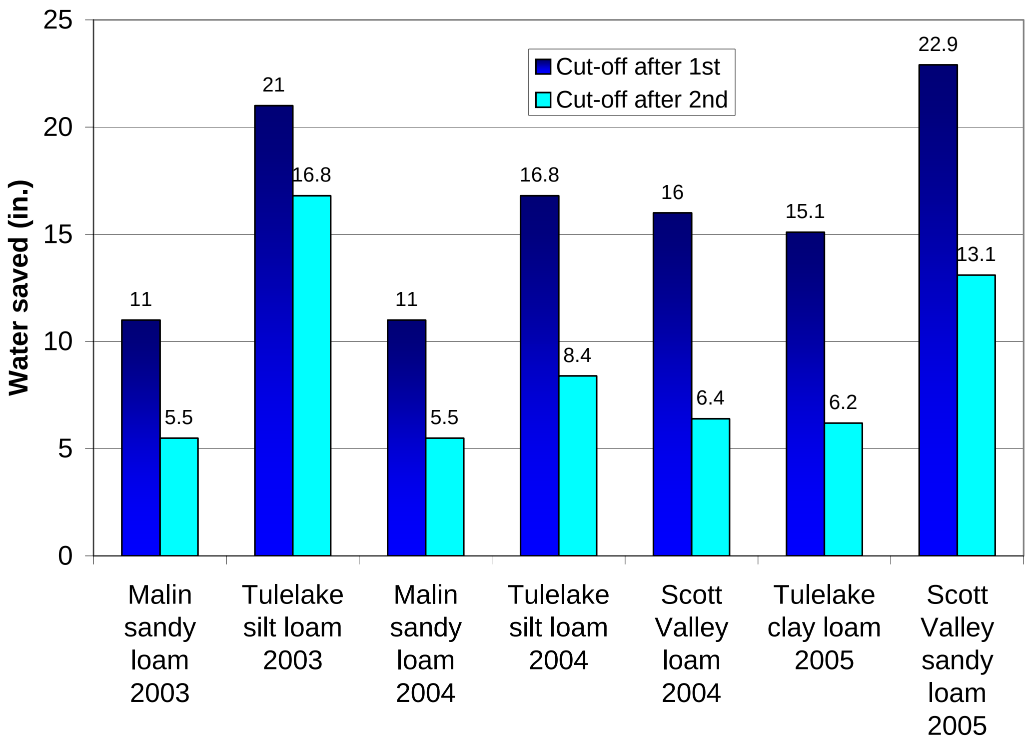

Figure 2. Water Savings from Intermountain Deficit Irrigation Sites

Yield Impacts - Intermountain

Yield was reduced at all sites when irrigation was withdrawn after first or second cutting. Irrigation termination after 1st cutting reduced yield by 0.60 to 2.20 tons per acre (average yield reduction over 7 sites was 1.10 tons per acre). Ceasing irrigation in July after second cutting had less of an effect, reducing yield by 0.29 to 1.23 tons per acre (averaging 0.62 tons per acre). However, for practical purposes the yield reduction may be more than this amount. It may not be justified for a producer to harvest a cutting that is less than half a ton per acre because the income from such a small yield may not cover costs. Therefore, the total yield in the deficit irrigated plots should not include the yield obtained from individual cuttings where the yield was less than approximately 0.5 tons. The adjusted figures show a yield penalty of 0.69 to 2.82 tons per acre when fields were not irrigated after 1st cutting (Figure 3). The yield decrease averaged 1.31 tons per acre. When fields were not irrigated after 2nd cutting, the adjusted yield decrease ranged from 0.31 to 1.42 tons per acre (average of 0.75 tons per acre).

The degree of yield reduction varied considerably between sites depending on several factors including depth to the water table, soil type, the age and productivity of the stand, the number of total cuttings, and the growers' irrigation practices. Klamath Basin locations had a relatively high perched water table (wet soil occurred at about 3 – 3.5 feet), whereas, the water table at the Scott Valley sites was inaccessible to the alfalfa roots. Therefore, deficit irrigation generally had a greater effect on yield at the Scott Valley sites than at the Klamath Basin sites (Malin and Tulelake). The yield reduction was also usually greater at sites with lighter textured soil, loam or sandy loam, than with the organic soils in Tulelake. In fact, the yield per cutting in deficit irrigated plots at the Tulelake sites with organic soil never fell below 0.5 tons per acre, the

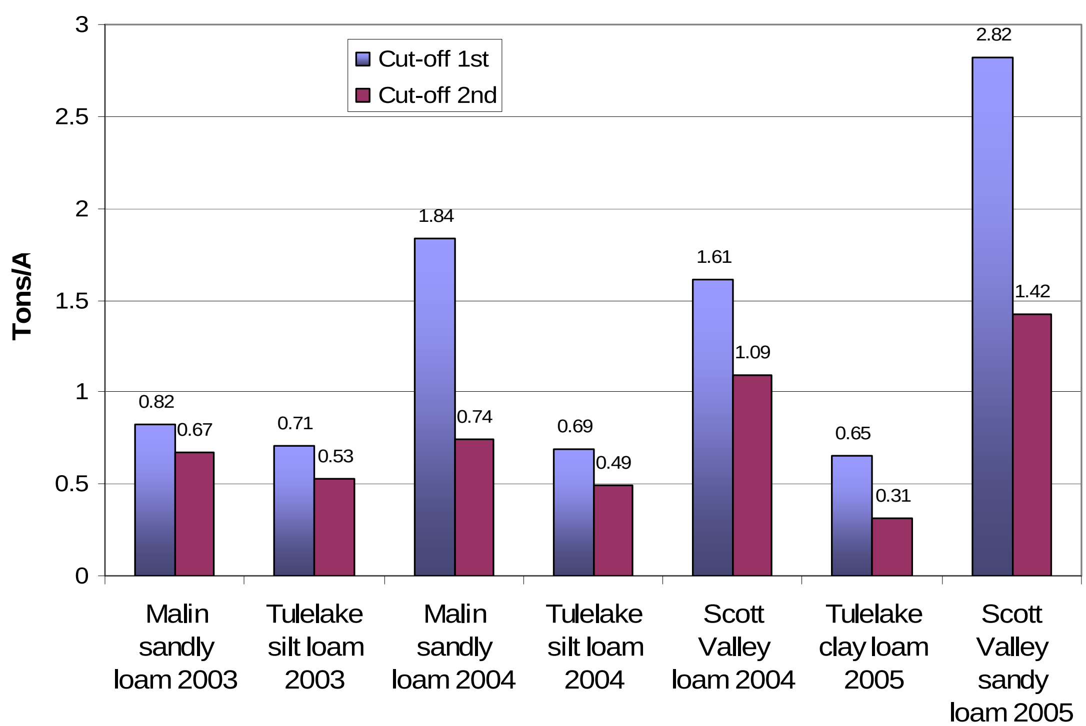

Figure 3. Practical Yield Loss from Intermountain Deficit Irrigation Sites.

amount assumed to be necessary to warrant harvest. The yield reduction was greater at sites that were adequately irrigated. Even the fully irrigated treatments were under-irrigated at some sites so the full difference in yield may not have been realized at these locations.

Alfalfa stand density was assessed the following spring by visual ratings and counting the number of stems per unit area. Stems were counted to better assess the health of the stand. It is conceivable that an alfalfa crown could survive the effects of deficit irrigation but be weakened and produce fewer stems per crown. However, we found no difference in visual stand ratings or stem numbers between fully irrigated and deficit irrigated plots. First cutting yields the year following deficit irrigation were the same (data not shown) for all treatments indicating no residual effect from the deficit irrigation treatments.

Evapotranspiration – Sacramento Valley

The Sacramento Valley Sites are a 6-8 cut system compared with a 3-4 cut system in the intermountain region. The summer dry-down treatments in these studies occurred in July, and yields were measured in July, August, and September/October, depending upon the year. It is much more difficult to measure exactly the amount of irrigation water used in these flood irrigation systems than in sprinkler systems. However, we did measure Evapotranspiration (ET) in these plots (Figure 4). How much ET is reduced in deficit irrigated alfalfa is not well known and depends on several factors including soil moisture content, which is influenced by previous

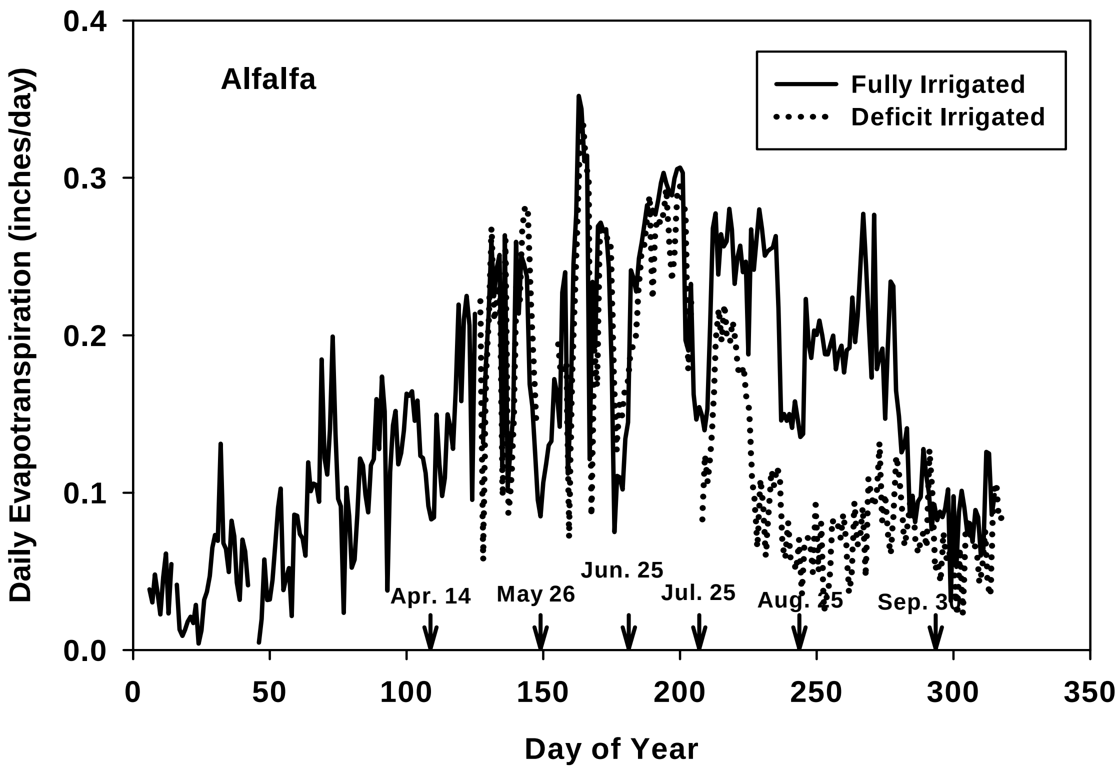

Figure 4. Alfalfa Evapotranspiration for fully irrigated and deficit irrigated alfalfa, Sacramento Valley, Site 1, 2005. The arrows and dates indicated harvest dates. Deficit irrigation started July 25, 2005.

irrigation practices, soil type and the presence of a perched water table. The fully irrigated data showed increasing ETc with day of year (DOY) up to about DOY130 (Figure 4). Considerable variability occurred in the data due to the highly variable climate behavior during the first part of the year. However, just after a cutting, smaller values of ETc occurred and then ETc increased with time after cutting until the next cutting. This pattern is very obvious after DOY180, but is less obvious earlier in the year because of the day-to-day climate variability. Cumulative ETc as of November 12, 2005 was 46.1 inches. This is very much in line with historical experience and other estimates of alfalfa ET which projects seasonal ET at 46-48" for this region.

Deficit irrigation (no irrigation) started on July 25 in 2005. After the July 25 cutting, ETc of the deficit irrigated part of the field was less than that of the fully irrigated field and eventually decreased to values between 1 and 2 mm/day (1/25 to 1/12 inches/day). Cumulative ETc between July 25 and November 12 was 35.6 inches for the fully irrigated treatment and was 24.9 inches for the deficit-irrigated treatment. The difference in ETc during the deficit-irrigated period was therefore 10.7 inches, according to this estimate.

Whether the potential for water transfer is equal to the amount of ET saved or alternatively the amount of water not applied (or water saved, as in Figure 2) during the period of deficit irrigation is a policy question with a significant technical dimension, discussed in more detail below.

Yield Losses – Sacramento Valley

Yield losses due to the deficit irrigation treatments ranged between 0.23 tons/acre to 2.69 tons acre in the Sacramento Valley, depending upon treatment, sites, and years. In 2003, July dry-down treatments resulted in 1.5 to 2.5 tons/acre yield decline, but the practical yield impact was greater than this (Figure 5). A 'practical' yield impact takes into account the fact that very

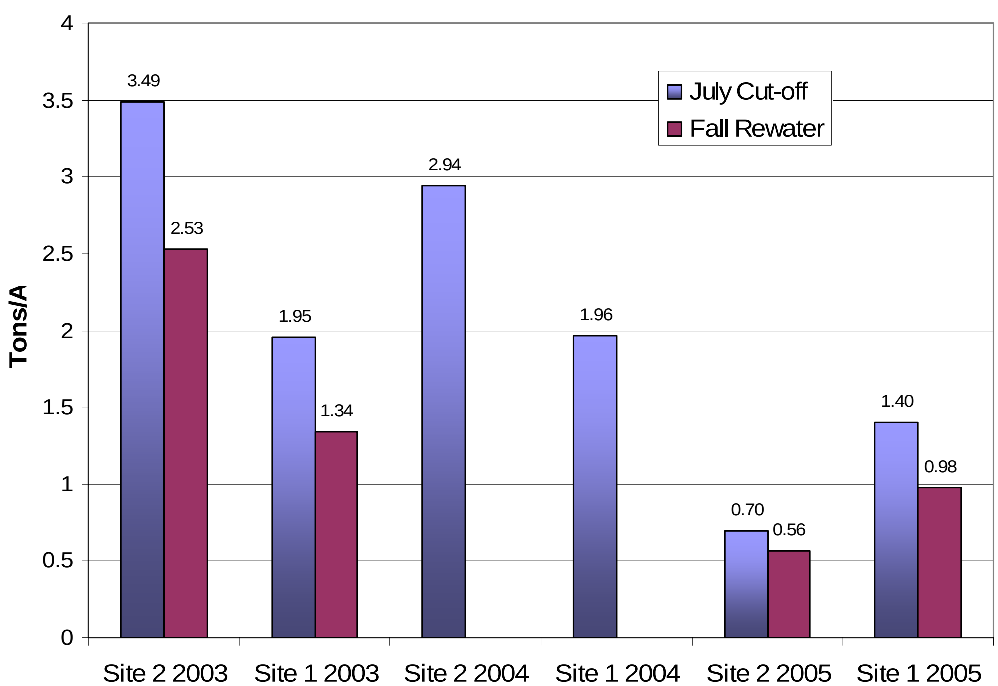

Figure 5. Effect of Deficit Irrigation on practical yield reduction-Sacramento Valley sites (Yolo County).

low yielding fields would not be harvested, since harvesting costs may exceed the value of the low yield. In 2005, summer dry down was not accomplished until August due to logistical constraints, and yield decline was less in this year due to generally low yields, and the fact that only two cuts were affected by the treatments. These fields at both sites were in the final year of production, and with the excessive heat in late summer, yields were low.

Alfalfa stand density was assessed the following spring in each year by visual ratings and stand counts. First cutting yields were measured in 2004 and 2005 to assess the effects of previous-year's irrigation treatments. Similar to the intermountain region, we found no significant differences at these two sites in stand decline or in relative next-season yield due to the irrigation treatments.

A yield of less than 0.5 tons per acre was considered not worth harvesting so the "Practical Reduction" excludes such low-yield cuttings. The last cut of the re-water treatment was equal to the controls in this year. Practical reduction in yield was not calculated in this case, since control yields were below the ½ ton practical limit. The growers in both cases harvested their last cut in spite of the low yields.

Implication of Yield Studies

Although yield penalties were present in almost all cases, these results suggest that early curtailment of alfalfa irrigation to conserve water is a feasible approach to deal with water shortages in drought years in both the Intermountain and Sacramento Valley sites. The grower is still able to harvest the more valuable and higher yielding spring cuttings and, while total alfalfa yield for the season would be reduced, a significant proportion of the annual production is still obtained. In addition, we did not observe a reduction in alfalfa stand density or a negative carryover effect on yield the following year in these studies. It must be noted, however, that in desert locations (Imperial Valley, Palo Verde Valley), stand losses were a significant risk of deficit irrigation, particularly when deficit irrigation occurs for several consecutive years.

The Intermountain area exhibited less yield impact and was more variable in the results due to the importance of high water tables at several of the sites. When irrigation cut-off started in July, the yield impact in the Sacramento region were signficantly greater.

Determining Water Savings due to Deficit Irrigation

Determining an appropriate level of compensation for agricultural water is problematic. First, in many cases it is difficult to quantify how much water is truly saved by deficit irrigation. One viewpoint is that the water saved is equal to the total amount of water that would have been applied had the field been fully irrigated. Such a 'water savings' has been calculated from our field studies and reported in Figure 2. However, this may not be considered to be the 'true' water savings in all cases, depending upon hydrological and policy factors. Even after irrigation water is withdrawn, the alfalfa plant continues to transpire, utilizing residual soil moisture. Estimating the water conserved is especially complicated when the alfalfa roots are able to access a perched water table to satisfy at least a portion of its water needs, even when fully irrigated throughout the season. Is this water available for transfer?

Some believe it is incorrect to assume that the water not applied when deficit irrigating is the actual water saved. If a field is fallowed and void of vegetation, water loss is reduced to just the amount due to evaporation (not ET, which includes evaporation and transpiration through the plants). However, a deficit irrigated alfalfa field may continue to transpire, although at a reduced rate, depending on the amount of residual soil moisture and amount of foliar growth. The water that continues to be transpired by the alfalfa plant even after irrigation ceases is water that in some cases could have become drain water and been recycled and used to irrigate another field. Or, it is water that may have eventually reached an aquifer that is pumped for irrigation or used for some other beneficial use. Therefore, some contend that the water saved through deficit irrigation should only be considered to be equal to the reduction in evapotranspiration.

Whether the amount of water saved should be considered the amount of water that is not applied or just the reduction in evapotranspiration depends to a large degree on the site and the hydrology and the fate of water applied in excess of crop ET. For example, the water saved might be considered equal to the water not applied at a location without a perched water table where any deep percolating water is not recycled and the soil moisture profile is filled at the end of each production season by winter rainfall. At some locations the groundwater aquifer is connected with a river system and deep percolating water that reaches the groundwater may exit the system during periods of high flow in the river and serve little beneficial use. At other locations, this water may contribute to stream flows for wildlife habitat or be captured and recycled to irrigate other fields or for other beneficial uses. At still other locations, deep percolating water may contribute to saline groundwater that is not usable. In situations where it is clear that water in excess of crop ET is re-used effectively, it may be more appropriate to consider the water saved to be just the reduction in alfalfa ET.

Another consideration is the source for the irrigation water. For example, if not irrigating in July and August when water is typically scarcer allows water to remain in lakes or reservoirs or be diverted into streams for environmental enhancement, then compensation for the full amount of water not applied may be appropriate. Deficit irrigation, as evaluated in this research, allows for irrigation in spring when alfalfa's water use efficiency is higher and water is more plentiful and irrigation ceases in summer when water use efficiency is reduced and water supplies are oftentimes inadequate.

The Economics of Deficit Irrigation

Although determining the quantity of water saved is complex, assigning an economic value to the water conserved is not as easy a task as one might think for several reasons. From the grower's perspective, at a minimum, the value of water should make up for production losses. However, assessing potential losses is a complex issue itself due to the differences in losses between fields. In the intermountain area, the water price needed to make up for the reduction in yield that occurred when irrigation ceased after first cutting varied considerably between sites depending both on the degree of the yield loss and the amount of water applied to achieve full yield (Figure 5). On average, a water value of $119 per acre foot was needed to cover the loss in alfalfa yield assuming an alfalfa hay price of $120 per ton. The value ranged from $49 to $240 per acre foot depending on the site. These values are calculated based on gross returns and are not discounted for the reduction in inputs that would occur if yield was reduced due to deficit irrigation (examples include lower harvest cost, less fertilizer required, perhaps reduced pesticide inputs, etc.).

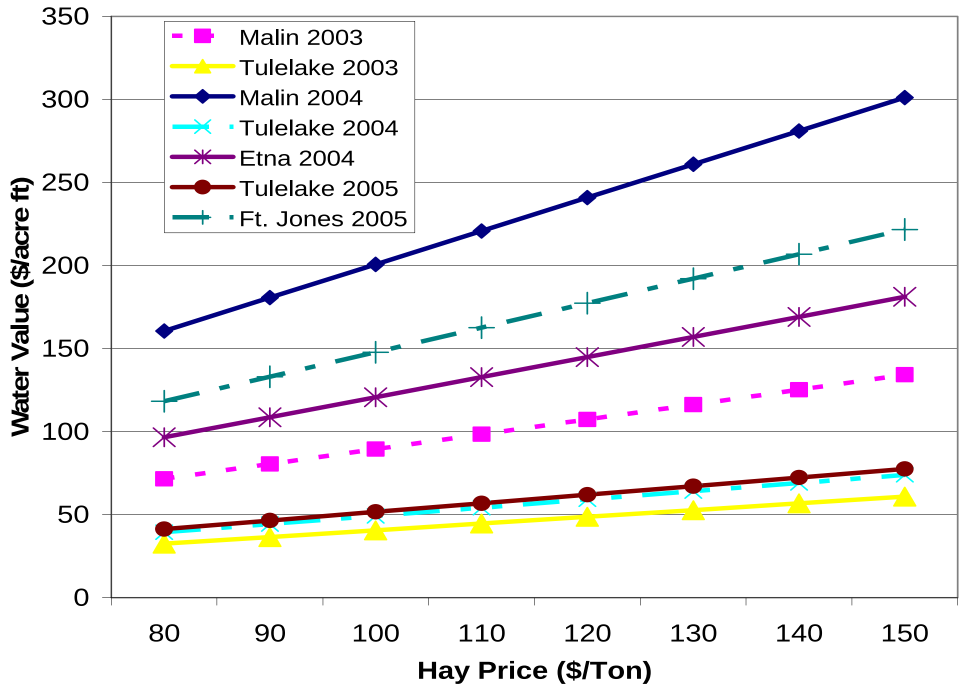

Figure 6. The water value necessary to compensate for alfalfa yield loss from ceasing irrigating after first cutting at several intermountain locations for a range of hay prices.

At the Sacramento Valley site 1, where ET of the two treatments was measured in detail, the loss in yield during the period July 25 through November 12, 2005 was 1.08 tons/acre, with an estimated ET difference of 10.7" of water. At various hay prices, the value of this loss in hay ranged from 96.9/AF through over 200/AF (Table 1), if ET were used to calculate water savings. The applied water saved is likely to be greater than this amount during August and September, and so if this calculation were done on an applied 'water saved' basis, the value of the water would be less than this amount.

Table 1. Direct value of water saved calculated from value of hay, Sacramento Valley Site 1, 2005. Water savings estimates are based upon differences in ET measured in the control plots compared with the plot where irrigation ceased in late July. Note: This is a single site, single year, and negotiated price of water may depend upon a range of factors.

	Price of Alfalfa Hay					
	$80/ton	$100/ton	$120/ton	$140/ton	$160/ton	$180/ton
	Equivalent worth of water saved ($/AF)					
Late July Irrig. Cut-off	$96.90	$121.12	$145.35	$169.57	193.79	218.02

Should compensation merely be reparation for lost yield? It is likely that growers would expect more incentives depending upon the situation. The issues related to maintaining customer supply (risk of loosing dependable markets), and long-term risk of loosing stands must be considered. The risk of stand loss does exist even though we did not observe a permanent effect on productivity or stand in these trials. Variable alfalfa production on a farm from year to year could also be problematic for producers. Established growers strive to develop a customer base; an interruption in total supply from one year to the next could be problematic.

Benefits to Growers

On the other hand, a payment for water transferred could benefit alfalfa growers because mid summer cuttings are often lower in yield and are typically the lowest in forage quality. Therefore, mid-summer cuttings are often more difficult to market and there is an abundance of mediocre quality mid-summer alfalfa hay often resulting in a poor price. A reduction in the supply of mid-summer alfalfa could improve price for all alfalfa hay producers if it were significant. In the Sacramento Valley, growers could probably forgo the expense of insect control on deficit plots during late summer months. However, the implications of these techniques on pests in general have not been fully explored. For example, lack of flooding may increase rodent problems or some insects.

Other factors should be considered when establishing a value for the transferred water including the value of the water to the end user, whether it is urban uses or for environmental benefits. Economists are examining several different methodologies to establish a value for water. Whatever method is selected, growers should be confident that the value provides adequate compensation for their losses, and provides incentives for participating. Cooperation in transfer arrangements—like the one this research suggests may be possible—could benefit farmers in the long run by providing water for other uses in drought years while helping to obtain a more secure water supply for agriculture.

Conclusions

Deficit irrigation of alfalfa shows promise as a strategy for dealing with water shortages. These data suggest that water transfers from alfalfa for other uses in drought years may be agronomically feasible. Under ideal conditions, this may be one of the few win:win scenarios when it comes to proposals to deal with water shortages in drought years. Water could be voluntarily transferred in critically dry years to satisfy urban requirements or for environmental needs, if the grower is adequately compensated for forgoing a portion of their production. Further work to understand the impact of deficit irrigation on yields and plant stands, and under different soil and hydrological conditions is needed, particularly to understand methods of controlling plant growth when high water tables occur. A better understanding of measurements of water savings, and to assure orderly transfer protocols are required for this to be successful.

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Distribution of Water-Run Nitrogen Fertilizer in Furrow-Irrigated Row Crops

Stuart Pettygrove, Extension Soils Specialist
Dept. of Land, Air & Water Resources, University of California
One Shields Avenue, Davis, CA 95616
530-752-2533, 530-752-1552 (fax), gspettygrove@ucdavis.edu

Lawrence J. Schwankl, Extension Irrigation Specialist
Dept. of Land, Air & Water Resources, UC Kearney Research & Extension Center
9240 S. Riverbend Ave, Parlier, CA 93648
559-646-6500, ljschwankl@ucdavis.edu

Carol A. Frate, Cooperative Extension Farm Advisor
4437 S. Laspina St., Ste. B, Tulare, CA, 93274
559-685-3309 X214, cafrate@ucdavis.edu

Kent L. Brittan, Cooperative Extension Farm Advisor
70 Cottonwood St., Woodland, CA 95695
530-666-8733, klbrittan@ucdavis.edu

Mick Canevari, Cooperative Extension Farm Advisor
420 So. Wilson Way, Stockton, CA 95205
209-468-2085, wmcanevari@ucdavis.edu

Introduction

Injection of fertilizer in irrigation water (fertigation) – in furrow and border check irrigation systems is a common practice in California and elsewhere in the western U.S. It is a convenient, low-labor requiring method of application, and in mid to late season, is the most practical method for applying N to non-drip irrigated row crops. Fertigation with low-cost anhydrous and aqua ammonia is common in California. These materials cannot be injected in drip systems due to the potential for formation of precipitates or in sprinkler systems due to the very high ammonia volatilization losses that usually occur.

The main limitation of fertigation in surface gravity irrigation systems is the potential for non-uniform nutrient application, which can cause N deficiencies in some parts of the field and excessive N and nitrate leaching losses in other parts of the field. Two factors can contribute to this non-uniformity: (1) non-uniform irrigation water application, and (2) loss of N by ammonia volatilization.

Although fertigation with ammonia fertilizers is an old practice, and industry advisories have been published (e.g., Warnock, 1966), surprisingly little research has been conducted on the conditions and management practices that influence spatial distribution of water-run N fertilizers in these systems. The few studies that have been conducted are in disagreement on the severity of the non-uniformity and the role of ammonia volatilization. Some researchers have reported that when irrigation water was properly controlled in furrows, water-applied ammonium concentrations varied within 5% between the head and end of the furrows (Chapman, 1956; Leavitt, 1957). In a 2003 UC study of dairy lagoon water applied in a furrow system in the San Joaquin Valley, Schwankl et al. observed no change in the ammonium and organic N concentrations of the water sampled along a furrow over a 1250-ft distance, even though the ammonium concentration was relatively high at 100 mg N/L.

On the other hand, researchers in Australia measured NH_4 concentration drops of 50% from top to bottom of the field (Denmead et al., 1982) in NH_3-fertigated corn. Using micrometeorological methods, they were able to attribute this drop to ammonia volatilization. The main factors influencing ammonia loss from water are ammonium concentration, pH, water depth, wind speed, and temperature (Jayaweera and Mikkelsen, 1990), and the different results between experiments can probably be accounted for by variations in these factors.

Improvements in irrigation water distribution uniformity can improve application uniformity of water-run fertilizers and other injected chemicals, but such improvements – achieved, for example, by cutting field lengths – are often costly or for other reasons are unattractive to growers. Another way to improve the distribution uniformity of fertilizer in furrow irrigation systems is to delay the injection of fertilizer until the water has advanced some distance down the furrow (Fishbach, 1971). This avoids fertilizer application on the upper end of the field during the period of the most rapid infiltration.

However, a standard reference on fertigation used by industry in California (Burt et al., 1998) recommends against delaying injection of fertilizer or other chemicals in surface gravity irrigation systems. The authors note that properly operated, such systems will generate tail water containing the fertilizer, which then unavoidably will be applied at the beginning of the next field or irrigation set, thus defeating the tactic of delayed injection.

We are conducting field studies to determine the effectiveness and practicality of delaying the timing of fertilizer injection during an irrigation set. Objectives are the following:

1. Investigate the relationship of timing of water-run fertilizer injection during irrigation events on N application uniformity and determine the role of ammonia volatilization.
2. Develop recommendations for N fertilizer injection timing for soils with different textures or water intake rates.

We report here on the first year results.

Procedures

We conducted on-farm trials in four corn fields in Tulare and San Joaquin Counties in 2005 – four with coarse-textured soils and one with clay or clay loam texture and ranging in length from 1000 to 2000 ft. The experiments were conducted when corn plants were small, so that the advancing furrow water could easily be seen. At each site, data were collected from a single furrow during each of three furrow irrigation sets on consecutive days. The farmers or their fertilizer suppliers provided a standard anhydrous ammonia tank with the regulator set to provide 40-60 lb N/acre during the normal irrigation. At three sites (T1, SJ1, SJ2), ammonia was injected into a head ditch, and the field was irrigated by siphon pipe. At the fourth site (T2), the ammonia was injected into a stand pipe, and the field was irrigated from alfalfa valves. To carry out delayed fertilizer injection treatments, the anhydrous ammonia tank valve was not turned on until shortly before water had advanced about 50% or 75% of the distance across the field. In order to provide the same total amount of N per acre in the considerably shorter time of injection in the delayed treatments, a higher NH_3 flow rate was used. This required us to guess the time that would be required to finish the irrigation on those sets. During each irrigation set, water flow rate in the furrows was monitored with a flume placed near the head of the field, and advance times for the water were recorded at 100-ft intervals. At 30- to 60-minute intervals, water samples were collected from points along the furrow. Samples were collected in bottles containing a small amount of sulfuric acid so that they were acidified to pH 2. Samples were analyzed for ammonium later in the laboratory. Water pH, air temperature, and wind speed were measured in the field.

To calculate the N application rate along the length of the furrow, we used the water advance data to estimate the coefficients of an exponential infiltration function; in the delayed N injection treatments, we used this same function to calculate cumulative infiltration up to the time that the N fertilizer "arrived", and then by difference we determined the water infiltrated after N arrived. Multiplying water infiltrated by the measured concentration of fertilizer N gave the mass of N applied at each point. This procedure for calculation of water infiltrated is an idealization of the real situation in which infiltration varies spatially depending on soil properties. We chose fields with generally uniform soil texture, so while the application at any one point would be uncertain, the general trend shown by our analysis over the entire furrow length is probably reasonably close to reality.

Results and Discussion

At all sites, ammonium N concentrations in furrow water decreased substantially from the upper to the lower ends of the fields, with decreases ranging from 20 to more than 50%. Some examples of the results are shown in Fig. 1.

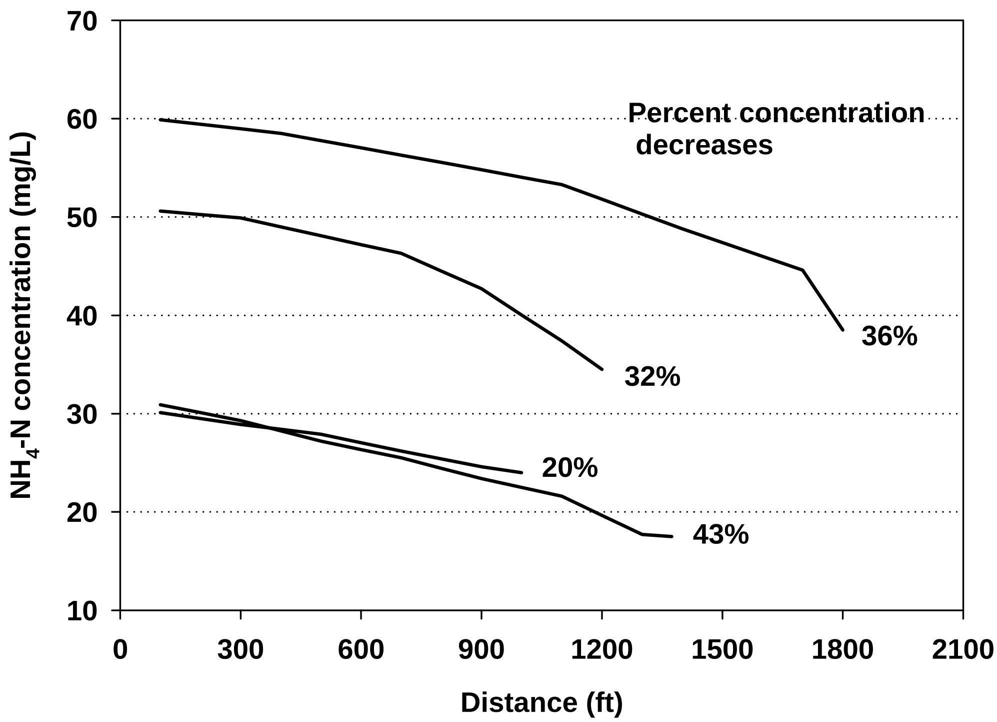

Figure.1. Ammonium-N concentration decreases in furrow water at four locations in the San Joaquin Valley during anhydrous ammonia fertigation. At each site, samples were collected simultaneously at 200-ft intervals shortly before irrigation was completed.

The likely explanation for the decrease is ammonia volatilization. Furrow water pH during NH_3 fertigation in our experiments ranged from 9.6 to 10.0 – which indicates a high potential for volatilization (Jayaweera and Mikkelsen, 1990). When anhydrous NH_3 is injected in water, a dynamic equilibrium is established between ammonium (NH_4^+, an ion) and dissolved ammonia gas (NH_3(aq)). The latter has a high vapor pressure and can volatilize. At pH 7, less than 0.5% of the N is in the NH_3(aq) form, but as pH increases, NH_4^+ loses a proton; at pH 10, about three-fourths of the N in solution exists as NH_3(aq); as it volatilizes, there is a continuing shift of NH_4^+ to the gaseous form. When anhydrous NH_3 is injected in water, the conversion of some of the NH_3 to NH_4^+ causes a large increase in pH. Furthermore, the equilibrium between ammonium and ammonia is sensitive to temperature, with a greater proportion existing in the gaseous form (at a given pH) as the temperature increases. On a hot day, cool water entering the field will become significantly warmer as it travels down a furrow, further increasing the potential for NH_3 volatilization. We observed some cases of this temperature increase and plan to further document it in 2006.

The N application rate at each point along the length of the field is the combined result of the time for infiltration (opportunity time) and the concentration of N in that water. In Fig. 2, examples of the N application distribution patterns at one of the sites (SJ2) are shown. In the continuous treatment (i.e., anhydrous ammonia injected during the entire irrigation set) (Fig. 2a), the opportunity time – and therefore the amount of water applied – decreased from the top to the bottom of the field. The N rate applied decreased proportionately even more due to the combined effect of decreased water infiltrated and N volatilization loss.

In the delayed treatments, in which NH_3 injection was not started until water had advanced 50% (Fig. 2b) or 75% (Fig. 2c) of the distance across the field, the resulting N application distribution is more complicated. For the 50% delay (Fig. 2b), a more uniform N application resulted in the first 600 ft of the run; then at the point where the fertilizer "caught up" with the water, the application rate actually increased over a 300- to 400-ft distance due to the presence of the fertilizer N during the initial very rapid infiltration phase. But in the last 300 ft or so, the decreased opportunity time combined with NH_3 volatilization loss dominated, resulting in a lower application rate. In the 75% delay treatment, the short infiltration opportunity time dominated, and the greater N application rate where N "caught up" with water did not occur until water had almost reached the end of the field.

It can be seen in Fig. 2 that very different amounts of water and nitrogen were applied on the three irrigation sets, even though the irrigations were carried out by the grower on three consecutive days in the same field. We increased the NH_3 flow rate from the anhydrous tank in anticipation of shorter injection periods for the delayed treatments; and the resulting furrow water concentrations (at the head of the field) were 31, 68, and 109 mg N/L for the continuous, delay-50%, and delay-75% treatments, respectively. However, the variation in the total water applied, as well as our inaccurate predictions of the amount of time remaining in the set after starting the fertilizer injection, led to large differences in the average amount of N applied.

Water and nitrogen average application rates and distribution uniformities for this site and the other three are shown in Table 1. Distribution uniformity (DU) is defined as the rate applied to the quarter of the locations in the field receiving the lowest amount as a percent of the average amount applied to the entire field. (We are using data from a single furrow to represent the "entire field".) At site SJ2, the continuous and delay-75% treatments showed similar irrigation amounts and water distribution uniformities (DU), but the DU for N application was much better for the delayed treatment. At site SJ1 (clay soil), comparisons are not straightforward due to the variation in irrigation DU values among treatments. But even though the irrigation DU values were much lower for the two delayed treatments (52-55% vs. 89%), the NH_3 application DUs remained high (72-84%).

At site T1, the irrigation ran much faster, and we would not expect a delayed injection to show as much advantage; and in fact, the N application DU value for the delay-50% treatment was even lower than the irrigation DU, in part due to ammonia volatilization loss. The irrigation on the delay-75% treatment went so fast (and unexpectedly so), that the irrigation was nearly completed when fertilizer injection was begun, and as a result only 4 lb N/acre were applied.

Conclusion

First-year results were affected by several non-treatment factors, including unequal irrigation set times among treatments and inability to deliver the desired fertilizer nitrogen to the measurement furrow at the right time and concentration. We plan to conduct similar experiments in 2006 and are investigating field research procedures and equipment to allow better control of N fertilizer injection timing and rate and to achieve the desired N application target rate. So far, the results, though somewhat confounded by the difficulties, indicate that

- Anhydrous ammonia applied in furrow irrigation water is subject to volatilization loss, resulting in significantly lower (30-50%) N concentrations in water at the lower end of fields 1000-2000 ft long; and these translate into lower N application rates in the lower ~ quarter of the field.
- Delaying injection of N fertilizer may improve N application distribution uniformity where irrigation set times are long and water distribution uniformity is low.

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Acknowledgements

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Table 1. Irrigation water applied and distribution uniformity in anhydrous ammonia fertigation experiment.

Site/Treatment	Irrig set time	Irrigation water Applied	Irrigation water DU	NH_3 fertilizer Applied	NH_3 fertilizer DU
	hours	*inches*	*%*	*lb N/acre*	*%*
T1-sandy loam					
Continuous	6	2.1	73	21.4	60
Delay 50%	6	2.9	67	23.5	74
Delay 75%	5	2.5	86	4.1	66
T2-sandy loam*					
Delay 75%	8	6.2	49	35.7	74
SJ1-clay/clay loam					
Continuous	9	4.8	89	30.0	80
Delay 50%	9	6.5	52	44.2	72
Delay 75%	9	6.1	55	35.9	84
SJ2-sandy loam					
Continuous	7	4.0	87	22.4	64
Delay 50%	7	5.9	63	53.1	61
Delay 75%	7	4.4	80	47.8	89

* At site T2, there were problems with the anhydrous fertilizer injection into the head ditch, and therefore N concentration data from the continuous and "delay-50%" treatments are not included in this report.

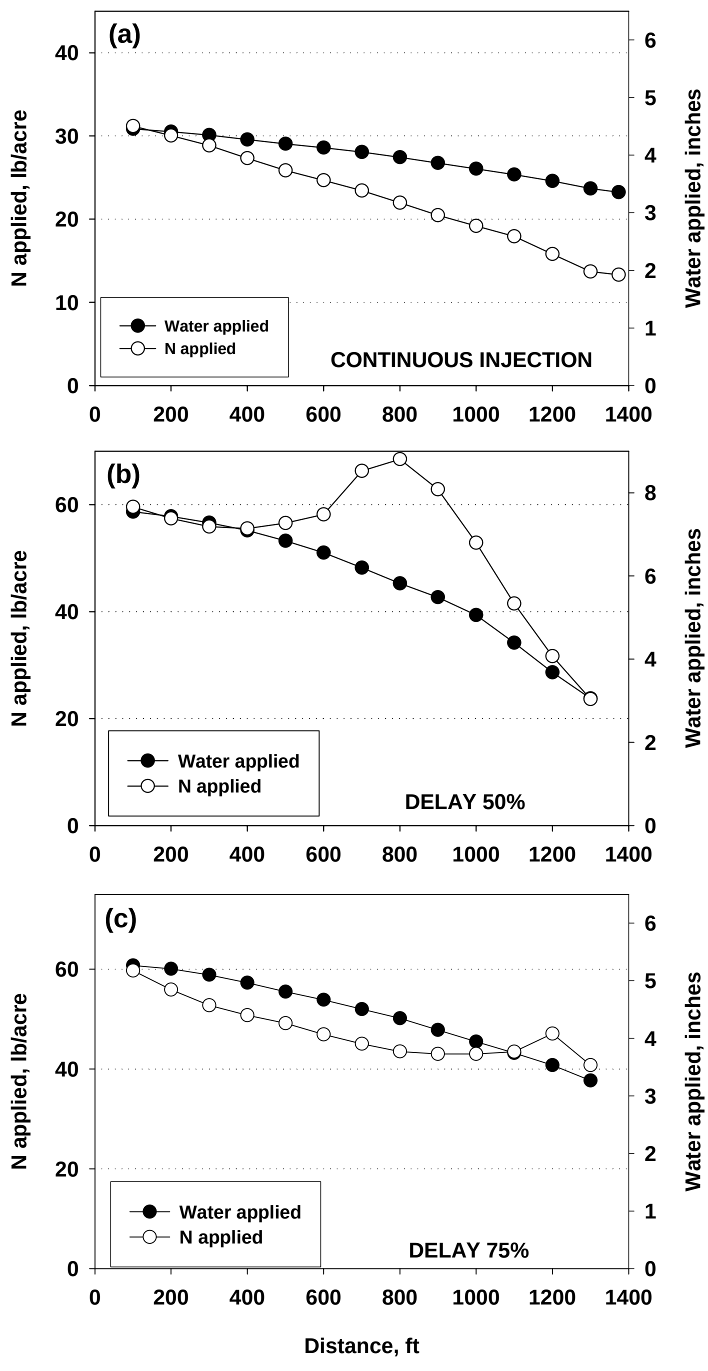

Fig. 2. Irrigation and N application spatial distribution measured down length of single furrow in sandy loam soil for (a) continuous fertilizer injection, (b) delayed injection until water advanced 50% of field length, and (c) delayed until water advanced 75% of field length.

Fate of Soil-Applied Nitrogen Under Irrigated Cotton Production

Felix B. Fritschi, USDA/ARS, Crop Diseases, Pests & Genetics RU,
9611 S. Riverbend Avenue, Parlier, CA 93648
Phone (559) 596-2931, FAX (559) 596-2921, ffritschi@fresno.ars.usda.gov

Bruce A. Roberts, Department of Plant Science, CSU Fresno
2415 East San Ramon Avenue M/S AS 72, Fresno, CA 93740-8033
Phone (559) 278-1758, FAX (559) 278-7413, baroberts@csufresno.edu

Robert B. Hutmacher, Extension Specialist, UC Shafter Res. & Extension Ctr.,
17053 N. Shafter Ave., Shafter, CA 93263
Phone (661)746-8020, FAX (661) 746-1619, rbhutmacher@ucdavis.edu

D.W. Rains and R.L. Travis, UC Davis, One Shields Ave., Davis, CA 95616

In recent years nitrogen fertility management for cotton production has received renewed attention in many parts of the world, including CA. The stated objectives of these studies generally center on increasing yield while maintaining or improving lint quality, and minimizing negative environmental impacts. Many of the studies conducted investigate the effects of amount, timing, and frequency of fertilizer N application usually taking residual soil mineral N into account and in some instances also examining combinations of irrigation and fertilization treatments. The responses examined typically include yield and frequently also crop growth responses. In terms of soil N dynamics, data reported rarely go beyond soil nitrate-N levels in the top 1 m of soil and tend to be restricted to samplings conducted in the spring sometimes including data from samples collected after harvest. While these studies certainly are of agronomic and economic importance for cotton producers, they are by and large not designed to elucidate N dynamics under cotton production in greater detail. The stable isotope ^{15}N can be used as a tool to explore the effects of management options on N dynamics in greater detail and has been employed in a few studies to trace N in cotton production systems.

This report is a synthesis of information collected from studies conducted to reevaluate N fertilization guidelines for CA cotton producers. Here we focus on describing the fate of soil-applied ^{15}N fertilizer in irrigated cotton production in the San Joaquin Valley, CA. Field studies were conducted at two locations: (1) on Panoche clay loam, for both Acala and Pima cotton; and (2) on Wasco sandy loam and for Acala cotton. ^{15}N-labeled urea was applied to microplots at selected N rates. N-level targets, 56 and 168 kg N ha^{-1} in one year and 56, 112, 168, and 224 kg in an other year, were achieved by addition of an amount of fertilizer N equivalent to the difference between target rate and spring soil nitrate-N in the upper 0.6 m of the soil profile. The 15N isotope was used estimate N fertilizer use efficiencies as well as to trace the fertilizer N in the crop and the soil. Average N fertilizer use efficiency as estimated by ^{15}N dilution, varied between 43% and 49% for both Acala and Pima. Fertilizer use efficiencies were not significantly different between N treatments, however, the significant interaction effect of N treatment by location suggests soil-type dependent modulations in the N dynamics. Under Acala production, fertilizer-N recovery in the soil averaged 43% and was not different between the Wasco sandy loam and the Panoche clay loam soils. Fertilizer-N recovery in the soil under Pima production on Panoche clay loam averaged 42%. Fertilizer-N recovery in the soil was not significantly affected by N treatment. Soil samples were collected to a depth of 2.4 m, but most (>75%) of the ^{15}N-fertilize recovered was found in the top 0.9-m soil layer. Recovery of ^{15}N fertilizer in soil and plant combined averaged across all treatments was 89%.

Observations conducted for two additional cotton cropping season following ^{15}N-fertilizer application revealed that Acala recovered only 5.8% in the second year and 3.3% or less in the third year. Most of this ^{15}N recovered by the plants cycled through soil N pools rather than originating from aboveground residue incorporated into the soil at the end of the growing season. One and two years after residue application, ^{15}N contained in the incorporated aboveground plant material remained almost exclusively in the top 0.3-m of soil. In comparison, ^{15}N remaining in the soil (not from above-ground residue) after the first cotton growing season was found mainly in the upper 0.6 m of the soil. At the end of the third cotton season after ^{15}N fertilizer application, 37% of the fertilizer applied in the first season still remained in the top 0.6 m of the soil profile. In light of the relatively low amounts of ^{15}N-fertilizer recovered in the second and third crop after application, it appears that much of this fertilizer was stabilized into more recalcitrant soil N fractions. It is expected that recovery of N from these more stable organic matter pools should occur with only small losses since seasonal mineralization pattern and plant N uptake/requirements are likely to coincide.

Session IV

Site Selection & Development for Trees and Vines

Session Chairs:

Ben Nydem, Dellavalle Labs

Dave Woodruff, Woodruff Ag Consulting

NEW SOIL SURVEY TOOLS FOR PERMANENT CROP SITE SELECTION

Kerry D. Arroues, Supervisory Soil Scientist
USDA, Natural Resources Conservation Service
680 Campus Drive, Suite E, Hanford, CA 93230
Phone (559) 584-9209, Ext. 113; Fax (559) 584-8715
Kerry.Arroues@ca.usda.gov

Introduction

We want people to understand and value soils because soil is important to all of us. Charles E. Kellogg once said that "Civilization has its roots in the soil." The crop that is grown on the land should be guided by the soil that is beneath it. The soil becomes a critical factor when choosing to grow a permanent crop. The decision to plant a permanent crop becomes even more daunting when one considers that, like snowflakes, no two soils are exactly the same. One of the primary references available to help land users determine the potentials and limitations of soils is a soil survey. Soil surveys are available in a wide range of formats—and the list is changing rapidly. In this short paper I will explain some of the more recent advances in accessing soil survey information. I will concentrate on agronomic interpretations that can assist growers who are making decisions related to their soils suitability for prospective permanent crops such as almonds or pistachios.

Sources for access of soil surveys

Soil surveys are still available in book format for a specific soil survey or a county. They are available from the local Natural Resources Conservation Service (NRCS). In the San Joaquin Valley, most areas are covered by a published hard copy soil survey. A hard copy soil survey has been the established method of publication of soil surveys for more than a hundred years. Probably the most prominent feature of the soil survey is the detailed soil map section. In the short-term these maps will continue to be published as hard copy map separates. The rest of the soil survey includes the general soil map with descriptions, detailed soil map unit descriptions, detailed descriptions of each of the soils, tables such as interpretive tables, crop yield tables and prime farmland tables. Many other features are also part of the published soil survey. In the future most of the written information will be available on a CD. Users can create hard copies of part or all of the soil survey as needed. The type of information collected and the use of that information has changed over the years.

There are four internet options that all soil survey users should be aware of:

1. http://websoilsurvey.nrcs.usda.gov for soil survey maps and report
2. http://soildatamart.nrcs.usda.gov for soil data
3. http://soildataviewer.nrcs.usda.gov to create soil-based thematic maps
4. http://soils.usda.gov for information about soils

The following is a brief description of each of these internet options for accessing soil surveys:

1. Web Soil Survey allows online viewing of soil survey maps and reports. This new application greatly enhances access to information on soils.
2. Soil Data Mart allows you to determine where soil tabular and spatial data is available and then to download this data. A variety of reports can be generated.

3. Soil Data Viewer is a tool built as an extension to ArcMap that allows a user to create soil-based thematic maps and access soil interpretations and soil properties.
4. The NRCS Soils Web Site provides a base to launch into a variety of related websites that provide the utility to access other portions of the soil survey. Examples include books such as the National Soil Survey Handbook at http://www.soils.usda.gov/technical; and > 20,000 Official Series at http://www.soils.usda.gov/technical/classification/osd/index.html; and soil lab data at http://ssldata.nrcs.usda.gov.

All of this data can be a massive amount of information to absorb. One way to address this issue is to narrow the scope of the question to one basic question such as the following: Is my soil suitable for growing almonds?

Examples of How to Use a Soil Survey

The following procedure can be used as a guide to determine the answer to this question: What soil characteristics are best suited for a productive almond orchard? For purposes of this exercise lets concentrate on two soil properties—drainage and salinity. Almonds prefer a well drained, non-saline soil. In Kings County where I live, we have a published soil survey that has a good number of hard copies available to anyone who requests a copy. A potential almond grower should first take a careful look at the soil survey that covers the proposed location of the almond orchard. In this exercise we will use a location in Kings County. The following questions can be answered based on the given location:

1. What topographic map quadrangle is this area located on? Answer: Sheet 4, Lemoore
2. What is the map unit symbol at this location? Answer: 121
3. What is the map unit name? Answer: Grangeville fine sandy loam, saline-alkali, partially drained (pages iv or 149)
4. What is the dominant soil and what percentage of the map unit does it occupy? Answer: Grangeville fine sandy loam, saline-alkali, partially drained, 85 percent (page 31 in the Detailed Soil Map Units section)
5. What landform does the dominant soil occur on? Answer: Alluvial fans and flood plains (page 31)
6. What is the natural soil drainage of this soil: Somewhat poorly drained (page 31)
7. What is the depth to high water table? > 48 inches (page 31) and four to six feet (page 207)
8. What is the salinity? Answer: four to eight decisiemens/meter (this is the preferred unit of measure now and is equal to mmhos/cm; page 203 in Table 15—Physical and Chemical Properties of the Soils section)
9. Is the salinity considered a limitation for almond growth? Answer: Yes, it is inferred by the statement "This unit is suited to irrigated crops that are salt- and alkali-tolerant. It is limited mainly by the saline-alkali condition of the soil and by wetness." (page 31)
10. What crops are commonly grown on these soils? Answer: Cotton, barley, safflower, alfalfa hay (page 151 in Table 5—Yields Per Acre of Irrigated Crops)
11. What are the Land Capability class and Storie Index of this soil? Answer: 2w-6 (page 31) and 48 (page 155).
12. What is the clay content of the surface layers? Answer: 8-18 (page 203 in Table 15—Physical and Chemical Properties of the Soils)
13. How many acres of this map unit are in the survey area? Answer: 6,665 acres (page 149 in Table 4—Acreage and Proportionate Extent of the Soils)

Soil Properties
There are many soil properties that affect a soil's behavior for growing an almond orchard. The following list includes some of the soil properties related to growing almonds that are detailed in soil surveys: available water capacity, bedrock and other restrictive layers, calcium carbonate, cation-exchange capacity (CEC), drainage class (natural), flooding, high water table, organic matter, permeability, reaction (soil pH), rock fragments, root restrictive layers, salinity, sodium adsorption ratio (SAR), slope and soil texture (USDA). Since we are concentrating on drainage and salinity as it relates to growing almonds we will discuss our example from the Kings County Soil Survey.

The natural drainage of Grangeville soil is somewhat poorly drained. The definition found in the Glossary on page 137 states that somewhat poorly drained soils "are wet close enough to the surface or long enough that planting or harvesting operations or crop growth is markedly restricted unless artificial drainage is provided. Somewhat poorly drained soils commonly have a layer with low hydraulic conductivity, a wet layer high in the profile, additions of water through seepage, or a combination of these." In our example from the soil survey the depth to a high water table is four to six feet. According to the soil survey on page 31 "This soil is considered to be partially drained because of the dams and reservoirs in the Sierra Nevada, pumping from the water table, tile and interceptor drains, and filling and leveling of the sloughs in the vicinity."

The salinity is four to eight decisiemens per meter according to the soil survey Physical and Chemical Properties of the Soil Interpretations Table. This would be a severe limitation for growth of a successful almond orchard if the salinity is actually this high now. It is important to note that salinity is a transitory feature and that we completed this soil survey in 1980.

This almond orchard is projected to be planted on an area less than 30 acres in size. On-site investigation and lab analysis will be necessary to determine more specifically whether planting this site to almonds will be a good investment with respect to the soil properties. Soil lab analysis indicates an increase in soil salinity with depth. The salinity of the soil at a depth of three feet is 2.6 decisiemens per meter which is less than the four which was described in the soil survey. The sodium adsorption ratio is 17. Some areas of this field are likely to have higher levels of salinity in the top three feet of soil. On-site investigation revealed a highly stratified soil with textures ranging from fine sandy loam on the surface to silt loam and loamy sand in the underlying material. Reddish brown redoximorphic features beginning as high as 16 inches, indicating past or present standing water, are present in several strata with a current high water table around six feet.

There are excellent references that illustrate the relative yield of various crops as a function of soil salinity. In the "Pistachio Production Manual, Fourth Edition, 2005" yield reduction for almonds for various electrical conductivity (EC) is clearly shown. At an EC of four decisiemens per meter this chart shows approximately a 50 percent reduction in yield (Ferguson, et. al, 2005). This is the kind of yield reduction that might take place in this field when the almonds are mature and send roots deeper in the soil profile. If these soils were planted with pistachios the predicted results would be much more positive since the salt tolerance of pistachios is close to that of cotton (Ferguson, et. al, 2005).

This is a simplified actual example illustrating how utilization of a soil survey and on-site investigation and lab analysis can work together to assist growers with making an informed decision before planting a permanent crop.

Tips to Help Avoid Misusing Soil Surveys

1. Make sure you know where your property is and where it is located on the map.
2. Remember the scale since most soil surveys are published at a scale of 1:24,000. Enlarging the soil maps creates a sense of increased precision that is not realistic. The soil maps are designed for a certain level of planning. More detailed planning requires on-site investigations. When soil surveys become digitized, it is even easier to have this kind of misuse.
3. Be aware of inclusions or minor components. Inclusions or minor components are described in the map unit descriptions. A small project or practice may be located entirely on an inclusion.
4. Read the book—don't just copy the description. As demonstrated, many important properties of the soils are described in the soil survey. Just reading the name of the soil series or map unit does not tell you all you need to know about it.
5. Learn the meaning of slight, moderate and severe and limitation values. A severe rating does not mean that a practice cannot be done, only that it may cost more to implement and may carry high risk. For example, you can build your house in a flood plain, but you may have to replace it once in awhile.
6. Ask for help. It is not expected that everyone will understand everything about the information in the soil survey report.

GIS Thematic Maps

Newer soil surveys such as the Fresno County, Western Part Soil Survey will usually have numerous GIS thematic maps that can be very useful when choosing sites for permanent crops such as almonds and pistachios. The Fresno County, Western Part Soil Survey will include GIS thematic maps for the following themes that can be used to assist in choosing soil types that are conducive to permanent crop selection: General Soil Map, Dominant Landforms, Dominant Natural Soil Drainage Class, Salt-Affected Soils, Sodium-Affected Soils and Minimum Depth to Water Saturation.

Summary

There is a significant amount of information about soil that is easily accessible in the older book version copy as we have illustrated with this example from the Kings County Soil Survey that was written in 1980. All of the information and data mentioned previously is still available. Some soil surveys are in book form and are also available in various forms, including online versions, for example, the Tulare County, Western Part Soil Survey is available as a hard copy book and online at: http://www.ca.nrcs.usda.gov/mlra02/wtulare.html.
The Fresno County, Western Part Soil Survey maps and data I recently completed are available at the web soil survey website. These three soil surveys, Kings, W. Tulare and W. Fresno Counties are all available in varying formats and they are indicative of the many ways to access soil survey information.

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Trees Ain't Cotton! Guidelines for Transitioning from Agronomy to Pomology

Robert H. Beede, University of California Farm Advisor, Kings and Tulare Counties
680 North Campus Drive, Suite A, Hanford, California 93230
Phone (559) 582-3211, Extension 2730, FAX (559) 582-5166, bbeede@ucdavis.edu

Introduction

In the 27 years I have worked in grapes, tree fruit and nut crops, I have lost track of the number of farm calls paid to top-notch agronomic crop farmers now planning to "take the plunge" into tree crops. There is no question they know how to farm, because they have done well enough over the years to afford the huge initial investment needed to establish a long-lived perennial and wait four to six years before the first crop is harvested. However, it is this well developed row crop skill set that often makes it very difficult to advise them on the transitions they face in tree production and the importance of executing them with the intensity they applied to their former crops. This paper briefly outlines the factors to be considered in successfully making this expensive and risky transition.

Know your Ground

The fact that your future orchard soil produces four-bale cotton is not the standard by which to measure its potential for high tree yields. Granted, it says something about soil quality, but most agronomic crops are substantially more salt tolerant than trees, with the exception of pistachio. They have recently been shown to tolerate total salt levels (EC_e) of at least 5 ds/m in the soil and 4 ds/m in the irrigation water. In contrast, almonds can be adversely affected by EC_e's above 2 ds/m, depending upon the concentration of specific cations represented in the saturation extract. For example, exchangeable sodium percentages (ESP) greater than 5 can negatively affect almond productivity. Other elements of concern are boron and chlorides. Salt content of the irrigation water should not be above 1.1 ds/m. Therefore, not knowing the salinity tolerance of your selected tree crop and the soil chemistry of the planting site can be the perfect recipe for transition disaster.

It therefore is of critical importance for transition growers to consult their local soil survey and dig backhoe pits to physically examine their soil with someone knowledgeable about the requirements of your intended tree crop. Backhoe pits allow identification of stratified soil horizons (layering), assessment of perched water tables, and selected soil sampling for salinity evaluation within the future root zone. Land used for row crops often has compaction and salinity accumulation at about three feet. This is the result of cultivation and soil water extraction patterns associated with cotton, corn, and alfalfa rotation cycles. Soils typically used for agronomic crops are also usually located near the edge of floodplains or alluvial fans. These soil types can have considerable texture differences with depth. Failure to homogenize them by slipplowing as deeply as six feet can adversely affect root development and water movement through the future tree root zone. Many new tree growers have ignored the need to aggressively modify layered soils and instead, performed chiseling common to preparing for another season of row cropping. The result can be shallow root development and susceptibility to blowover, soil water saturation within the root zone from restricted movement, uneven tree growth, shortened tree life, and less than optimal production.

In areas with suspected high water tables, backhoe pits should be left open overnight to allow accurate assessment of effective rooting depth. Observations of soil profiles may also influence decisions on the irrigation system selected. Shallow, sandier soils may be best farmed with drip or mini-sprinklers rather than flood, especially if water costs are high. In summary, the value of backhoe pits should not be overlooked. They are the single greatest investment a grower can make to insure identification of problems before tree establishment.

Know Yourself

We all have strengths and weaknesses. The grower transitioning to tree crops will greatly benefit from having a plan for capitalizing upon their strengths and obtaining professional assistance in areas where one is less capable. If you are a great mechanic or bookkeeper, it may be an unnecessary cost to farm those out. However, if you have never designed an irrigation system or laid out an orchard, now is the time to quickly admit assistance is needed for project success. This self-assessment applies to the following multitude of new issues faced by growers changing from row to tree crops:

1. What resources am I going to use to make all these new decisions on what to plant, nursery source, soil modification requirements, orchard design, irrigation system, planting method, and initial tree care?
2. Where do I plan to acquire the technical knowledge or expertise needed for irrigation management, pest and disease control, nutrition, tree training, and problem identification?
3. To what degree do I wish to be technically capable of participating in these new management decisions? How am I going to acquire this expertise? How much time is it going to take from my other responsibilities?
4. How much decision-making do I want to do, and what do I wish to delegate? How do these allocations affect the potential success of my planting? How do I assess the quality of the decisions I delegate to others?
5. Who is going to be in charge of record keeping, so that we know what we did, when we did it, and how much it cost?
6. How am I going to develop or acquire the skilled labor force to execute my management plan? Can my existing employees be successfully retrained to carry out most of my needs?
7. Who do I wish to involve in assessing at the end of the season what worked, what did not and why?

   Granted, these are all things, as a farmer, that you presently do. However, you are now performing them on a crop you are unfamiliar with. What you used to perform routinely with confidence, is now contemplated and discussed. With the row crops, you knew exactly what to expect and look out for, but now you must rely upon newly acquired knowledge and professional support to avoid getting caught off guard. The result of these new challenges is stress, because the economic ball you are rolling is a sizeable one. Having a plan in place to address the above issues will help secure your success and hopefully reduce the daily turmoil.

Timing , Execution, and Communication: Keys to Success

When it came to the cotton, you knew when to plant, how you wanted to prepare your beds, the depth to plant, and all the other scores of activities necessary to produce large quantities of high quality cotton. The timing and execution of these events was second nature and you knew the "window" available for accomplishing them successfully. Now, that has all changed. You must learn "new windows" for tasks such as dormant spraying, insect and disease management, fertilization, orchard floor weed control, tree training, and harvest, to name a few. Attempting to apply your old windows to your new crop without understanding its fit can cause you trouble and frustrate those you have hired to assist you in your transition. An example would be mite management. Having looked at the orchard yourself, you decide that "the mites aren't too bad" based upon your experience in row crops, and begin to irrigate without first communicating with your pest consultant. You are therefore unaware that his presence/absence sampling shows the mite population has risen significantly in the past seven days, and predation is low. He has already made arrangements to treat, but is dumbfounded to find the water running upon his arrival. This scenario is common among new and experienced tree farmers. Whether the cause is ignorance or poor planning, the result is the same; poor timing, execution, and communication places your new, expensive tree crop at greater risk, and makes the banker nervous. Much of this can be avoided by having a plan and following it. Creating well-defined lines of authority, responsibility, and communication greatly facilitates timely and proper execution of new farming events. It is the same framework that made you a successful agronomic farmer.

Conclusion

Making the transition from agronomic to tree crops is costly, stressful, and mentally demanding. These challenges in no way reflect a lesser skill set, but simply a different one! Rapid recognition of these differences allow the transitioning farmer to assimilate perennial plant technology and apply it to their benefit, rather than being met with the frustration and disappointment of discovering "what you should have done" after it is too late. Acquisition of this new knowledge involves identification and utilization of reliable information sources, establishment of effective working relationships with service-providing professionals, and application of one's farming experience to address and resolve key issues faced during the transition. The result can be exciting, satisfying, and profitable!

Soil and Water Quality for Trees and Vines

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

Introduction

Declines in row crop commodity prices, increases in water and land costs have fueled rapid conversion of older farms into housing developments and pushed growers to consider more marginal soils for permanent crop plantings. A basic understanding of soil and water quality parameters, tolerance limits and amendment strategies is important to achieve a profitable result.

Evaluating soil physical characteristics

Orchards with soils that vary from sands to clay texture are subject to variable water stress across the orchard because of different water-holding capacities of the soils. Layers of different soils in the rootzone can cause water logging by slowing water movement through the root zone and creating temporarily saturated soil layers. These injure roots by depriving them of oxygen and enhancing conditions that favor root diseases. Some subsoil layers can form physical barriers to roots that simply cannot grow through hard, dense, or compacted layers. The result is nonuniform orchard growth and production, especially under surface irrigation where infiltration rates can vary considerably from one area to the next. Evaluation and appropriate modification of orchard soils provides the following benefits:

1) Reduced physical barriers to drainage and root development.
2) Increased uniformity of water infiltration and water-holding characteristics.
3) Improved leaching of excess salts.
4) More uniform and increased vigor resulting in less time to achieve full production.

Soil survey data

The best place to begin your evaluation is with the **USDA Natural Resource Conservation Service soil surveys**. There are 170 published surveys for California alone – starting with the first Fresno County survey in 1900 to the most recent Western Tulare County survey in 2003. Many of these surveys are revisions of earlier surveys, changing and adding to earlier soil series descriptions. The surveys published since 1970 have the best maps (Plate 1.) and soil series detail.

On-line access: Unfortunately, only a small number of these surveys are available online. Use the following links to obtain information:

List of all California soil surveys:
http://www.soils.usda.gov/survey/printed_surveys/california.html

Full surveys published online:
http://www.ca.nrcs.usda.gov/mlra02/
Colusa County, Intermountain Area, Mendocino County (Western), Napa County, Santa Cruz County, Stanislaus County (Western), Tulare County (Western), Yolo County

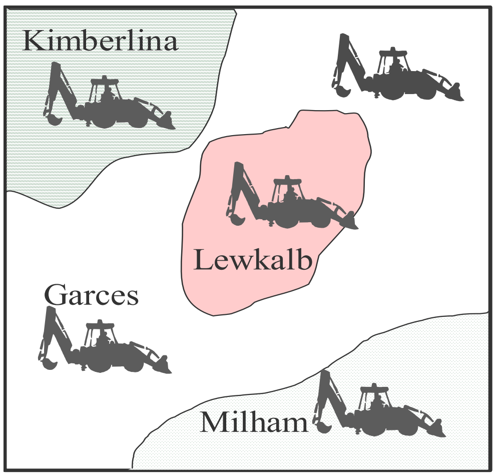
For georeferenced spatial and tabular data available for California (more difficult to access and requires use of GIS software):
https://soildatamart.nrcs.usda.gov/County.aspx?State=CA

For locating NRCS offices in the US:
http://offices.sc.egov.usda.gov/locator/app

For most areas it may be necessary to contact the local NRCS office and consult the area conservationist and a paper hard copy of the survey. Most current surveys are supposed to be online by 2008.

Identifying physical limitations

The soil survey, along with aerial images and personal observation of row crops previously grown in the field is very useful for identifying "zones" that should be sampled and viewed separately. Commercially available equipment (i.e. EM-38 and VERIS equipment) that use electromagnetic or conductivity sensors and global positioning systems technology can also map soil variability. When properly calibrated, the sensors detect changes in soil salinity and major differences in water holding capacity. The diagram illustrates the potential variation one might find in a possible 160 acre orchard development in Western Kern County.



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 to what depth tillage is required. One alternative to backhoe pits is the use of a soil probe to pull undisturbed soil cores for evaluation. Special equipment is required for this option if you want to examine the profile down to six feet and it must be done 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.

Evaluating soil and water salinity/chemical characteristics

There are two basic philosophies for sampling soils and water to diagnose and manage salinity/quality problems

(1) **Preplant sampling followed by annual or biannual sampling required:** This approach is usually required if marginal soil/water quality is often found in the area being developed.

(2) **Trouble-shooting or infrequent analysis only:** In areas where soils and water are mostly uniform, of good quality and previous crops show no toxicity symptoms, soil and water sampling is only necessary to troubleshoot problems that may appear after planting or when forced to switch water supply.

Regardless of which approach you chose, soil and water sampling must reasonably represent the average condition for the area of concern for the analytical results to be of value. Results from unrepresentative sampling (i.e. soil pulled from just one or two backhoe pits) may be misleading and costly. Although obtaining representative, composite samples involves some effort and expense, it should not require more than 8 hours of labor and $550 ($7/acre) in lab fees every one or two years for an 80-acre orchard or vineyard. The Table 1 describes the salts and ranges typical for ag.

Table 1. LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS

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

(This publication is one of the most extensive references on water quality and can be downloaded for free at the above website.)

Water parameter	Symbol	Unit[1]	Usual range in irrigation water	
SALINITY				
Salt Content: Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or) Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	meq/l	0 – 20	meq/l
Magnesium	Mg^{++}	meq/l	0 – 5	meq/l
Sodium	Na^{+}	meq/l	0 – 40	meq/l
Carbonate	CO^{--}_3	meq/l	0 – .1	meq/l
Bicarbonate	HCO_3^-	meq/l	0 – 10	meq/l
Chloride	Cl^-	meq/l	0 – 30	meq/l
Sulphate	SO_4^{--}	meq/l	0 – 20	meq/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(meq/l)[1], [2]	0 – 15	

[1] dS/m = deciSiemen/meter in S.I. units (equivalent to 1 mmho/cm = 1 millimmho/centi-metre)

mg/l = milligram per litre ≃ parts per million (ppm).

meq/l = milliequivalent per litre (mg/l ÷ equivalent weight = meq/l); in SI units, 1 me/l= 1 millimol/litre adjusted for electron charge.

[2] NO_3 -N means the laboratory will analyse for NO_3 but will report the NO_3 in terms of chemically equivalent nitrogen. Similarly, for NH_4-N, the laboratory will analyse for NH_4 but report in terms of chemically equivalent elemental nitrogen. The total nitrogen available to the plant will be the sum of the equivalent elemental nitrogen. The same reporting method is used for phosphorus.

[3] SAR is calculated from the Na, Ca and Mg reported in meq/l ($SAR = Na/((Ca+Mg)/2)^{0.5}$).

Table 2. 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 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.

Water/Soil toxicity ranges

Your irrigation water quality is always the place to begin as this will be the long-term constraint on where your final soil salinity ends up. **In general, the average rootzone soil salinity will be about double the irrigation water salinity with a 15% leaching fraction.** Table 2 to the left gives the general range of no restriction to severe problems for most permanent crops. As a general rule of thumb you can double these numbers for guidelines when checking soil saturation extract analyses.

Pistachios have proven to be the winner for permanent crops when it comes to salt tolerance. Studies in NW Kern County, UC Riverside and Iran have shown that this tree is as salt tolerant as cotton. Most row crops, except for some sensitive veg crops, have no problem tolerating irrigation water at the "Severe" restriction limit in Table 2.

Figure 1 shows almond and pistachio relative yield as a function of salinity ($EC_{soil\ ex}$) in comparison to alfalfa and cotton. (The curve shown is for the UCB1 rootstock, Pioneer Gold was the same or possibly greater tolerance. Symbols on lines are for legend identification and do not represent specific data points.)

Water can only move into plant roots by osmosis, which means that the xylem sap in the plant must have a much higher concentration of solutes than the soil water in the rootzone. 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 solutes to maintain crop growth and yield. In general, the plant is good to a certain threshold. As salinity increases above

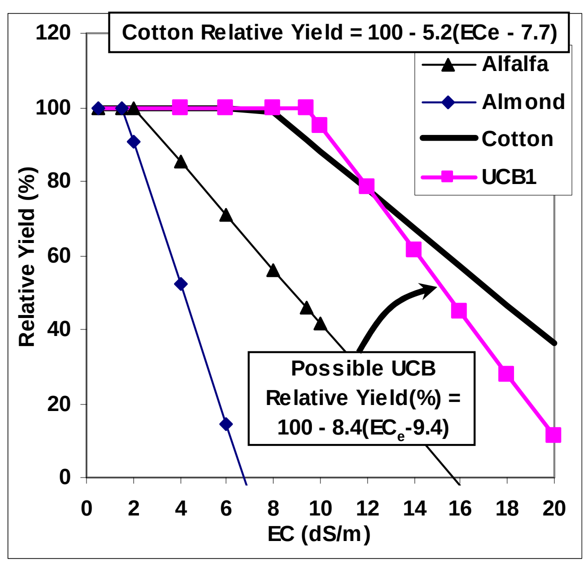


Fig. 1. Relative yield (RY) of various crops as a function of soil EC_e (Sanden, B.L., L. Ferguson, H.C. Reyes, and S.C. Grattan. 2004. Effect of salinity on evapotranspiration and yield of San Joaquin Valley pistachios. Proceedings of the IVth International Symposium on Irrigation of Horticultural Crops, Acta Horticulturae 664:583-589)

this threshold, crop water use begins to decrease and eventually will cause a decline in yield.

Table 3 summarizes EC thresholds and the slope of the yield decline (Relative yield (%) = 100 – Slope(Soil ECe – Threshold EC)), along with specific ion toxicities for various tree and vine crops in California. Many crops, and especially different varieties and rootstocks do not have documented thresholds. Remember, these numbers are guidelines only. The soil texture/mineralogy, drainage/aeration, irrigation system/scheduling and the ratio of certain salts to others will shift these numbers up or down. Rootstock and variety (especially with grapes) can also have a significant impact. 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 times the calcium and the orchard performs poorly.

Table 3. 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, et al., 2004)

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	**9.4**	**8.4**	**20-50**	**20-40**	**3-6**
Plum	1.5	18	S	10-25	0.5-0.75
Walnut			S		0.5-1.0

Correcting water quality with gypsum

The following example calculations show how to estimate the quantity of gypsum required to improve infiltration. (Tables 4 and 5 give detailed information on the chemistry, equivalent rates and comparative costs for calcium and acid-type amendments. The following example refers to these tables.)

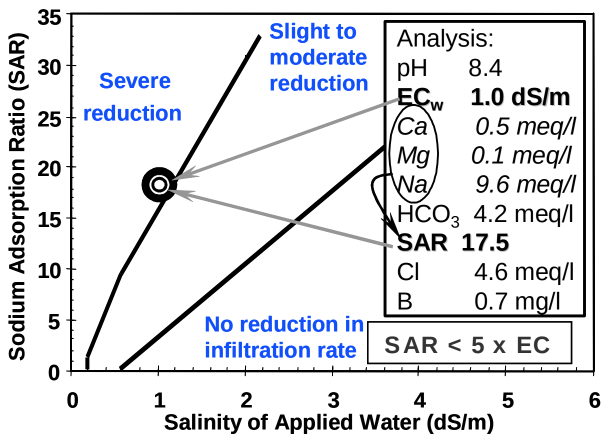


Fig. 2. Estimating potential infiltration problems and determining amendment options from an irrigation water analysis.

Example: calculating gypsum rates

A partial water analysis is shown in Figure 2. This water presents absolutely no salt or ion tolerance problems for the most crops, but the high SAR, especially given the high pH and bicarbonate levels, indicate significant infiltration problems, as indicated by the large black circle in the figure. This means salts can accumulate with little or no leaching and cause problems to sensitive crops like almonds. To achieve good infiltration some of the Na needs to be offset with Ca. You want to treat the water by injecting gypsum. Four steps are required to calculate the right rate:

Example (continued)

1. Determine the purity of the gypsum and the actual lbs/ac-ft needed for 1 meq/l Ca:
   From Table 4, 234 lbs/ac-ft @ 100% = 1 meq/l If the solution gypsum purity ~ 92%:
   234 / 0.92 = 254 lb/ac-ft/meq/l Ca
2. Use desired application rate to calculate additional Ca and new water EC:
   (500 lb/ac-ft) / 254 ≈ 2 meq/l
   New EC = 1.0 + 0.2 = 1.2 dS/m
3. Calculate the new SAR = $Na/((Ca+Mg)/2)^{0.5}$
   SAR = $9.6/((2.5+0.1)/2)^{0.5}$ = 8.4
4. Locate the intersection of the new SAR and EC on the infiltration chart (as shown in Figure 2).

You can see that adding another 250 lbs/ac-ft (a 50% increase) gives a very small additional infiltration benefit and is not cost effective.

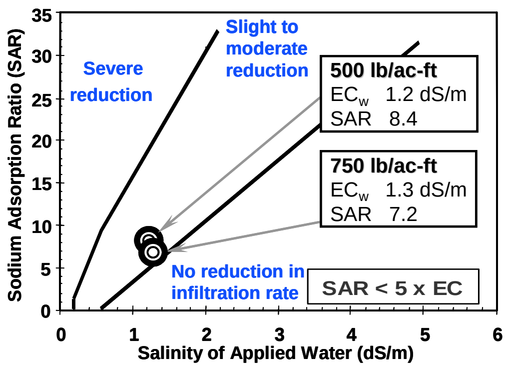


Fig. 3. Revised infiltration potential after gypsum amendment to irrigation water for 500 and 750 lb/ac-ft injection rates.

Practical field application example
(using above water)

Field size / system:	80 acre, single-line drip
Application rate:	0.45in/day
Flowrate:	700 gpm, 3.12 ac-ft/day
Required gypsum over 80 acres:	1,556 lb/day
Net gypsum application:	19.4 lb/ac
Total injection days for 25 ton silo:	**32 days**
Total season 100% gypsum:	**622 lb/ac**
(Using Table 4)	
Cost of solution gypsum:	**$29.50**
Cost of 2 t/ac pit gyp, applied:	**$59.90**

For most field settings, it is rarely necessary to inject gypsum all the time. Most growers will inject every other or every third irrigation (as would be the case in the above example) – often ending the season with a total application of 600 to 1000 lb/ac of 92% gypsum. This may or may not be sufficient for your ground, but even if you doubled the application frequency in the previous example, the cost of the 1,200 lb/ac high quality bulk gypsum would be the same as 2 ton/ac pit gyp applied during the dormant season. And the benefits of gypsum injection during the season are virtually always superior to dormant season applications.

Table 4. Amounts of amendments required for calcareous soils to replace 1 meq/l of exchangeable sodium in the soil or to increase the calcium content in the irrigation water by 1 meq/l.

Chemical Name	Trade Name & Composition	[a]Pounds/ Acre-6" to Replace 1 [b]meq exch Sodium	[a]Pounds/ Ac-ft of Water to Get 1 meq/L Free Ca
Sulfur	100% S	321	43.6
Gypsum	$CaSO_4 \cdot 2H_2O$ 100%	1720	234
Calcium polysulfide	Lime-sulfur 23.3% S	1410	191
Calcium chloride	Electro-Cal 13 % calcium	3076	418
Potassium thiosulfate	KTS -- 25 % K_2O, 26 % S	[c] 1890 3770	[c] 256 513
Ammonium thiosulfate	Thio-sul 12 % N, 26 % S	[d] 807 [e] 2470	[d] 110 [e] 336
Ammonium polysulfide	Nitro-sul 20 % N, 40 % S	[d] 510 [e] 1000	[d] 69 [e] 136
Monocarbamide dihydrogen sulfate/ sulfuric acid	N-phuric, US-10 10 % N, 18 % S	[d] 1090 [e] 1780	[d] 148 [e] 242
Sulfuric Acid	100 % H_2SO_4	981	133

[a] Salts bound to the soil are replaced on an equal ionic charge basis and not equal weight basis. Laboratory data show an extra 14 to 31%, depending on initial and final ESP or SAR, of the amendment is needed to complete the reaction
[b] The meq of exchangeable sodium to replace = Initial ESP – Desired ESP x Total meq/100 grams soil Cation Exchange Capacity.
[c] Assumes 1 meq K beneficially replaces 1 meq Na in addition to the acid generated by the S.
[d] Combined acidification potential from S and oxidation of N source to NO_3 to release free Ca from soil lime. Requires moist, biologically active soil.
[e] Acidification potential from oxidation of N source to NO_3 only.

Acids and acid-forming materials: Commonly applied acid or acid-forming amendments include sulfuric acid (H_2SO_4) products, soil sulfur, ammonium polysulfide, and calcium polysulfide. The acid from these materials dissolves soil-lime to form a Ca salt (gypsum), which then dissolves in the irrigation water to provide exchangeable Ca. The acid materials react with soil-lime the instant they come in contact with the soil. The materials with elemental sulfur or sulfides must undergo microbial degradation in order to produce acid. This process may take hours or years depending on the material and particle size (in the case of elemental sulfur).

Water-run acid: The water used for the Fig. 2 gypsum example would be a good candidate for acidifying amendments. Starting in the late 1950's sulfur burners were used to meter ground elemental sulfur into a small furnace. The burning produces sulfur dioxide which combines with water trickled through the machine to make sulfuric acid which is then injected into the irrigation water. In recent years, better pumps and safeguards have been developed to inject concentrated sulfuric acid directly.

Returning to our example water: you can see that the pH is quite high (8.4) and the bicarbonate, HCO_3, is 4.2 meq/l. If you add gypsum to this water and run it through a drip system you will significantly increase your chances of plugging the system with lime precipitate. Chances are that the soil to be irrigated with this water is also alkaline. If the soil pH>8, acidification of this water and/or the soil may be beneficial to crop growth. Neutralizing the HCO_3 will definitely increase free Ca in the soil/water matrix and improve infiltration. Using Table 1 we see that it takes 133 lbs/ac-ft of 100% pure sulfuric acid to release 1 meq/l Ca. (This assumes the acid contacts lime, $CaCO_3$, in the soil neutralizing the carbonate molecule and releasing the Ca^{2+}.)

This is the same amount of acid required to neutralize 1 meq/l of HCO_3 in the water. For our example water; you then need 4 x 133 = 532 lbs/ac-ft of 100% sulfuric acid. Additional acid drops the pH rapidly and you should have a "pH stick meter" or use a swimming pool test kit to make sure you know how much acid can safely be added to the water to avoid pH < 4.5. Damage to brass valves and other irrigation components can occur when pH<4.5.

Table 5. Approximate bulk purity and moisture content, field tons required and applied cost/acre for various calcium supplying amendments to provide for a 1 to 4 ton/ac 100% pure gypsum requirement. (Costs determined for Kern County, Fall 2005.)

				Field Tons & Total $/ac to Meet the Below 100% Gypsum Requirements					
	Average Purity	Average Moisture	Approx	1 ton/ac		2 ton/ac		4 ton/ac	
Amendment	(%)	(%)	Cost/Ton	Tons	*$	Tons	$	Tons	$
Westside Pit Gypsum	50	8	$14	2.17	**65**	4.35	**123**	8.70	**246**
'Lima' Gypsum (Ventacopa)	75	4	$23	1.39	**59**	2.78	**105**	5.56	**207**
Bulk Solution Gypsum[1] (dlvd)	92	3	$95	1.12	**106**	2.24	**213**	4.48	**426**
Ground Wallboard	92	5	$27	1.14	**55**	2.29	**98**	4.58	**189**
Soil Sulfur ("popcorn")[2]	99	6	$85	0.20	**32**	0.40	**51**	0.80	**89**
Soil Sulfur (granular)[2]	99	2	$90	0.19	**32**	0.38	**51**	0.77	**90**
Sulfuric Acid (applied)[2]	98	NA	$120	0.58	**76**	1.16	**151**	2.33	**302**
Thio-Sul[1,2] (delivered)	N-12, S-26	NA	$160	0.47	**80**	0.94	**160**	1.88	**319**
Lime Sulfur[2,3]	Ca-6, S-23	NA	$260	0.67	**194**	1.34	**374**	2.68	**736**
N-pHuric 10/55[1,2] (delivered)	N-10, S-18	NA	$210	0.63	**133**	1.27	**266**	2.54	**533**
Beet Lime[4]	60	10	$12	1.08	**37**	2.15	**60**	4.31	**113**

*Price assumes freight @ $10/ton, spreading (where applicable) @ $13/ac to 3t/ac. [1]Chemigation, no application cost.
[2]Free lime must be present in soil. [3]Some free Ca but soil lime needed for complete reaction. [4]Acid soil only.

Rootstock Selection for Grapevines

Jennifer Hashim-Buckey, Farm Advisor, University of California Cooperative Extension
1031 South Mount Vernon Avenue, Bakersfield, CA 93307
Phone (661) 868-6200, FAX (661) 868-6208, jmhashim@ucdavis.edu

Abstract

Rootstocks are required in many grape-growing regions of the world due to soil pests such as phylloxera and nematodes and various soil problems. This paper will examine the origin of rootstocks and rootstock hybrids, discuss current rootstock breeding and evaluation programs and describe the characteristics of the most commonly used phylloxera and nematode resistant rootstocks.

Introduction

Roots of grapevines host numerous soil pests with phylloxera and nematodes being the most damaging to production viticulture. Grape phylloxera (*Daktulosphaira vitifoliae*), is an aphid-like insect that feeds on damages the roots of grapevines (Grape Pest Management, 1992). It is native to the eastern United States. and was inadvertently exported to France and England on the roots of American grapevines. The pests rapidly spread throughout Europe and before the end of the nineteenth century were responsible for the near extinction of grape-growing in Europe, killing two-thirds of established vineyards on the continent (Pongracz, 1983).

Phylloxera can be found in most grape-growing regions of California, though the incidence is much higher in cooler growing areas where finer-textured soils are prevalent. The pest damages the root systems of grapevines during feeding, causing the actively growing rootlets and mature roots to swell, stunt and eventually dieback. The extent of damage to the root system depends on the severity of infestation, vine age and vigor, soil type, temperature and drainage. For example, vigorous vines or those grown on deep and well drained soils tolerate phylloxera infestations much better than vines that are weak and grown on shallow, heavy and poorly drained soils (Grape Pest Management, 1992). The swellings or galls caused by phylloxera feeding impair the absorption of nutrients and water and affect the vine's overall productivity.

In the warmer regions of central and southern California, and where coarse-textured soils (sand, loamy sand and sandy loam) are prevalent, the root-knot nematodes (*Meloidogyne* spp.) are the most important of the root pests. It is estimated that these nematodes can reduce grapevine yields by as much as 25% (Anwar and McKenry, 2000). Juvenile root-knot nematodes damage the roots directly by penetrating the root tip to establish feeding sites. Penetration and subsequent development within the root results in the formation of a gall. These galls or "knots" may disrupt the root's ability to take up water and nutrients; but just as important the adult female becomes a sink for vine energy (Grape Pest Management, 1992). Additional damage may occur to the root system, since nematode feeding provides an entry site for secondary pathogens.

A common management practice to overcome the damaging effects of both nematodes and grape phylloxera is to use resistant rootstocks (Winkler et al., 1974; Pongracz, 1983; Christensen et al., 2003). Almost all wine, raisin and table grape varieties grown in California are of pure *Vitis vinifera* parentage, and this species is particularly susceptible to attack by both phylloxera and nematodes (Christensen et al., 2003). Resistant rootstocks are derived from other grapevine species or hybrids of other species (including *V. vinifera*). These species have unique resistance mechanisms to the aforementioned pests that may include the ability to exude repellant biochemicals, the presence of physical barriers in the root that prevent penetration, the stimulation of a hypersensitive response that inhibits pest development and feeding, or simply the absence of nutrients required for pest development.

In addition to the level of resistance to present and potential soil pests, rootstock selection should also consider scion compatibility, ease of grafting, site suitability, appropriateness of irrigation practices, trellis design, soil texture, soil depth, soil chemistry (pH, salinity, lime content) and potential vine vigor. The vigor imparted by certain rootstocks is of particular importance as enhanced vigor can cause excessive shading within the grapevine canopy that may result in negative effects on fruit quality and a reduction in bud fruitfulness and yield (May, 1994; Christensen et al., 2003; Peacock, 2005).

American Species Used As Rootstocks or Rootstock Hybrids

There is only handful of grapevine species used as today's current rootstocks or rootstock hybrids of choice. Most of these belong to the genus *Vitis*, which is derived from the Latin word 'viere' 'to attach' alluding to the tendrils and the climbing nature of plants in this genus (Galet, 1998). Without the discovery of phylloxera resistant rootstocks bred from American *Vitis* species (Table 1), the culture of *Vitis vinifera* varieties would be impossible in many important grape-growing regions throughout the world. The following outlines the characteristics of six principal American species (Galet, 1998; Walker, 2003).

Vitis berlandieri. *V. berlandieri* was found in the limestone hills of central and southwestern Texas. This species was imported to France during the late 1800's for rootstock breeding due to its excellent lime tolerance and good phylloxera resistance. It is extremely difficult to root and graft on its own and is used exclusively for hybridization. *V. berlandieri* has been crossed with *V. riparia*, *V. rupestris*, and *V. vinifera* to produce rootstocks with lime tolerance and phylloxera resistance. However, it is susceptible root-knot and dagger nematodes.

Vitis champinii. Also from central Texas, *V. champinii* is thought to be a natural hybrid between *V. candicans* and *V. rupestris*. *V. candicans*, known among the Native Americans as the 'Mustang' grape, is drought tolerant and found in abundance in Oklahoma and throughout Texas and Northern Mexico. *V. champinii* has been used directly as a rootstock ('Dog Ridge' and 'Salt Creek') and has been hybridized to form common rootstocks such as 'Freedom' and 'Harmony.' This species has good lime tolerance, moderate phylloxera and root-knot nematode resistance. *V. champinii* rootstocks can be extremely vigorous in deep, fertile soils and may be difficult to root.

Vitis longii. Known as the 'Gully' grape due to its presence in dry creek beds, *V. longii* is found in Central Texas, Oklahoma, New Mexico and Kansas. This species is easy to root, has good drought tolerance, moderate phylloxera resistance, and some accessions have nematode resistance.

Vitis riparia. Of all of the American *Vitis* species, *V. riparia* is the most widespread. It is found throughout Canada, Texas and Louisana. It is also found from the Rocky Mountains to the

Atlantic. It grows naturally on river banks and is often near moist, fertile soils. *V. riparia* was directly used as rootstock in Europe ('Riparia Gloire'), but does not tolerate calcareous soils. The species has strong resistance to phylloxera, roots and grafts well but does not generally tolerate nematodes. Hybrids of *V. riparia* and *V. berlandieri* are among the most popular rootstocks in the world.

Vitis rupestris. *V. rupestris* is considered a rare species, and its disappearance can be traced to cattle grazing in the Midwest and southern states. *V. rupestris* is distinct from the other species because it is unusually bushy and rarely climbs. It is currently found near gravelly banks of streams in northern Arkansas, Missouri and Tennessee. *V. rupestris* is moderately resistant to phylloxera and grafts and roots well, but it is highly susceptible to nematodes and lacks lime tolerance. The most common pure *V. rupestris* rootstock is 'St. George.'

Muscadinia rotundifolia. Native to the southeastern U.S., *M. rotundifolia* grows throughout eastern Texas and central Arkansas. It is considered to be in a separate genus because it has two additional chromosomes and is morphologically distinct as compared to *Vitis*. Its excellent characteristics of nematode and phylloxera resistance coupled with resistance to many fungal diseases, such as powdery mildew, make *M. rotundifolia* highly desirable in breeding programs. This species does not root directly from cuttings.

Current Rootstock Breeding Programs

While much of the earlier research on rootstocks was devoted almost entirely to phylloxera resistance in wine grape vineyards, the objective of new work by the following investigators is to develop and evaluate rootstocks with broad and durable resistance to nematodes while maintaining desirable horticultural traits for table, raisin and wine grapes (Table 2).

Andy Walker--UC Davis. The Walker breeding program has been developing nematode resistant rootstocks for over a decade. The goals of the program are to develop broad and durable resistance to nematodes and to provide an alternative to '039-16,' a grapevine fanleaf tolerant rootstock (Walker, 2005). Parents of seedlings produced to date were identified to have strong nematode resistance and include *V. candicans*, *V. champinii*, *V. cinerea*, *V. rufotomentosa* and *M. rotundifolia*. *M. rotundifolia* is the central part of the grapevine fanleaf virus resistance breeding program as it has excellent resistance to dagger nematode *(X. index)*, the vector of the virus, and imparts grapevine fanleaf tolerance to the scion variety. All rootstocks are tested against various species of root-knot nematode (including more virulent biotypes) as well as citrus, lesion, pin and ring nematode individually and in combinations. Phylloxera resistance, fungal resistance, drought and salinity tolerance and viticultural traits and also examined. Genetic mapping of resistance mechanisms is a key component of this program (Walker, 2005).

Peter Cousins--USDA-ARS at Geneva, N.Y. The objective of the USDA Grape Rootstock Improvement Program is to breed, evaluate and introduce rootstocks that are resistant to root-knot nematode species, with specific emphasis on the resistance-breaking biotypes (Cousins, 2005).

David Ramming--USDA-ARS, Fresno, CA and Michael McKenry--UC Riverside. The emergence of resistance-breaking biotypes of the root-knot nematode *Meloidogyne arenaria* and undesirable horticultural characteristics such as excessive vigor of existing rootstocks prompted an intensive screening of 520 selections from 1988 to 1992 at the USDA Plant Breeding Station in Fresno, CA (Anwar and McKenry, 2002). The rootstocks '10-17A,' '6-19B,' '10-23B,' 'RS-2,' 'RS-3' and 'RS-9' are products of the screening. The RS series rootstocks are hybridized 'Ramsey' (*V. candicans* x *V. rupestris*) and 'Schwarzmann' (*V. riparia* x *V. rupestris*) rootstocks. 'RS-3' and 'RS-9' rootstocks were released in 2004 to Foundation Plant Services in Davis, California and are already available in limited supply. The 'RS-3' rootstock is a moderately vigorous stock and is resistant to all common root-knot species plus the currently known resistance-breaking biotypes. It reduces ring nematode populations by half and exhibits resistance to dagger (*X. index*) and root lesion nematodes, plus it has useful resistance to citrus nematode. In contrast, 'RS-9' is a lower vigor rootstock with similar nematode resistance characteristics as 'RS-3' except it offers no apparent protection against ring nematode (Hashim, 2004). The '10-17A,' '6-19B' and '10-23B' rootstocks also exhibit resistance to all common root-knot species and resistance-breaking biotypes and have varying degrees of resistance to other nematode species. Of the latter three, 10-17A offers the broadest nematode resistance.

Results from rootstock trials conducted in Kern County and other areas in California indicate that '6-19B' is far too weak (low vigor) to be a suitable table grape rootstock. The rootstocks '10-23B' and '10-17A' were observed in a Kern County vineyard to be of low to moderate vigor and to perform well in terms of yield and quality, particularly for extremely vigorous scion varieties such as the white mid-season seedless variety 'Princess' (Figures 1 and 2). However, it must be noted that the devigorating effect (in the absence of soil pests) of these two rootstocks on 'Princess' may not be observed on other scion varieties. Furthermore, this trial was established in 2002 and different trends may arise as the vines mature (Hashim and Schrader, 2004).

In conclusion, grape rootstocks have played a vital role in production viticulture and are to date the only practical method of controlling the soil pest phylloxera. In reference to the great phylloxera devastation in Europe, the author of *Practical Viticulture* and *Rootstocks for Grapevines*, D.P. Pongracz said, "rootstocks are the foundation on which the culture of *V. vinifera* varieties has been built (1983)." Additional work on rootstocks with broad and durable nematode resistance will provide growers with an even better selection of planting materials. Currently, there is much information available on rootstock suitability for a particular vineyard situation and as advances in rootstock breeding and evaluations are made, deviation in our current information is to be expected. Furthermore, there are many ongoing rootstock trials being conducted by University of California Cooperative Extension (UCCE) farm advisors and these trials continue to provide current information on rootstock performance.

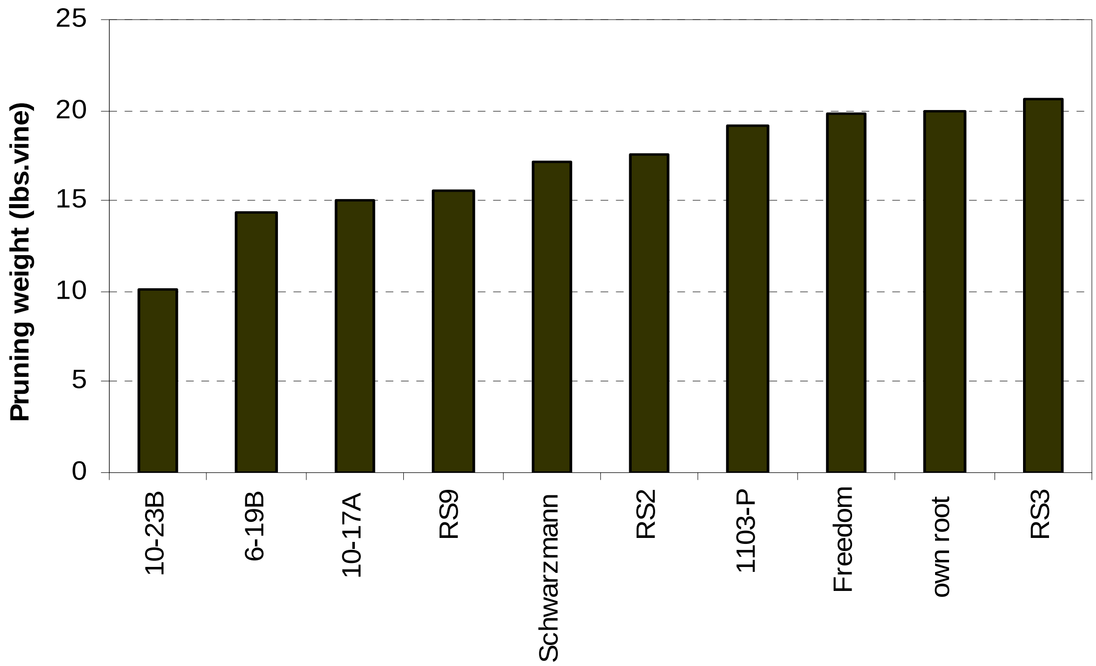


Figure 1. Influence of rootstock on pruning weight for a 2-year old Princess vineyard. Arvin, CA. 2004

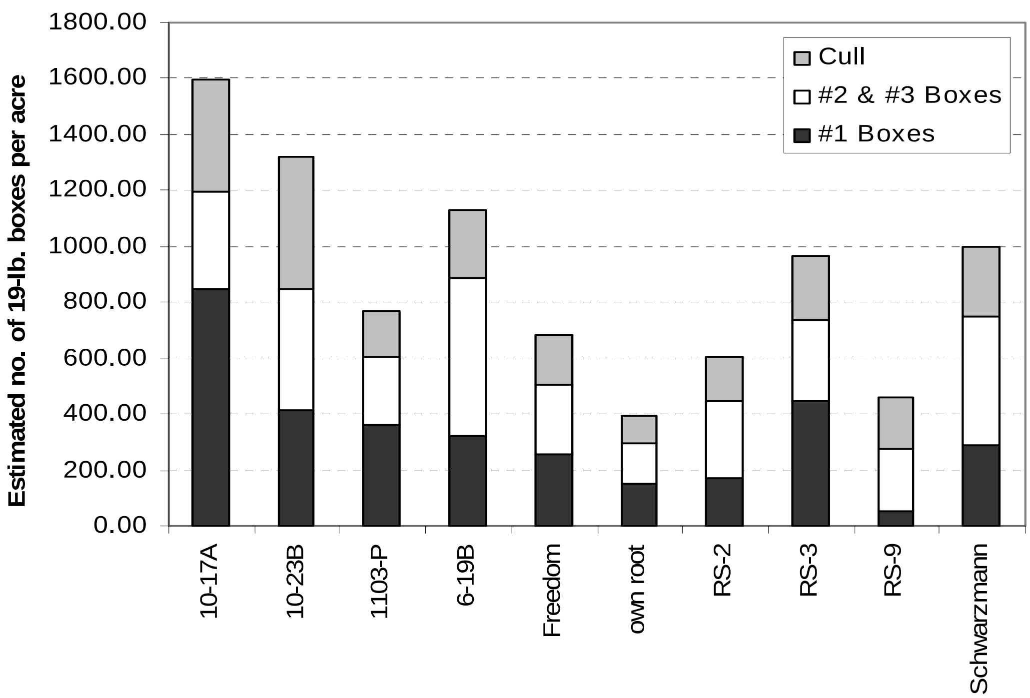


Figure 2. Influence of rootstock on yield (19-lb. boxes per acre) for a 2-year old Princess vineyard. Arvin, CA. 2004

Table 1. Common Phylloxera Resistant Rootstocks[a]

Rootstock	Parentage	Drought Tolerance	Lime Tolerance	Effect on scion: Vigor	Effect on scion: Mineral Nutrition	Other
Riparia Gloire	*V. riparia*	Low	Low	Low-med	N,P: low K, Mg: low med	Adapted to well drained, deep, fertile soils.
St. George	*V. rupestris*	Med-high	Medium	High	N,K: high P: variable	Tolerant to latent viruses. May have problems with fruit set on certain scions.
Kober 5BB	*V. berlandieri x V. riparia*	Medium	Med-High	Medium	N: med-high P,K,Zn: medium	Well adapted to moist, heavy/clay soils.
Teleki 5C	*V. berlandieri x V. riparia*	Low	Medium	Low-med	N: low P,K: med Zn: low-med	Well adapted to moist, heavy/clay soils.
SO4	*V. berlandieri x V. riparia*	Low-med	Medium	Low-med	N: low-med P: med K: med-high	
420A	*V. berlandieri x V. riparia*	Medium	Med-High	Low	N,P,K: low	Well adapted to fine textured, fertile soils.
110R	*V. berlandieri x V. rupestris*	High	Medium	Medium	N: medium P: high K: low-med	Recommended for hill-side vineyards and dry-farmed situations. May induce high vigor on fertile soils.
101-14 Mgt	*V. riparia x V. rupestris*	Low-med	Low-med	Medium	N,K: med-high P,Mg,Ca: low Zn: med	
1616 C	*V. longii* x *V. riparia*	Low	Low-med	Low	N: low K: med-high	Performs well on heavy, water logged soils.
44-53 Malegue	*V. riparia x (V. cordifolia x V. rupestris)*	High	Low-med	Medium	N: low-med P, Mg, Ca: low	Extremely sensitive to low Mg soils

Table 2. Common Nematode Resistant Rootstocks[a]

Rootstock	Parentage	Drought Tolerance	Effect on scion: Vigor	Effect on scion: Mineral Nutrition	Nematode Resistance: Common Root-knot	Nematode Resistance: Aggressive Root-knot	Nematode Resistance: Dagger *X.index/X. americanum*
Freedom	*V champinii x 1613C*	Medium	High	N,P,K: high Mg: medium Zn,Mn: low	Resistant	Highly susceptible	Resistant/ Susceptible
Harmony	*V champinii x 1613C*	Low-medium	Medium-High	N: low P: medium K: high Zn: medium	Resistant	Highly susceptible	Resistant/ Susceptible
Salt Creek (Ramsey)	*V. candicans x V. rupestris*	Medium-high	High	N,P: high K: med-high Zn, Mg: low	Resistant	Highly susceptible	Some Resistance/ Susceptible
Schwarzmann	*V. riparia x V. rupestris*	Medium	Low-Medium	N,P: medium K: med-high Mg: low	Some Resistance	Resistant on older roots	Some Resistance/ Susceptible
039-16	*V. vinifera x M. rotundifolia*	Low	High	N,K: high P: low-med Zn: low	Susceptible	Susceptible	Resistant/ Slightly susceptible
USDA 10-17A	*V. simpsonii x Edna ((V. lincecumii x V. rupestris) x V. vinfera)*	NA	Medium-High	N: high P: low K: medium Zn: low-med	Resistant	Resistant	Resistant/ Slightly susceptible
USDA 6-19B	*V champini x GA-3,4,5*	NA	Low	N: high P: medium K: high	Resistant	Resistance Unstable	Susceptible / Susceptible
USDA 10-23B	*V. doanianna*	NA	Med	N: high P: low K: medium Zn: low-med	Resistant	Resistant	Some Resistance / Susceptible
RS-2	*(V. candicans x V. rupestris) x (V. riperia x V. rupestris)*	NA	Medium-High	NA	Resistant	Resistant	Some resistance
RS-3	*(V. candicans x V. rupestris) x (V. riparia x V. rupestris)*	NA	Medium	NA	Resistant	Resistant	Resistant/ Susceptible
RS-9	*(V. candicans x V. rupestris) x (V. riparia x V. rupestris)*	NA	Low	NA	Resistant	Resistant	Resistant/ Susceptible

[a]Tables adapted from Christensen, L.P., Dokoozlian, N.K., Walker, M.A. and J.A. Walker. 2003. Wine Grape Varieties in California. Publication 3419. University of California Division of Agriculture and Natural Resources. and McKenry, M. 2000. IPM-Based Guidelines for Replanting Grapes in 2000 without Methyl Bromide. Additional information on nematode resistance was provided by Michael McKenry, Department of Nematology, University of California, Riverside and Kearney Agricultural Center.

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Canopy Light Management for Orchards

Kevin R. Day, Tree Fruit Advisor
University of California Cooperative Extension
4437 S. Laspina, Tulare, CA 93274
Phone (559) 685-3303, FAX (559)685-3319, krday@ucdavis.edu

It is only through the design of an efficient orchard system that profits can be maximized. Doing so can be complicated and involves integrating many different factors, issues and concepts. Before discussing other horticultural specifics it pays to keep in mind four essential principles of orchard design:

- The primary goals of a tree are to 1) keep itself alive and 2) to perpetuate the species.
- Grower goals are not necessarily the same as the "goals" of the tree.
- Trees can be viewed as solar collectors that convert sunlight into carbon.
- An acre of ground provides one with access to an acre of sunlight – never more.

A thorough understanding of these general concepts will help lay the foundation for better light management strategies and tactics.

Photosynthesis

It is through the process of photosynthesis that trees convert light and water into carbon and oxygen. Mediating this process are environmental factors including the quality and quantity of light, temperature, overall tree stress. The resultant carbon structures, called photosynthates, can then used to produce shoots, roots or fruits, or to simply maintain the plant. It is important to note that trees usually have an abundance of photosynthates – however, they are not always used to produce fruit. The challenge then becomes in helping the tree use the photosynthates in the most efficient way possible. One of the best ways of doing so is through improving light interception by the orchard and light distribution throughout the tree. To do this requires an understanding of the tree species in question and the planting system in which it is grown.

Orchard Intent – or "What is the Crop?"

There are obvious differences between the various species of fruits and nuts, just as there are obvious differences between fruits. The most striking of these are inherent tree size and potential for harvest mechanization. Walnut trees grow to be a much larger than does a prune tree. Consequently, different management philosophies are needed for each. Virtually all nut trees are mechanically harvested in California, but few fruits are. Those that are mechanically harvested can be allowed to grow larger than hand harvested crops since the issues of worker access and safety are removed from the equation. For this reason, almonds are allowed to grow much larger than their cousin the peach despite having similar vigor and usually being grown on the same rootstock.

Another issue regarding orchard intent is that of maximization of yield vs. the importance of "quality," or some other less easily defined and measured term. Maximizing yield is not always the most effective way to maximize profits. A striking non-orchard example of this can be found in raisin grapes. The training systems used in these vineyards were designed over the years to maximize drying time of trays on the ground. Consequently this solar energy is "wasted" in the sense that it cannot be intercepted by the vine and used to support plant functions. Growers are willing to accept this because the importance of drying the crop during late summer overrides the issue of wasted light energy during the rest of the year. For similar reasons, growers of fresh fruits prune heavily and keep tree sizes down, reducing potential yields, so that crop quality can be increased and labor access improved.

Orchard Design and Tree Form

Rootstock choice, and tree density and configuration are critical issues in orchard design, as is tree species. An acre of land buys access to an acre of sunlight, and the properly designed orchard will intercept and use that sunlight as efficiently as possible. A poorly designed orchard will waste that sunlight – either it will fall uselessly to the orchard floor in too great an amount, or it will be intercepted mostly by the top or periphery of the tree and not penetrate into the middle and lower portions of the canopy. A useful rule of thumb is that a fully leafed-out, hand-harvested orchard should intercept about 75% of available sunlight at any given moment. More than that and shading problems can occur.

A well-accepted axiom of orchard design is that a tree should fill its allotted space as quickly as possible and then maintain itself in that space as easily as possible. During the first several years of orchard life the emphasis should be placed on maximizing vegetative growth – building the ability to intercept light. After that, the grower should try to reduce vegetative growth and bring the tree into a reproductive mode and ensure light penetration and distribution throughout the entire tree canopy. That type of balance is difficult to achieve in the real world however, and is why it is so important to understand the vigor of the species in question, the vigor of the location – both in terms of climate and soil, and the vigor of the rootstock.

Tremendous changes in planting philosophies have occurred over the past 30-40 years in the crops that can be grown on dwarfing rootstocks – the best example of this is in apple. Today it is common to have apple plantings that are as dense as 1200 trees per acre – equivalent to a 3' x 12' spacing. This is vastly different from the long time standard of about 100 trees per acre planted at 20' x 20' or even wider. These high density plantings are attractive in that 1) the trees are usually smaller, and 2) the orchard may reach full bearing more quickly than wide spaced trees simply because the trees do not have to grow as large. Drawbacks include greater orchard cost and more intensive management needs and expertise.

While most apples are gown at more moderate densities such as 300-400 trees per acre, this is an example of a crop that is grown both on a more dwarfing rootstock and more densely than it was 25 plus years ago. Conversely, other commodities such as walnut are now being grown primarily on a more vigorous rootstock – Paradox Hybrid – than in years past because it helps the trees to fill their allotted space more quickly and reach full bearing potential sooner that with other less vigorous rootstocks.

In either instance, the role of light interception is critical. In the small apple trees, it is important to have uniform light distribution throughout the tree canopy so that fruit quality is maximized and fruits are brought close to the ground where they are easy for workers to access. In the larger walnut trees the goal is to fill space quickly so that early yields are maximized. The issue of tree height is made irrelevant by mechanical harvesting, and the most important light interception issue is merely maintaining the proper overall amount. This will of course change as the tree ages – and that is why it is important to have an understanding of how large the average walnut tree will grow, and not to plant the trees at too great a density so that severe tree-to-tree shading occurs.

Tree form or shape includes branch angle, scaffold count, density, and tree conformation. Common tree forms are open center (vase) and central leader (figure 1). In California, the central leader is typically more useful in species that are weaker, since the upright growth habit tends to channel vigor into the single central leader. The vase is best suited for more vigorous species since the flatter, more open form and multiple upper growing points tend to suppress vigor. In addition to these general forms, plantings can be separated into open center and hedgerow systems. Hedgerow systems are usually planted in a north-south orientation and are dependent upon morning light on one side of the tree and afternoon light on the other. During the middle of the day, much of the light energy is wasted in the row centers. Open center systems can be oriented in any direction, and achieve their maximum light interception during the middle portions of the day when light levels are at their greatest, and as long as the centers are kept open, that light tends to be intercepted in both the tops and lower portions of the tree. Regardless of tree form or system, the overreaching orchard goals are the same – the efficient capture and use of sunlight.

Handling the Orchard

Once the orchard has been planted, the greatest weapon in the grower's arsenal for managing light is pruning. An emphasis is often placed on the role of summer pruning in developing, maintaining and improving this relationship, but the importance of dormant pruning should also be appreciated. The dormant season allows growers the opportunity to encounter an ideal perspective on tree structure, limb placement and number, and tree height. A great deal of information can be gained by observing how much of a shadow a dormant tree casts when its leaves are absent. In some instances just the scaffold structure of the tree – in the dead of winter – has the capacity to shade a large percentage of the orchard floor. This can translate into severe shading problems in the next season. Such problems are most apparent in older plum, apricot, and nut orchards, but can occur in any orchard. Much of the time these problems are easily fixed by complete removal of several large secondary or tertiary scaffolds. This action has several benefits including, 1) immediate improvement of light penetration to the middle and lower parts of the tree, 2) reduction in growing points for interior watersprouts and suckers, and 3) reduction in per tree dormant pruning costs. Other tree responses can include a reduction in fruit set and subsequent thinning requirements – which can be either good or bad depending on the season or situation, and improvement in shoot and spur vigor in the middle and lower parts of the tree.

Summer pruning is most commonly practiced in the higher value fresh-shipping crops and can have tremendous effects on fruit quality. It is well known that fruit grown in high light portions of the tree is larger, sweeter, and better colored than fruit in low light areas. This is cause for reflection upon the overall importance of proper orchard design, but summer pruning can be of value in both well and poorly designed orchards. The typical method involves removal of light blocking watersprouts. Performed two to three weeks prior to harvest this can drastically alter the light characteristics of the tree and cause improvements in all fruit quality indices.

Another method of improving tree light environment is to place products on the orchard floor to reflect light back into the trees. Depending on the situation, these products can be of slight to a great deal of help. However, they must be used in conjunction with summer pruning to achieve maximum effectiveness.

Other cultural practices should be evaluated on how they affect orchard vigor and modified accordingly. Fertilizers should be used judiciously or even not at all in orchards that are too vigorous. Also, there are often situations in which applied water can be reduced – especially after harvest – thereby better balancing orchard vigor.

Summary

Efficient light use by an orchard requires balancing vigor and managing the tree form so that light is distributed throughout the canopy. It is also important to keep in mind that the natural inclination of the tree may be somewhat to vastly different than the goals of the grower – for example growing lots of small peaches as opposed to growing a fewer number of high quality fruit. Through an understanding of these relationships a grower can make better decisions about cultural practices so that tree performance is shifted in his favor.

Figures

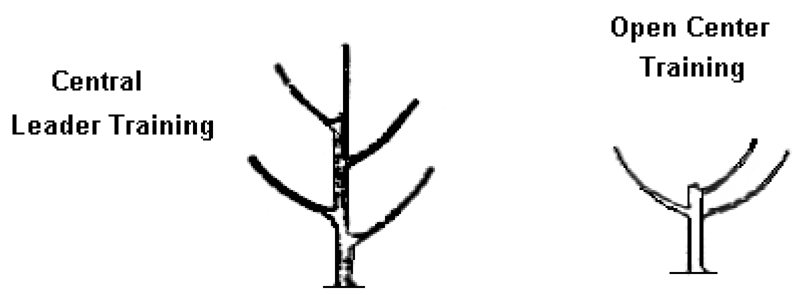

Figure 1. Idealized central leader and open center forms.

Nematodes and Fumigation for Trees and Vines

Becky B. Westerdahl, Extension Nematologist / Professor of Nematology, Department of Nematology, One Shields Avenue, Davis, CA 95616
Phone (530) 752-1405, FAX (530) 752-5674, bbwesterdahl@ucdavis.edu

Nematodes

Plant parasitic nematodes, non-segmented, microscopic roundworms, are a factor that should be considered by a grower planning to plant trees and vines. The nematodes that parasitize and damage trees and vines are less than one tenth of an inch long and are found either in soil or within roots. Nematodes are aquatic organisms. Within the soil, they live and move within the film of water which lines soil pore spaces. They are small enough to move between individual soil particles. It is not uncommon for a single teaspoon of soil from a prune orchard to contain 50 nematodes or for a single inch of feeder root to contain 200.

Nematodes have a relatively simple body structure. When viewed under a microscope, the external covering or cuticle is transparent permitting the viewing of major organs such as the digestive tract and reproductive system. They possess a spear or stylet which is used to pierce and feed on plant tissues.

Plant parasitic nematodes exhibit several different life history patterns. For ectoparasites, all stages of the life cycle are passed outside of roots in the soil. Examples of ectoparasites that are commonly found in orchards or vineyards are ring, pin, and dagger nematodes. For migratory endoparasites such as root lesion nematodes, life cycle stages may be found within roots as well as in soil. Root-knot and citrus nematodes are sedentary endoparasites. The second stage juvenile of root-knot nematode enters a root, takes up a permanent feeding site and then develops to an immobile adult female within the root. The root cells around her head enlarge to form a gall or knot. Knowledge of these life history patterns can be helpful when making management decisions. For example, if endoparasitic nematodes were present in the previous crop in a replant situation, the ability of a fumigant to penetrate into remaining root tissue should be considered. It is not uncommon for an orchard or vineyard to have multiple genera and species of nematodes present.

The nematode life cycle consists of an egg stage, four gradually enlarging juvenile stages, and an adult stage. The length of a single generation varies depending on the species, the soil temperature, and other factors. Under optimum conditions (approximately 65-85 F) four to eight weeks are required for one generation of root lesion, ring, pin, or root knot nematodes. In most growing areas, there can be several generations of these parasites each year. Dagger nematodes, on the other hand, may require a full year. Adult females of all these nematodes can lay several hundred to a thousand eggs apiece.

Nematodes do not typically kill trees and vines. They are plant stressors and act in conjunction with other stress factors in orchards and vineyards to reduce growth and yields. Penetration and movement by nematodes through plant tissues results in mechanical injury to cells and subsequent cell death and necrosis. Mechanical injury interrupts the uptake and flow of water and nutrients from roots and the flow of food from leaves to roots. In addition, nematodes create openings in roots through which other microorganisms can enter. All of the above increase the susceptibility of trees and vines to environmental stress.

Sampling for Nematodes

If a previous orchard or vineyard had a nematode problem, it is highly likely that a subsequent planting will also have problems. Because there are no distinctive diagnostic symptoms or signs, soil and root samples should be taken and sent to a diagnostic laboratory prior to making a decision on preplant nematode treatments. To begin the procedure, visually divide the site into sampling blocks that represent differences in soil texture, drainage patterns, or cropping history. Take a separate sample from each block so that each can be managed separately. Because nematodes are usually not uniformly distributed within a field, it is necessary to take a series of sub-samples from throughout the area to more accurately determine if nematodes are present. In a fallow field, collect sub-samples from several locations within the sampling block. Be sure to sample down to three feet deep if the field was previously in woody perennial crops. In an established orchard or vineyard, collect separate sub-samples from the soil around trees that show symptoms and from the soil around adjacent, healthy looking trees or vines for comparison. Sub-samples should include feeder roots, when possible, and be taken in frequently wetted zones at the edge of the leaf canopy. Because nematodes feed on roots, they are more prevalent in the rooting zone of the crop and this is the area from which sub-samples should be taken.

Mix the subsamples together and place about one quart of the mixed soil and roots into a plastic bag. Seal the bag, place a label on the outside of the bag, keep samples cool (do not freeze), and transport as soon as possible to a diagnostic laboratory. Inform the laboratory of the cropping history of the location and about what you plan to plant so that they can use appropriate extraction techniques. Request a diagnosis to species level if root lesion nematode is found. If dagger nematode is found in a vineyard location, a distinction should be made between *Xiphinema index* and other *Xiphinema* species. Your local Farm Advisor can help you locate a diagnostic laboratory.

During recent years, increasing emphasis has been placed on the development and use of damage thresholds for making management decisions for aboveground pests. For many reasons, it is difficult to establish damage thresholds for nematodes. These include difficulties in obtaining representative samples and variability in extraction methods and efficiencies of different laboratories as well as the many biotic and abiotic factors that influence populations. Once results are obtained from the laboratory, you should discuss them with your local Farm Advisor to determine if any of the nematodes present warrant preplant fumigation.

Preplant Fumigation

Nematicides will not eradicate nematodes from soil. Properly conducted applications will allow as much as six years for healthy root system development before nematode populations increase to damaging levels. Label usage recommendations should be precisely followed in all respects. Planting too soon after application can result in phytotoxicity. Mycorrhizal fungi, which are symbionts and essential to growth of certain crops, can be killed by fumigation. The subsequent crop may not do well until these organisms are restored.

Soil preparation is extremely important for successful use of any of the registered preplant nematicides. For a nematode-infested location that is to be planted following a previous orchard or vineyard, a year-long procedure is suggested to prepare the area for fumigation. Beginning in summer or fall, remove trees or vines along with as many residual roots as possible, destroy plant residues, deep cultivate, and break up cultivation pans and soil layering. Next, during winter and spring, plant deep-rooted grasses (e.g. sudangrass) to help dry the soil and harvest the grass in summer.

If you will be planting in a field following an annual crop, a shorter procedure can be used to prepare the area for fumigation. Plant the annual crop in spring, use it to dry the soil, and harvest it in summer. Following harvest of the grass or annual crop, level the land (if necessary), cultivate, and do other operations required for planting. Finally, in late summer or fall, rip the soil to at least a 24 inch depth. If the subsurface soil is dry, surface clods are a problem, and you are in an area where light rains (less than 1 inch) occur in summer and fall, you may wish to wait to fumigate until after a light rain that would help to break up surface clods.

Prior to fumigation, the soil temperature should be checked at a one-foot depth and the soil moisture at one foot intervals to a five foot depth. This is important because the amount of fumigant that should be used is based on the soil texture and temperature and the percent soil moisture. In general, the finer the soil texture, the more fumigant is necessary. A coarse textured soil (high percentage of sand) has large pore spaces in which the fumigant can disperse more readily than in a fine textured soil which has small pores and dries more slowly. If soil temperatures are too low, the fumigant will not volatilize and move through pore spaces. If temperatures are too high, the fumigant will volatilize and dissipate too quickly. If soil moisture is too low, the fumigant will not move properly and may adsorb to soil particles. If it is too high, the water in the soil pore spaces hinders movement. The Phytonematology Study Guide (UC ANR Publication 4045) contains a chart indicating the amounts of fumigants needed for various soil types and the ranges of temperatures and soil moistures over which they can be successfully fumigated.

Fumigation should be completed prior to November 15 because of the increasing possibilities of heavy rainfall and low soil temperatures. If surface clods are not a problem, fumigate in September or October when soils are dry. Observe the waiting period on the fumigant label before planting.

To tarp or not to tarp is a significant question. A tarp slows down the rate at which the fumigant volatilizes to the atmosphere, keeping it in the top few inches of soil long enough for nematodes to be killed. Untarped applications will miss nematodes present in the top six inches. In fields which have been fallow for several months during hot weather proceeding fumigation, this may not be a problem because high soil temperatures can kill the nematodes present. Otherwise, this problem can be remedied by turning the top 12 inches of soil under with a plow and conducting a second treatment after the initial fumigant has dispersed. Strip treatments and treating individual replant sites will also miss a significant number of nematodes and will result in more rapid reinfestation of the root zone than will broadcast applications.

Most nematicide failures result from the chemical not reaching the nematode in sufficient concentration. For preplant applications, this is usually due to improper land preparation or applications outside of acceptable ranges of soil temperature and moisture.

Liquid and gaseous fumigants have traditionally been applied via knife like blades called shanks. A tube carrying the product runs down the back of each shank to the tip. In traditional fumigation, the product is injected below the surface of properly prepared soil and applied in a narrow band as the fumigation equipment moves across the field. The surface of the soil is sealed or compacted by pulling a ring roller or other soil sealing device behind the fumigation equipment or behind a second tractor.

The oldest fumigation rigs operated via gravity flow. The rate of flow of fumigant from the barrel was controlled by valves and orifices (small brass or stainless steel disks with small holes in them). Rate of flow can also be controlled by a wheel which runs on the surface of the ground and operates a small pump. The tank holding the fumigant can also be pressurized by a cylinder of nitrogen. Rate of flow is controlled by pressure, orifice size, and rate of movement across the field. Commercial applications are typically applied with relatively massive pieces of equipment capable of applying the product with computerized accuracy, laying a tarp, and gluing together adjacent edges in one operation.

Different depths of injection and shank spacing are used for different situations. Local Farm Advisors, PCA's or professional applicators can be consulted for suggestions on particular applications. In general, deeper injections and closer shank spacing provide increased control in well prepared soils but also require a slower speed and more powerful equipment to achieve and so increase the cost of the application. Shanks with multiple openings have been developed to improve distribution in soil types in which fumigants do not move well or for use with products which only move a few inches in the soil.

No matter which product is used, or how complex or simple the apparatus used to apply it, the goal of fumigation is to inject a liquid or gas beneath the surface of the soil where it will spread out in all directions from the point of injection through the air in soil pores and dissolve in the film of moisture surrounding the soil pores to kill nematodes.

Some nematicides have been shown to move more effectively in water run applications than by shank injection or by application to the soil surface followed with irrigation. In flood or furrow applications, it is important to try to move the treated water across the treatment area as rapidly and uniformly as possible. At times, this can be aided by a preirrigation, followed by waiting for the soil to drain to field capacity, and then applying the treatment. In recent years, sprinklers have been used extensively for the application of certain products. Considerable effort has been undertaken by nematologists to investigate and develop methods to apply nematicides via drip irrigation systems. For tree and vine situations, it is essential to keep in mind that one is trying to move the product several feet deep in the soil and for products applied in water, this means the soil must be saturated essentially to the depth at which one wants effective treatment.

Session V

Water Quality & Management

Session Chairs:

Al Vargas, California Department of Food & Agriculture

Findings of the Irrigated Lands Waiver Water Quality Monitoring - Is the Glass Half Empty or Half Full

Michael L. Johnson, Director, Aquatic Ecosystems Analysis Laboratory, University of California, Davis, One Shields Ave, Davis, CA 95616
Phone (530) 752-8837, FAX (530) 754-9369, mbjohnson@ucdavis.edu

Melissa A. Turner, Aquatic Ecosystems Analysis Laboratory, University of California, Davis, One Shields Ave, Davis, CA 95616
Phone (530) 297-4684, FAX (530) 297-4684, mmturner@ucdavis.edu

INTRODUCTION

Water quality monitoring under the auspices of the Central Valley Regional Water Quality Control Board's (CVRWQCB) Conditional Waiver for Irrigated Lands program has been in existence for almost 2 years. Most of the grower-established water quality coalitions have sampled water bodies in their regions for two summers and one winter. Coalition groups have now turned in two monitoring reports with data on various water quality constituents ranging from pH to agricultural chemicals. Additionally, the CVRWQCB has been sampling for two summers and one winter for their Phase II monitoring program across the Central Valley from Redding to Fresno. After all of the effort, time, and expense, a considerable amount of data has been generated but the interpretation of the data has proved contentious. Part of the difficulty lies in the limited environmental variability experienced during the two years of sampling. It's not clear that the data reported below reflect "average" results.

To place the issue of data interpretation into context, one needs to understand the parties involved in the process of regulating irrigated agriculture. On one side is the environmental community and the Regional Board who claim that there has been an exceedance of a water standard at every site (glass is mostly empty). On the other side is the agricultural community who claims that the number of exceedances is very low relative to the total number of samples collected (glass is mostly full). Here we review the results of the monitoring programs from the Regional Board and the San Joaquin County and Delta Water Quality Coalition (SJCDWQC) and the East San Joaquin Water Quality Coalition (ESJWQC). These two coalitions include the central and south Delta, and the irrigated agriculture in San Joaquin, Stanislaus, Merced, and Madera Counties.

MONITORING PROGRAMS

Components of monitoring vary by coalition region due to the specific agricultural activities and prior knowledge of discharges in the region. However, the monitoring elements mandated by the CVRWQCB include:

> Toxicity testing – 3 species water column tests; sediment toxicity with Hyallela
> Water chemistry – varies by coalition but must include diazinon and chlorpyrifos
> Physical parameters – flow, pH, temperature, EC, TDS, TOC, turbidity, color
> Drinking water parameters – *E. coli*

Coalitions are required to report all exceedances of applicable water quality objectives. Exceedances are established by assigned beneficial uses, and very few of the coalition monitoring sites are located on water bodies that have been assigned beneficial uses. If no beneficial uses are assigned to a water body, it is automatically given a Municipal water supply beneficial use (MUN) and as a result of the "tributary rule" is also assigned the beneficial uses of the closest downstream water body that does have beneficial uses. The water quality objectives apply to all water bodies including agricultural discharge dominated water bodies and engineered drains.

The CVRWQCB also maintains a monitoring program with the primary differences being the addition of several chemical constituents and the no sampling for *E. coli*.

MONITORING PROGRAM RESULTS

Results from the Regional Board's monitoring program and the results of the monitoring programs of the East San Joaquin Water Quality Coalition and the San Joaquin County and Delta Water Quality Coalition were tabulated and summarized in Table 1. We used a very conservative interpretation of exceedance that did not rely on water body-specific beneficial uses. For example, although the irrigation and drain canals of the Delta do not have assigned beneficial uses of either cold or warm water fishery habitat, we applied both standards to those water bodies to tabulate exceedances. We also applied chronic criteria for concentrations of diazinon and chlorpyrifos in the water even though the chlorpyrifos standard has recently been demonstrated to have been calculated in error.

One of the more interesting results is the number of tests for which the results of both sampling programs are similar. Of the 13 water quality tests in Table 1, the results from 9 of the tests are similar across programs. The three tests that appear to differ are concentrations of diazinon and chlorpyrifos, and Selenastrum toxicity. In all three cases, the Regional Board's data indicate a greater percentage of exceedances than does the coalition data. Interestingly, establishing exceedances for those tests do not rely on the interpretation of the tributary rule, beneficial uses and application of appropriate water quality objectives.

By far the biggest percentage of exceedances is for *E. coli*. *E. coli* is a generic measure of bacterial contamination and the source is completely unknown but can include humans, cattle, birds (domestic and wild), and companion animals. Also, recent studies indicate that exceedance of *E. coli* standards does not adequately reflect adverse health effects (Colbert et al. 2005). Finally, although the Regional Board has designated *E. coli* as an indicator of pathogen loads, there is no *E. coli* standard in the Basin Plan.

Low dissolved oxygen is the next largest exceedance, although the exact percentage depends on the assigned beneficial use. If the water body has a designated beneficial use of cold water fish habitat or cold water fish spawning habitat, almost half of the samples have low dissolved oxygen. If the beneficial use assigned is warm water fish habitat, the percentage drops dramatically to 14%.

Table 1. Number of samples and the percentage of samples classified as exceedances in the monitoring programs of both the CVREWQCB and the ESJWQC and the SJCDWQC. Percentages are rounded to the closest whole number. Data include results through the irrigation season of 2005. Exceedances are based on water quality objectives in the Basin Plan. The Regional Board monitoring program does not sample for *E. coli*. Exceedances are also based on assumed beneficial uses for the water bodies. The DO standards are based on cold water fisheries (7 mg/L) or warm water fisheries (5 mg/L). Numbers in parentheses are based on a single sample per day when a water body was sampled multiple times during a day. See text for details.

Constituent	**Regional Board**		**Coalitions (ESJ, SJCD)**		**Combined**
	Total number of samples	% of samples as exceedances	Total number of samples	% of samples as exceedances	% of samples as exceedances
Diazinon	362 (332)	21 (16)	217	1	14 (10)
Chlorpyrifos	362 (332)	33 (28)	217	11	25 (21)
Ceriodaphnia toxicity	274	9	222	8	9
Selenastrum toxicity	273	29	226	7	19
Pimephales toxicity	273	2	213	4	3
Total Water Column Toxicity	820	14	661	6	10
Sediment toxicity	96	23	137	34	29
pH	477	7	213	8	7
EC	478	14	219	22	17
TDS	531	11	212	23	14
DO (<7)	439	50	217	33	45
DO (<5)	439	16	217	11	14
E. coli	-	-	205	47	47

Sediment toxicity is the next largest category of exceedances followed by the concentration of chlorpyrifos in the water. Results of sediment chemistry analyses performed by the Regional Board indicate that pyrethroids in the sediment are responsible for the majority of the toxicity observed. No sediment chemistry is performed by the coalitions at this time. Chlorpyrifos is known to bind with particles in the water column and in the sediment and was found to be a likely cause of toxicity in two cases of sediment Toxicity Identification Evaluations (TIEs).

Overall, there is relatively little water column toxicity observed, with the majority of the statistically significant effects involving reduced growth of Selenastrum. Ceriodaphnia and Pimephales (fathead minnow) toxicity were both below 10%. Generally, TIEs indicated that the cause of the toxicity was metabolically activated (organophosphate) pesticides such as chlorpyrifos or diazinon.

The remaining constituents are physical parameters with specific conductivity (EC) and total dissolved solids (TDS) values being somewhat different between the coalition and Regional Board monitoring programs. Both of these measures are indicators of salt and the higher values from the coalitions probably reflect the sampling effort in the San Joaquin Valley where salt is known to be problematic. High levels of EC and TDS in the Delta channels reflect the high concentration of salt in the San Joaquin River water used for irrigation. The Regional Board's monitoring program includes sampling sites in the Sacramento River watershed which is naturally low in EC and TDS. One of the issues with these exceedances is a function of the TDS water quality objective imposed by the Regional Board. The value selected is the lowest limit of a range of acceptable values (450 – 2000 mg/L proposed as a slight to moderate potential irrigation problem, see Table 1 of Ayers and Westcot [1985]) established to quantify the effects of salt on agriculture in arid environments. The value (450 mg/L) is lower than the current drinking water standard (500 mg/L – primary MCL) and consequently, according to these standards, the water is safe to drink but not for use in irrigation.

Although the data are not presented here, there is an exceedance of a water quality objective at every site in both coalition regions. However, these may involve only a single exceedance of a physical parameter (e.g., pH, DO) and may have occurred only once during the entire sampling period. On the other hand, there are sites with exceedances on multiple dates.

The final aspect of the monitoring programs is to identify sources of the exceedances. For chemical exceedances, the method used by both coalitions is to obtain the pesticide use reports for the two weeks immediately prior to the sampling event and determine where within the watershed the chemicals were applied. In some instances, this process has resulted in no reported applications within the watershed. This suggests that either the applications have been unreported to the County Agricultural Commissioners, or that the applications are from a non-agricultural source. While the coalitions have attempted to establish sampling sites with no urban inputs, the population growth in the Central Valley has made it difficult to monitor sites with absolutely no urban inputs.

CONCLUSIONS

The data summarized in Table 1 will not tip the scales of the "half empty-half full" debate in either direction. Coalition monitoring is likely to continue for several years and will provide a substantial amount of data with which to evaluate water quality in the Central Valley. Additionally, these data will be collected against the background of greater environmental variability allowing each year's results to be placed into context. Although the current status of water quality in the valley may be unclear, what is clear is that both sides are committed to identifying the causes of water quality impairments and implementing management measures to improve water quality.

ACKNOWLEDGEMENTS
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Evidence for Groundwater Contamination Vulnerability in California's Central Valley

Jean E. Moran
L-231, P.O. Box 808 Lawrence Livermore National Laboratory, Livermore, CA 94550; phone (925)423-1478; fax (925)422-3160; e-mail: moran10@llnl.gov

Roald Leif
L-396, P.O. Box 808 Lawrence Livermore National Laboratory, Livermore, CA 94550; phone (925)422-2469; fax (925)422-5673; e-mail: leif1@llnl.gov

Bradley Esser
L-231, P.O. Box 808 Lawrence Livermore National Laboratory, Livermore, CA 94550; phone (925)422-5247; fax (925)422-3160; e-mail: esser1@llnl.gov

Michael J. Singleton
L-231, P.O. Box 808 Lawrence Livermore National Laboratory, Livermore, CA 94550; phone (925)424-2022; fax (925)422-3160; e-mail: singleton20@llnl.gov

INTRODUCTION

The California Water Resources Control Board, in collaboration with the US Geological Survey and Lawrence Livermore National Laboratory, has implemented a program to assess the susceptibility of groundwater resources. Advanced techniques such as groundwater age-dating using the tritium-helium method, extensive use of oxygen isotopes of the water molecule ($\delta^{18}O$) for recharge water provenance, and analysis of common volatile organic compounds (VOCs) at ultra-low levels are applied with the goal of assessing the contamination vulnerability of deep aquifers, which are frequently used for public drinking water supply. Over 1200 public drinking water wells have been tested to date, resulting in a very large, tightly spaced collection of groundwater ages in some of the heavily exploited groundwater basins of California. Smaller scale field studies that include shallow monitoring wells are aimed at assessing the probability that nitrate will be transported to deep drinking water aquifers. When employed on a basin-scale, groundwater ages are an effective tool for identifying recharge areas, defining flowpaths, and determining the rate of transport of water and entrained contaminants. De-convolution of mixed ages, using ancillary dissolved noble gas data, gives insight into the water age distribution drawn at a well, and into the effective dilution of contaminants such as nitrate at long-screened production wells. In combination with groundwater ages, low-level VOCs are used to assess the impact of vertical transport. Special studies are focused on the fate and transport of nitrate with respect to vulnerability of aquifers in agricultural and formerly agricultural areas.

BACKGROUND AND METHODS

The basic premise for using groundwater age to establish vulnerability is that young groundwater has been transported to a well capture zone relatively rapidly from the earth's surface. Most contaminants have been introduced in shallow zones by human activity in the past 100 years, so younger groundwater is more likely to have intercepted contamination. On the other hand, old groundwater is likely to be isolated from the contaminating activities that are ubiquitous in modern urban and agricultural environments. The age measures the time since the water sample was last in contact with the atmosphere. Well water samples are always a mixture of water molecules with an age distribution that may span a wide range. The reported groundwater age is the mean age of the mixed sample, and furthermore, is the age only of the portion of the water that contains measurable tritium. Groundwater age dating has been applied in several studies of basin-wide flow and transport (Solomon et al., 1992, Ekwurzel et al., 1994, Manning et al., 1995). A groundwater age analysis requires measurement of tritium, a radioactive isotope (half life 12.3 yrs) of hydrogen that is part of the water molecule, and of its daughter product, dissolved ^{3}Helium. Dissolved noble gas samples are collected in copper tubes, which are filled without bubbles and sealed with a cold weld in the field. Dissolved noble gas concentrations are measured at LLNL after gas extraction on a vacuum manifold and cryogenic separation of the noble gases. Tritium samples are collected in 1L glass bottles. The ratio of ^3He to ^4He is measured on a VG5400 mass spectrometer. After correcting for minor sources of ^3He not related to ^3H decay (Aesbach-Hertig et al., 1999; Ekwurzel et al., 1994), the measurement of both tritium and its daughter product ^3He allows calculation of the initial tritium present at the time of recharge, and mean apparent ages can be determined from the following relationship:

$$\text{Groundwater Apparent Age (years)} = -17.8 \times \ln\left(1 + {}^3He_{trit}/{}^3H\right)$$

Groundwater without detectable tritium recharged the aquifer more than about 50 years ago. Ages in the range of 0 to 50 years are reported with an analytical uncertainty of about +/- 1 year. This technique is particularly useful for identifying a component of groundwater that has been recharged in the last 15 years.

Just as tritium provides a time marker for groundwater recharge, so can chemicals that have been widely used only in post-industrial times. The presence of volatile organic compounds such as gasoline compounds, organic solvents, and applied agricultural chemicals is an indication that the sampled water recharged since the onset of intense human development. In this study, these compounds are measured with a reporting limit of 5 parts per trillion – well below routine monitoring and regulatory limits. When examined at sub-part-per-billion concentrations, these VOCs serve as useful environmental tracers, since they have a near ubiquitous presence at low concentrations near the earth’s surface due to common human activities. Their presence in groundwater is indicative of a component of post-industrial aged water. Thus, the interpretation of VOC detections in this study is not with regards to health or regulatory concerns, but rather as another tracer of recent groundwater recharge. And, since the number of years the different VOCs have been in common use differs – over 100 years for disinfection by-products, 50 to 60 years for heavy use of the solvents, and only 10 to 15 years for the gasoline additive MtBE, their presence or absence can be used to mark the time since recharge.

Surface nitrogen loading has dramatically increased in the last 70 years, making groundwater ages a useful first approach to vulnerability assessment. Fertilizer usage in California had doubled from 1950 to 1980 after which it leveled off at approximately 600,000 tons per year. Nationwide, nitrogen fertilizer use in the country increased over 300 percent from 1960 to 1988, with very little change in crop acreage and only a 40 percent increase in overall farm production. Field studies have shown that approximately one third of applied fertilizer is lost to leaching using older application methods. Furthermore, changes in fertilizer application may not be seen in groundwater for up to 60 years because of retention and cycling of fertilizer N in soil.

Transport of nitrate is important not only in evaluating the susceptibility of a pristine aquifer to nitrate contamination, but also in evaluating the time scale over which source controls will affect nitrate levels in a contaminated aquifer. In evaluating both uncontaminated and contaminated aquifers, the assimilative capacity of the aquifer for nitrate loading through denitrification also needs to be taken into account. Many of the studies of denitrification in the saturated zone have been sited in shallow and young groundwater systems affected by industrial or wastewater contamination. Groundwater pumped from California drinking water supply wells is generally deeper and older. The age of deep groundwaters allows time for oxygen depletion by aerobic microbial oxidation of dissolved organic carbon (or another appropriate electron donor). In the absence of a systematic survey of ambient oxygen levels in California groundwaters, oxygenation in deep drinking water aquifers cannot be assumed. Although alluvial aquifers in the Central Valley are often well oxygenated, examples of low oxygen waters do exist in both shallow and deep aquifers. In this study, denitrification is examined by analyzing the dissolved gas composition and stable isotopes of nitrogen and oxygen in nitrate. The end product of denitrification is nitrogen; this dissolved nitrogen can be quantified in groundwater once a correction is made for nitrogen from entrained air. Denitrification drives the isotopic composition of the residual nitrate to higher $\delta^{15}N$ and $\delta^{18}O$ values. The stable isotopes of nitrogen are more strongly fractionated during denitrification than oxygen, leading to a trajectory on a $\delta^{18}O$ vs. $\delta^{15}N$ diagram with slope of 0.5 (see review by Kendall, 1998).

FIELD STUDY RESULTS

An example of the application of the tritium-helium age dating method from the GAMA program is shown in figure 1. Forty drinking water wells from the Bakersfield, CA area produce groundwater with tritium-helium ages that span nearly the entire range of the method, from 2 to 50 years. Recharge of diverted Kern River and other captured and imported water sources in unlined canals that traverse Bakersfield leaves the dominant imprint on the pattern observed in groundwater age. Wells adjacent to canals, near the center of the urban area, produce groundwater that has predominantly recharged in only the last seven years, while downgradient wells in the outlying areas produce exclusively older groundwater that recharge more than 40 years ago. The coarse-grained alluvial sediments that make up the Kern River fan likely allow significant vertical transport in the areas of artificial recharge.

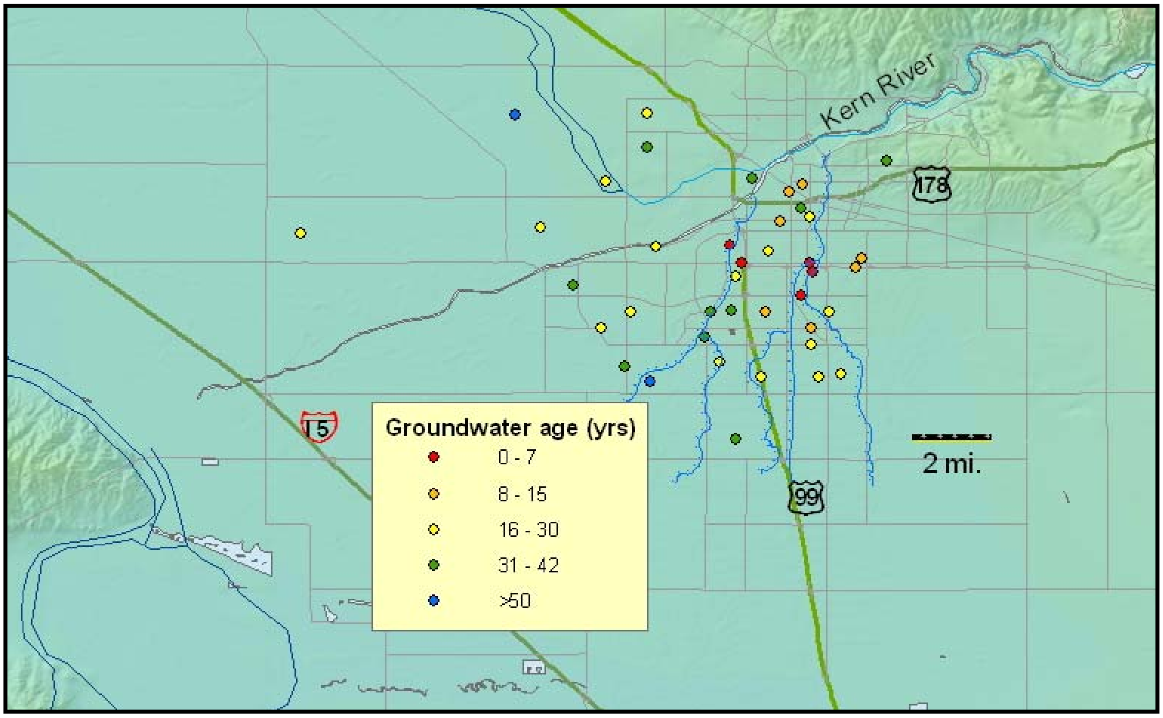

Figure 1. Tritium-helium groundwater ages show a pattern of increasing age toward the margins of the study area. Very recently recharged groundwater is produced at several wells along canals, in the center of the study area.

In the Bakersfield area, active recharge in an area of historical tetrachloroethylene (PCE, a solvent used in dry cleaning and industrial processes) contamination leads to entrainment of PCE in many of its drinking water wells (Figure 2). All Central Valley study areas visited so far show evidence for vulnerability with respect to transport of contaminants, especially PCE, to deep aquifers tapped for drinking water. This finding is in sharp contrast to results from Coastal aquifers such as Santa Clara Valley, where, despite the presence of a large number of contaminant plumes, deep wells are most frequently completely free of any VOC detections (Table 1).

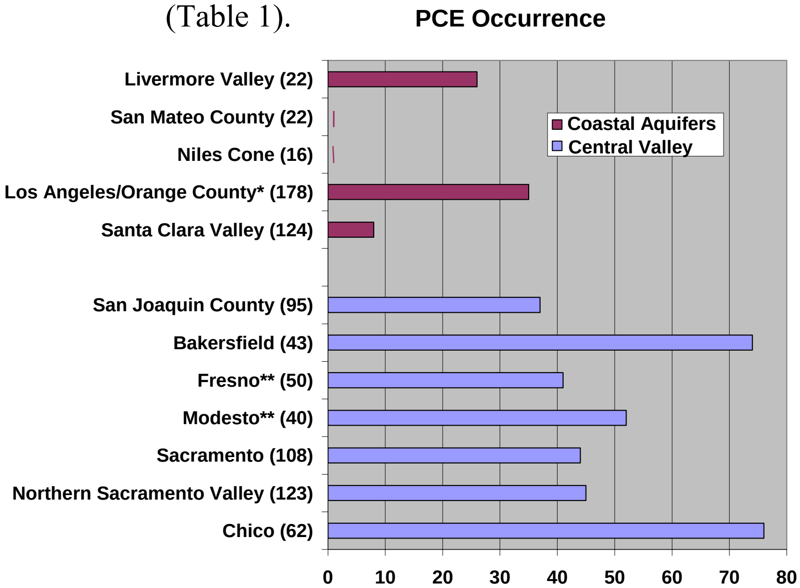

Figure 2. A comparison of percent of wells with PCE occurrence in GAMA focus areas reveals the ubiquity of low-level PCE in public supply wells in Central Valley study areas. Numbers in parentheses are the number of public supply wells sampled and analyzed for low-level PCE in the study area. Chico results are included in the overall results shown for the northern provinces. *USGS results from Shelton et al., 2001, with a lower reporting limit of 10 ng/L. **USGS results from Wright et al., 2004, with a lower reporting limit of 10 ng/L.

Table 1. Low-level VOCs results comparison for Coastal and Central Valley basins.

	Coastal Basins[1] N=194	Central Valley Basins[2] N=338
No VOCs[3]	105 (54%)	48 (14%)
MtBE	29 (15%)	87 (25%)
PCE	18 (9%)	166 (49%)
$CHCl_3$	68 (35%)	252 (74%)

1 Includes Santa Clara Valley, Basins of San Mateo County (San Mateo Plain, Westside Basin and Coastside Basin), Livermore-Amador Basin, and Niles Cone (Fremont, CA)
2 Includes Bakersfield, Chico and surrounding northern Sacramento Valley, Sacramento, and San Joaquin County urban areas (Stockton, Lodi, and Manteca); wells from areas outside of alluvial basins are not included on this table
3 Samples had <RL (reporting limit of 5 ng/L) for MtBE, chloroform, bromodichloromethane, chlorodibromomethane, bromoform, tetrachloroethylene (PCE), trichloroethylene (TCE), benzene, toluene, ethylbenzene, xylene, dibromochloropropane, and ethylene dibromide

Two contrasting field studies illustrate the utility of direct examination of denitrification indicators to assess contamination vulnerability and the fate and transport of nitrate (Figure 3a and 3b). In the Llagas basin of southern Santa Clara County, high nitrate concentrations are observed in shallow-screened wells, but not in wells screened exclusively below 200 ft. (with one exception; Figure 3a). Since groundwater is also stratified with respect to dissolved oxygen (deep water being devoid of DO), denitrification could be the cause of the observed sharp decrease in nitrate levels. However, no dissolved excess nitrogen was found in these wells, and stable isotopes of nitrate are indicative of a synthetic fertilizer source unaltered by denitrification. In this basin, deep groundwater is relatively invulnerable to shallow contamination because of physical barriers to vertical groundwater flow. Tritium concentrations below detection from deep wells support the notion that vertical transport is limited in the most contaminated areas of the Llagas Basin.

In contrast, results from a dairy site in Kings County show conclusively that denitrification is taking place in the saturated zone (Figure 3b). High concentrations of excess nitrogen are found in groundwater with low nitrate concentrations and stable isotopes of nitrate are shifted to higher values along a line of slope ½. Field studies utilizing age-dating, source attribution, and denitrification characterization are a powerful approach to designing appropriate nitrate management plans and to assessing the effectiveness of nitrate management plans. At the Kings County dairy site, nitrate loading is mitigated by denitrification, and nitrate will not be transported to the deep aquifer used for drinking water supply. In the Llagas Basin, deep wells have not yet been affected by nitrate from the contaminated shallow zone, and may not be for several decades.

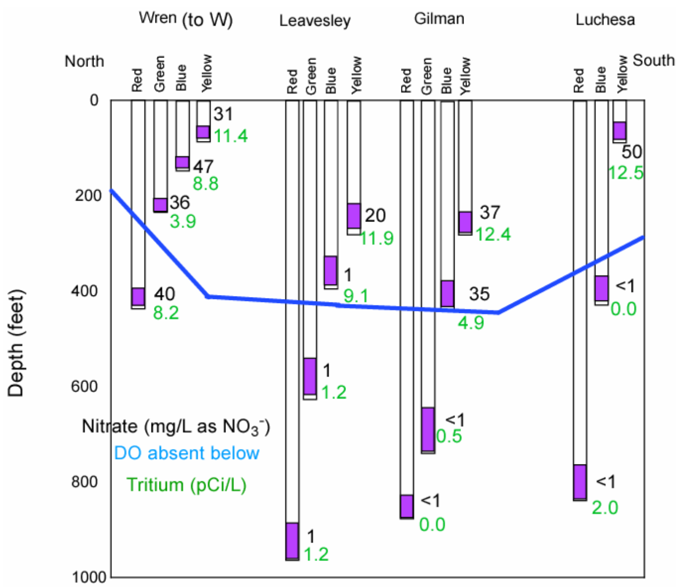

Figure 3a. Schematic cross section showing screened intervals (in purple) of nested monitoring wells in Gilroy. Groundwateris stratified with respect to nitrate, tritium, and dissolved oxygen (blue line signifies depth below which dissolved oxygen is near-zero).

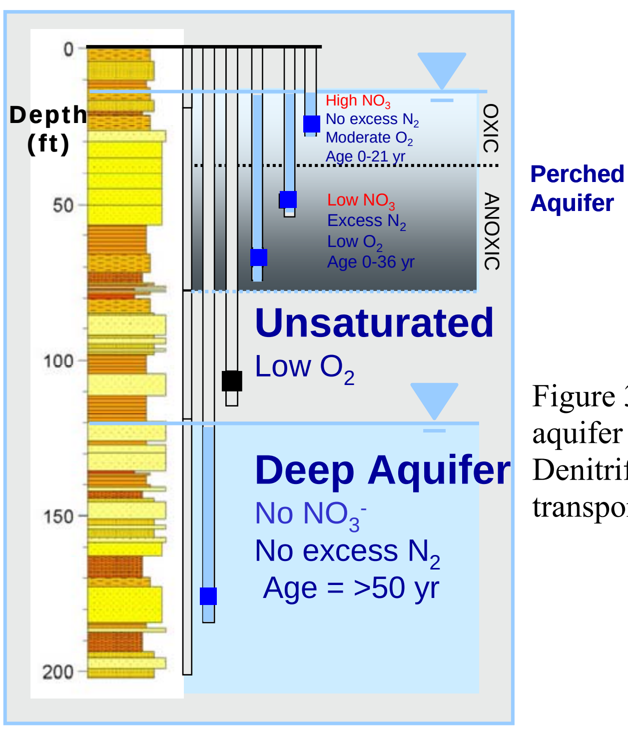

Figure 3b. Cross-sectional view of groundwater and aquifer characteristics at a Kings County dairy site. Denitrification in the shallow aquifer mitigates transport of N to deep aquifers.

Multi-level wells:
Excess N_2 by MIMS, Age by ^3H-^3He

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Investigations of Nitrate in the Lower San Joaquin River, California

Charles R. Kratzer, California Water Science Center, U.S. Geological Survey,
Placer Hall, 6000 J Street, Sacramento, CA 95819-6129
Phone (916) 278-3076, FAX (916) 278-3071, ckratzer@usgs.gov

Randy A. Dahlgren, Land, Air, and Water Resources, University of California, Davis
One Shields Avenue, Davis, CA 95616
Phone (530) 752-2814, FAX (530) 752-1552, radahlgren@ucdavis.edu

INTRODUCTION

Nitrate concentrations in the San Joaquin River (SJR) near Vernalis in 1951 were similar to concentrations in samples collected in 1908 and 1930 (fig.1; Van Winkle and Eaton, 1910; California Department of Public Works, 1931), although both 1908 and 1930 were relatively dry years, which may have caused somewhat elevated nitrate concentrations. The concentrations in the SJR have been increasing since the early 1950s (fig.1; Kratzer and Shelton, 1998; Kratzer et al., 2004). With the completion of the Delta-Mendota Canal in 1951, most of the water in the SJR that originated in the upper San Joaquin Basin (SJB) was replaced with water from the Sacramento–San Joaquin Delta. This water was enriched in nitrate compared with the Sierran water from the upper basin. Tile drains were first installed in the early 1950s in the Grasslands Drainage Project Area (fig. 2) to relieve the damaging effects of high ground-water tables on crops. The tile drainage flowed to the SJR via Mud and Salt Sloughs. The area of drained lands reached a maximum around 1983 at close to 60,000 acres. This drainage contains very high nitrate concentrations (averaging about 25 mg/L as N), mostly from the native soil nitrate in the former marine deposits of the Coast Ranges (Kratzer and Shelton, 1998). In addition to increases in nitrate from tile drainage, fertilizer applications in the SJB increased over the period 1950 to 1980 and manure production increased steadily since 1950. As a result, nitrogen in the soils of the lower SJB increased dramatically between 1945 and 2001 (DeClerck and Singer, 2003), and nitrate concentrations in ground water on the east side of the lower SJB increased over the period 1950 to 1990. Changes in nitrate concentrations in ground water since 1990 are inconclusive (Burow et al., 2002).

From 1950 to 1980, the nitrate increase in the SJR corresponded with increases in tile drainage and fertilizer applications. Discharges of municipal wastewater could also have been a contributing factor, although probably relatively minor compared with the tile drainage and fertilizer applications. Since 1980, the cause of the continual increases in nitrate concentrations is more difficult to relate to sources. The one source that has continued to increase is the production of manure in the basin, primarily from dairy operations.

The U.S. Geological Survey (USGS) and University of California at Davis (UC Davis) conducted a study of nutrient loads (and algae loads) in the SJR during 2000–2001 to better define the sources of nitrate during the summer and fall when dissolved oxygen levels in the Stockton Deep Water Ship Channel area (fig. 2) of the SJR are at their lowest. This oxygen deficit can stress and kill aquatic life and could inhibit the upstream migration of fall-run

Chinook salmon. Although summer and fall are the most critical seasons for low dissolved oxygen episodes, they are historically the seasons of lowest nitrate loads in the SJR, with the highest loads occurring in March with relatively high flows from tile drains and managed wetlands (see Grasslands Ecological Area, fig. 2). The wetlands are drained in spring after being flooded since fall for the winter duck season.

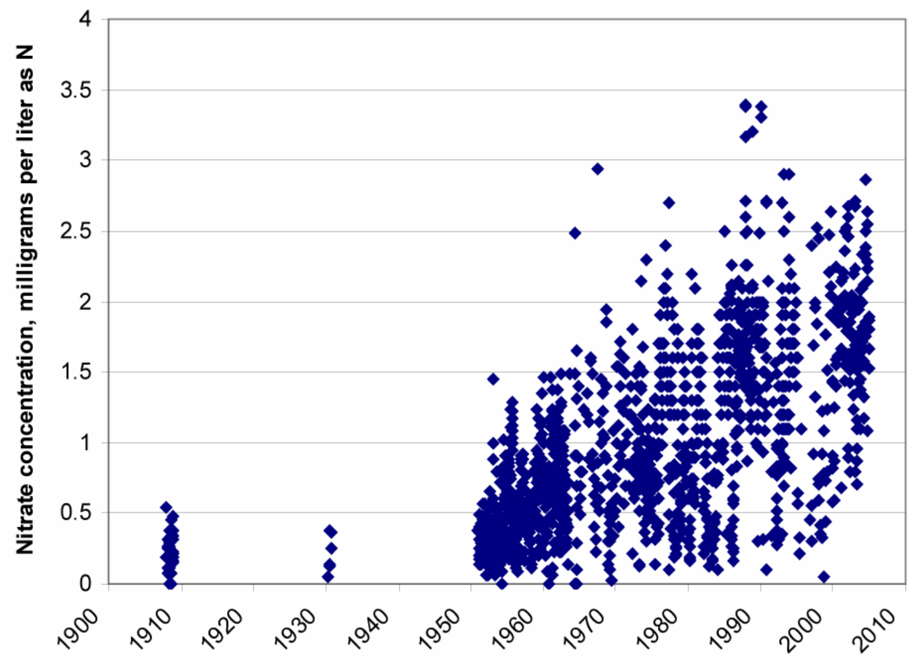

Figure 1. Nitrate concentration in the San Joaquin River near Vernalis, 1908 to 2005 (1908 data from Van Winkle and Eaton, 1910; 1930 data from California Department of Public Works, 1931; 1951–2005 data from U.S. Geological Survey's National Water Information System, U.S. Environmental Protection Agency's STOrage and RETrieval database, Interagency Ecological Program, and University of California, Davis).

2000–2001 STUDY

In 2000 and 2001, USGS and UC Davis sampled up to 20 sites in the lower SJB every 2 to 4 weeks during the summer and fall (fig. 3). The sites included seven sites on the mainstem of the SJR, four sites representing runoff from the Grasslands area (see Grasslands Drainage Project Area and Grasslands Ecological Area, fig. 2), six sites from the eastside of the SJR including the three major tributaries (Merced, Tuolumne, and Stanislaus Rivers), and three sites from the westside of the SJR. Samples were analyzed for nutrients, major ions, suspended sediment, organic carbon, chlorophyll and pheophytin, ultraviolet absorbance, and isotopes of carbon, nitrogen, and oxygen. Since this 2000–2001 study, USGS and UC Davis researchers have done some continuous diurnal sampling in the SJR and have discovered considerable diurnal fluctuations in summer nitrate concentrations. However, the pattern of the fluctuations is not yet as well defined as it is for chlorophyll and can not be used to refine our conclusions about long-term nitrate trends (Pellerin et al., 2005).

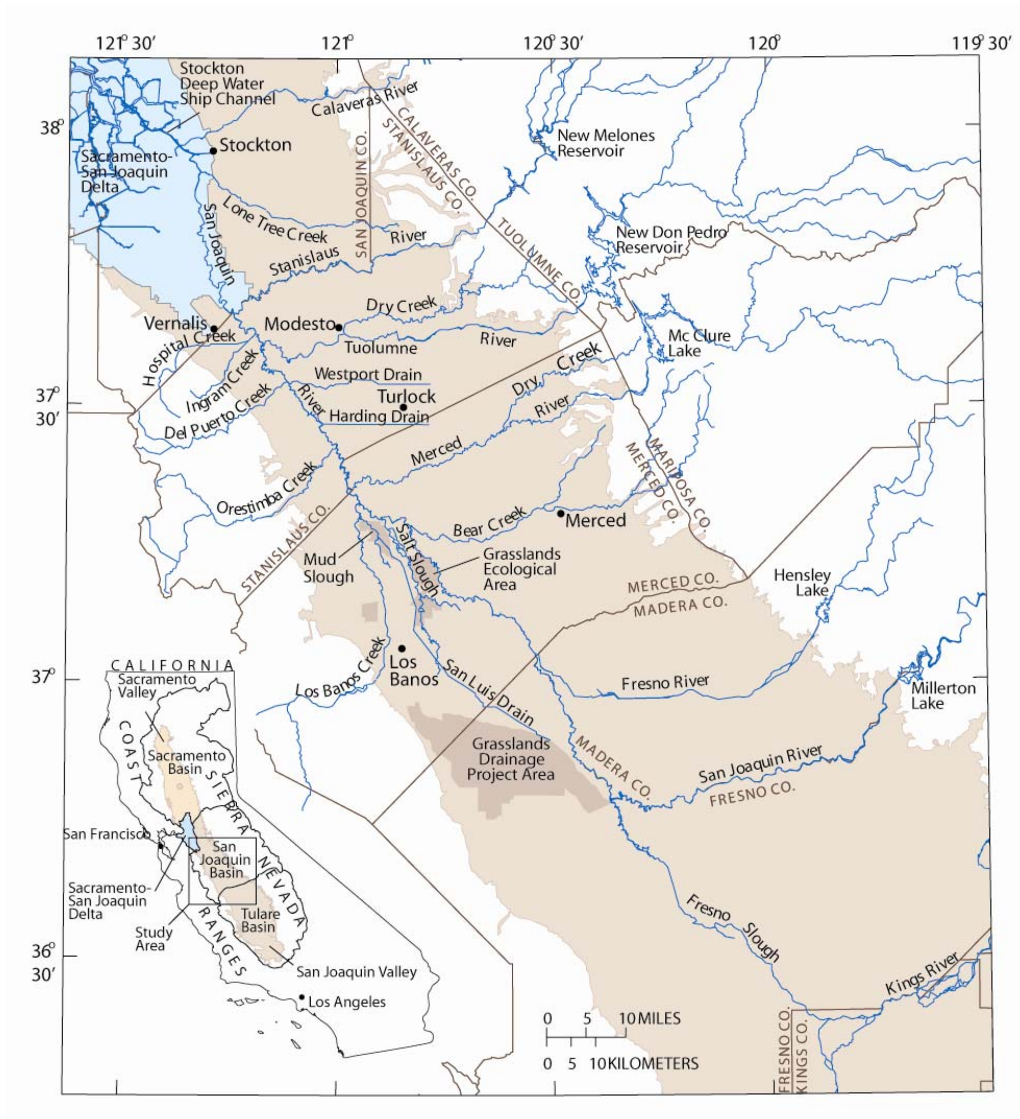

Figure 2. Portion of the San Joaquin Valley and Sacramento–San Joaquin Delta (from Kratzer et al., 2004).

On average, nitrate accounted for 72 percent of the total nitrogen in the SJR samples downstream of Stevinson (fig. 3, site 1). The Stevinson site had very low streamflows during this study and was therefore not included in the SJR median. The median nitrate concentration for the six SJR sites downstream of Stevinson was 3.0 mg/L as N and for the 10 tributary sites, excluding the three major eastside tributaries, was 4.1 mg/L as N. However, the median concentration of nitrate in all samples from the three major eastside tributaries (Merced, Tuolumne, and Stanislaus Rivers) was only 1.6 mg/L as N. The median concentration of nitrate in each of the three major eastside tributaries was 2.9 mg/L as N in the Merced, 1.7 mg/L as N in the Tuolumne, and 0.4 mg/L as N in the Stanislaus. The three major eastside tributaries account for two-thirds of the average annual streamflow in the SJR near Vernalis (Kratzer et al., 2004). Median streamflows at the time of sampling were 140 ft^3/s in the Merced, 324 ft^3/s in the Tuolumne, and 391 ft^3/s in the Stanislaus. Thus, differences in streamflow reduced the relative effect of the higher nitrate concentrations in the Merced on loading to the SJR.

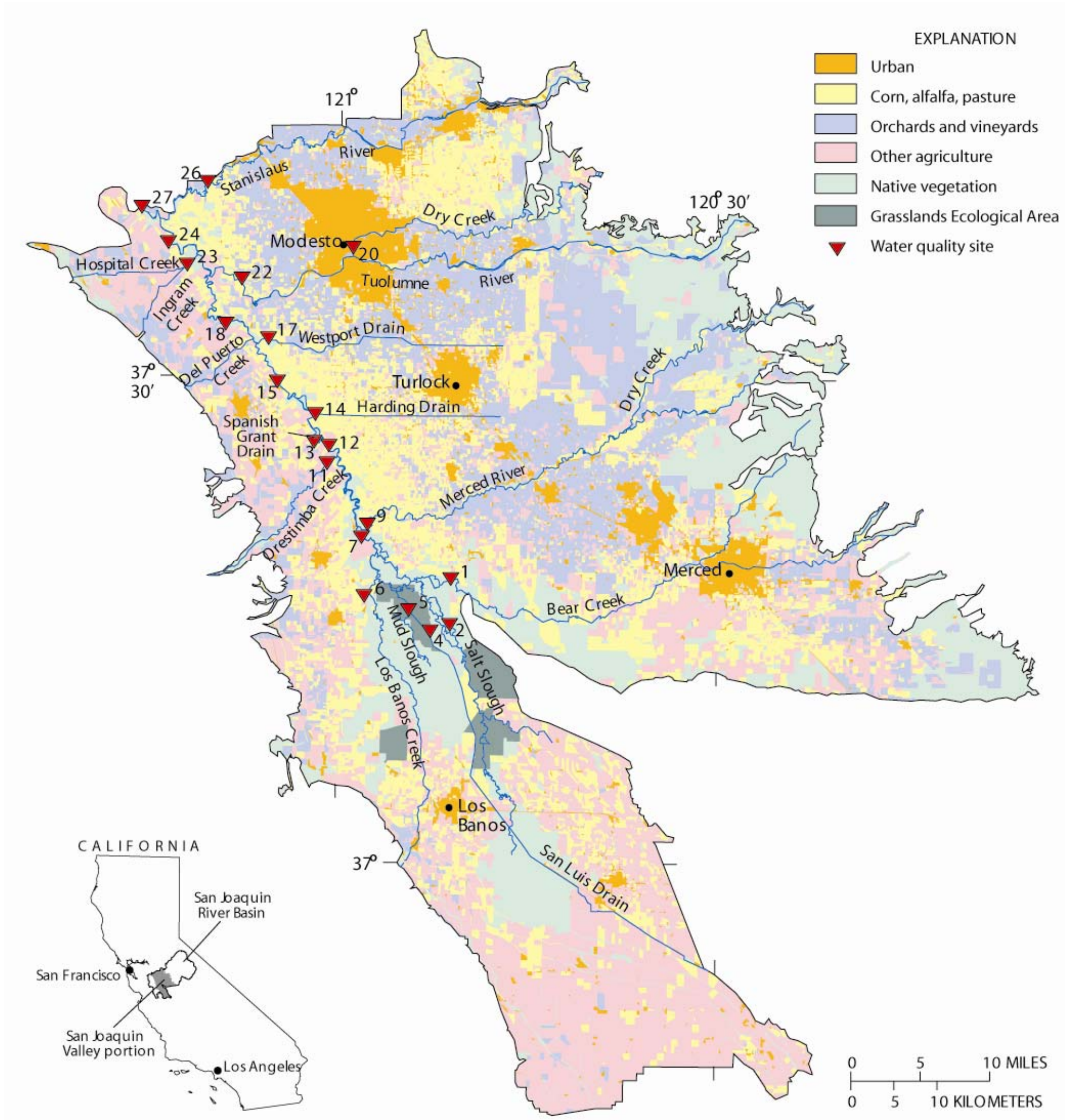

Figure 3. San Joaquin Valley portion of the San Joaquin River Basin, water quality sampling sites, and land use areas (from Kratzer et al., 2004)

In general, nitrate concentrations in the SJR between the Merced and Tuolumne Rivers decreased from summer to fall and were higher than concentrations downstream of the Tuolumne River. However, concentrations in the fall were frequently lower at Crows Landing (site 12) than at Vernalis (site 27), probably as a result of dilution from reservoir releases on the Merced River associated with the Vernalis Adaptive Management Plan, and wetland releases from Mud Slough. Unlike the nitrate-rich releases when the wetlands are drained in spring, the fall “floodup” of the wetlands with clean water produces a relatively low nitrate discharge to Mud Slough. As expected, loading rates in the SJR generally increased from upstream to downstream, except at times during the summer when loading rates at Vernalis were less than some upstream sites because of the diversion of upstream loads.

The most significant tributary inputs of nitrate in the summer and fall of 2001 were the Tuolumne River (site 22), Mud Slough (site 5), and Harding Drain (site 14). The sampled tributaries accounted for about 60 to 80 percent of the nitrate loads in the SJR in the summer and fall, leaving about 20 to 40 percent unaccounted for. However, some of the nitrate inputs to the eastside tributaries, especially the Merced River (site 9), are influenced by ground-water inputs as confirmed in the USGS’s National Water Quality Assessment Program study in the lower Merced River (Gronberg et al., 2004).

Isotope samples collected for all USGS samples in 2001 were analyzed at the USGS’s Menlo Park Stable Isotope Laboratory for $\delta^{15}N$ and $\delta^{18}O$ values of nitrate. Figure 4 shows the $\delta^{15}N$ and $\delta^{18}O$ values of nitrate measured in the SJR and tributaries superimposed on the fields of common isotopic compositions from different nitrate sources (Kendall, 1998). All but a few points from the SJR fell within the range of animal waste and sewage, whereas most of the tributary values were significantly lower in a range suggesting significant amounts of soil nitrogen and (or) inorganic fertilizer. Of the tributaries, the $\delta^{15}N$ values of Mud Slough and Westport Drain (site 17) fell mostly within the range of the SJR (fig. 5). Mud Slough receives wetland releases in October, resulting in lower nitrate concentrations, but the two highest $\delta^{15}N$ values, indicative of animal waste. However, there may also be denitrification occurring in the wetland discharges to Mud Slough that would have contributed to the higher $\delta^{15}N$ values. The Westport Drain sampling site is very close to the oxidation ponds for the City of Modesto Wastewater Treatment Plant, which could account for the relatively high $\delta^{15}N$ values, indicating sewage. Other than these two tributaries, the smaller tributaries had distinctly lower $\delta^{15}N$ values than the SJR. $\delta^{15}N$ values of nitrate from the three major eastside tributaries were measured for winter and spring samples only in 2002 by UC Davis. The Merced and Tuolumne values were much higher (+7 to +11 per mil) than the Stanislaus values (+1 to +3 per mil), consistent with higher nitrate concentrations and indicating more animal waste. These preliminary isotope data suggest that (1) animal waste and (or) sewage represented a significant source of nitrate in the SJR at the time of sampling, (2) the $\delta^{15}N$ values of nitrate in measured tributaries did not completely account for the $\delta^{15}N$ signature in the SJR (also confirmed by mass balance), and (3) that nitrate sources were locally variable in isotopic composition. However, preliminary results from recent studies by USGS and UC Davis indicate that there is rapid in-stream processing of nitrate in the SJR that could contribute to some of its higher $\delta^{15}N$ values.

CURRENT STUDY

As an extension of the 2000–2001 study, the USGS and UC Davis are currently studying the nitrate contribution to the lower SJR via ground water. Although it does not contribute most of the nitrate in the SJR, we hypothesize that ground water is the source driving the continued increase in nitrate concentration in the SJR despite a leveling off or decrease in other sources. Three approaches are being used to describe the spatial and temporal variability in ground water inputs of nitrate: (1) a boat reconnaissance to identify ground water "hot spots" that are based on temperature, electrical conductivity, and other tracers; (2) six fixed sites with nested monitoring wells instrumented with temperature probes and pressure transducers, and with monthly water quality samples; and (3) synoptic sampling events to look at temperature profiles, water quality, and hydraulic gradients in between the fixed sites. Isotopic methods are also being used to define the sources of the nitrate in the ground-water inputs.

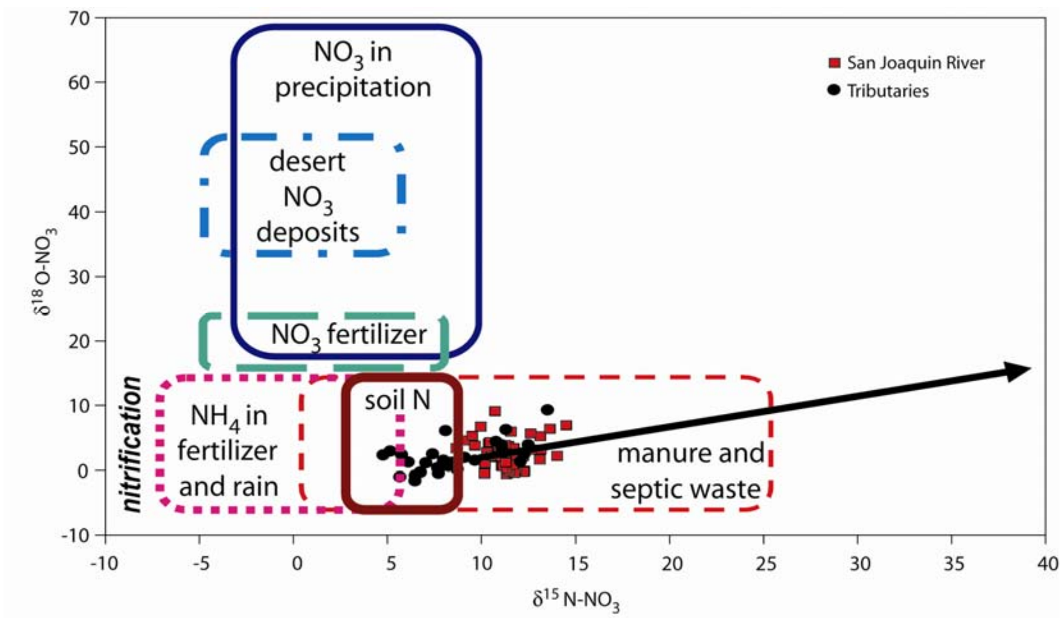

Figure 4. Delta nitrogen-15 ($\delta^{15}N$) versus delta oxygen-18 ($\delta^{18}O$) of nitrate (NO_3) for SJR and tributary samples for 2001 superimposed on fields of common isotopic compositions from different nitrate sources (and possible denitrification trend line) (from Kendall, 1998).

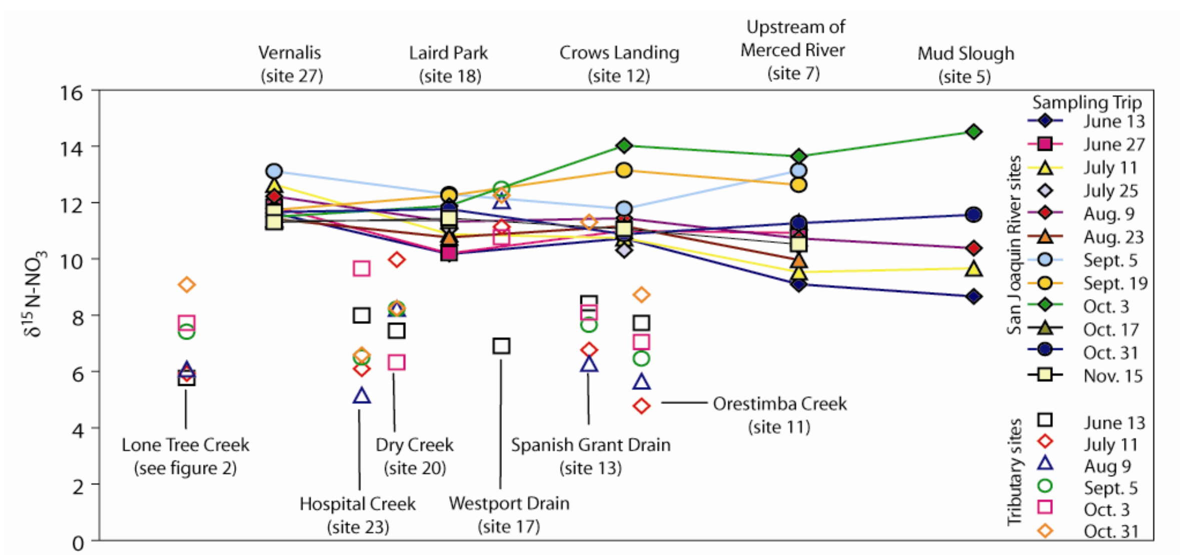

Figure 5. Delta nitrogen-15 ($\delta^{15}N$) of nitrate (NO_3) for San Joaquin River and tributary samples, 2001 (from Kratzer et al., 2004).

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A Better Way to Protect Ground Water

John Troiano, Sr. Environmental Research Scientist, Department of Pesticide Regulation, California Environmental Protection Agency, 1001 I St., Sacramento, CA 95812

Phone (916) 324-4115, FAX (916) 324-4088, jtroiano@cdpr.ca.gov

Mark Pepple, Sr. Environmental Research Scientist, Department of Pesticide Regulation, California Environmental Protection Agency, 1001 I St., Sacramento, CA 95812

Phone (916) 324-4086, FAX (916) 324-4088, mpepple@cdpr.ca.gov

Joe Marade, Assc. Environmental Research Scientist, Department of Pesticide Regulation, California Environmental Protection Agency, 1001 I St., Sacramento, CA 95812

Phone (916) 324-4119, FAX (916) 324-4088, jmarade@cdpr.ca.gov

Introduction

Detections of residues of 1,2-dibromo-3-chloropropane (DBCP) in 1979 were the first indications of potential contamination of California's ground water supply by pesticides (Peoples et al., 1980). Subsequent well surveys conducted by the Department of Pesticide Regulation (DPR, formerly the Division of Pest Management in the California Department of Food and Agriculture) indicated that the contamination was more prevalent than originally anticipated. In response to a report from the State Water Resources Control Board, the legislature passed the Pesticide Contamination Prevention Act (PCPA) (Pesticide Contamination Prevention Act,1985). The purpose of the act was to prevent further pesticide pollution of ground water aquifers that may be used for drinking water supplies. The PCPA required DPR to:

1. <u>Maintain a database of well sampling for pesticides</u>. All state and local agencies were required to report any well sampling for pesticides. DPR asked federal agencies, such as the USGS to report on their well sampling voluntarily.
2. <u>Develop a list of active ingredients with the potential to pollute ground water (the "Ground Water Protection List"- GWPL) and adopt that list in regulation (section 6800(b) of Title 3 of the California Code of Regulations (3CCR</u>)). As part of that process, the law also required DPR to develop and adopt by regulation numerical benchmarks for physical/chemical properties of pesticides used to identify pesticides on the GWPL.
3. <u>Monitor to determine whether pesticides on the GWPL were moving to ground water</u>. The DPR Environmental Monitoring Branch conducts ongoing well sampling to determine whether pesticides on the list are contaminating ground water.
4. <u>Review pesticides determined to move to ground water as a result of legal agricultural use to decide whether continued use can be allowed</u>. Currently registered active ingredients that have been found in ground water due to legal agricultural use and that have modifications of use are listed in 3CCR section 6800(a).

In order to fulfill these requirements, DPR developed a ground water program that included sampling from wells located in rural, agricultural areas. In contrast to data obtained from the Department of Health Services, which requires sampling from wells that supply public water connected to 25 or more households, wells sampled by DPR serve mainly single-family households, drawing water from relatively shallow ground water aquifers. Generally, these wells are most susceptible to contamination from chemicals applied to the soil surface because they are located near sources of pesticide applications with a relatively short travel time of solutes from the surface to the shallow aquifer.

Prior to the PCPA, certain soil fumigants (DBCP, 1,2-D, and EDB) were detected in many California wells at concentrations that exceeded health levels (Troiano et al., 2001). Since the mechanism of movement to ground water was poorly understood, there were no known mitigation measures that could be implemented to protect ground water. Eventually it was determined that these pesticides "demonstrated serious uncontrollable adverse effects," which is one of the conditions specified in the California Food and Agricultural Code under which pesticides can be quickly suspended and subject to cancellation. Registration of these soil fumigants was eventually cancelled because of worker safety and general human exposure concerns, and lack of management practices to prevent further ground water contamination. As the well sampling program expanded, other pesticides were detected in California ground water but at levels that did not initially exceed health levels. Under these conditions, there was time to review these pesticides under the specified PCPA process, and to begin to understand how these chemicals were moving to ground water. Studies were conducted to determine pathways for movement of residues to ground water and, upon identification, additional studies were conducted to determine specific mitigation measures. With the development of mitigation measures, prohibition of use was no longer the only regulatory option and was necessary only when management options were not available.

One final piece tying the program together was the development of a geographical information system (GIS). The need for GIS development was initially driven by our desire to develop an efficient monitoring program. Since the goal of the monitoring program was to detect pesticides that were moving to ground water, there was a need to determine where pesticides were being applied, and what soil types and depth to ground water were associated with detections. This information was then incorporated into a GIS system, which is used to indicate areas of the state where detections are most likely. This approach has been incorporated into the recent update of the ground water regulations enacted in May of 2004 where vulnerable areas, denoted ground water protection areas (GWPA), are defined by soil properties and depth to ground water.

Identifying Vulnerable Areas and Pathways to Ground Water

One result of the ongoing ground water sampling program was the development of a relatively large data set of wells containing pesticide residues that originated from non-point source applications. This data set was used as the basis for an empirical approach to determining spatial vulnerability of pesticide movement to ground water (Troiano et al., 2000). A vulnerable unit was defined as a section of land where pesticide residue had been detected in at least one well and the detection determined to result from non-point source applications where a section is a 1-square mile area of land (Davis and Foote, 1966). Soil data were obtained for each contaminated section and a statistical clustering method was used to group sections of land that had similar soil properties. For the first cut, soil texture, which was identified as a combination of permeability and shrink-swell variables, formed groups. Additional sub-groups were identified based on the presence of a hardpan layer in the soil and on the presence of an annual water table (Troiano et al., 2000).

One benefit of this approach is flexibility whereby vulnerable clusters can be more accurately described and/or additional vulnerable conditions can be identified as more geographic information becomes available. For example, depth-to-ground water data were not available for the first statewide assessment, but it is now an integral variable for identifying vulnerable areas. The vulnerability analysis has been used to focus our well sampling studies in areas with the highest probability for detections and it also forms the basis for changes in DPR's ground water regulations where use of certain management practices are required in vulnerable areas.

Regulation of Pesticides Detected in California's Ground Water

Although the prevailing opinion regarding regulations is that they are an impediment to pesticide use, the goal of regulating ground water contaminants is to encourage their continued use but under management conditions that will prevent their movement to ground water, thereby assuring their presence in the grower's toolbox. This course of action attempts to balance economic considerations with environmental protection. If a 6800(a) listed pesticide is used in a designated GWPA, the user is required to obtain a permit from the local Agricultural Commissioner (Table 1). One objective of the permit is to notify users that the pesticide they are applying has the potential to move to ground water in a vulnerable area. But more importantly, the permit will be conditioned with a mitigation measure that, when adopted by the user, will minimize movement of the chemical to ground water. Furthermore, DPR has developed a list of management practice options to give users flexibility depending on the situation. Management practice options may be added to the list as additional information is developed by DPR, user groups, and others. The regulations also encourage development of additional management practices, especially if the current ones pose a hardship.

The mitigation measures are tailored to the specified pathway to ground water where GWPAs are indicated as either leaching or runoff. Figure 1 illustrates the location of GWPAs in the San Joaquin Valley. Studies conducted in coarse-textured soils indicated the importance of managing percolating water, especially during the irrigation season (Troiano et al., 1993). The following list of mitigation options is available in leaching GWPAs where the normal soil water infiltration process predominates over surface runoff:

Leaching GWPA Management Options – Choose one:

- L-1. Do not irrigate for 6 months following application (usually applicable to noncrop uses);
- L-2. Irrigate so water does not contact treated area for 6 months following application;
- L-3. Irrigate efficiently for 6 months following application applying no more than 133 percent of water at each irrigation required to satisfy evapotranspiration losses;
- L-4. Use a scientifically-based alternative management practice approved by the Director as specified by an enforcement letter;
- L-5. Apply the pesticide with no use modification if none of the management practices are feasible, and the requestor submits and DPR approves a protocol for testing a new management practice.

In contrast to leaching GWPAs, runoff GWPAs are primarily characterized by soils that contain a hardpan layer located 2-3 feet below the soil surface where movement of residues to sensitive sites has been measured as a result of winter rain runoff (Braun and Hawkins, 1991). When agricultural practices are used that exacerbate compaction of soil, the resulting soil condition is characterized by low soil infiltration rates that favor runoff of water. A follow-up study indicated that incorporating herbicide residues by a mechanical method into soil prior to a precipitation event drastically reduced offsite movement of residues through a combination of reducing concentration in runoff water and reducing the amount of runoff water produced (Troiano and Garretson, 1998). The following list of mitigation options is available in runoff GWPAs where surface runoff predominates over the normal soil water infiltration process:

Runoff GWPA Management Options – Choose one:

R-1. Apply in a band not to exceed 33% of distance between crop rows, except in citrus where the band can extend to the dripline of the tree;
R-2. Disturb soil within 7 days before application (not an option for bentazon);
R-3. Incorporate the pesticide on 90% of the area treated within 48 hours after the day of application by mechanical means (disc, harrow, rotary tiller) or by pressurized irrigation (not an option for bentazon);
R-4. Apply between April 1 and July 31;
R-5. Keep runoff water onsite for 6 months. If kept in a storage basin, the basin should have a low percolation rate (<0.2 in/hr) unless the runoff water is recirculated within 24 hours;
R-6. Keep runoff water in an offsite low permeability (<0.2 in/hr) storage basin, under the control of the permittee, for 6 months.
R-7. Channel runoff onto an un-irrigated fallow field for 6 months after application, with full consideration of plantback restrictions.
R-8. Allow unchanneled runoff to move to an adjacent area equal in size to the area treated as long as the runoff does not move to sensitive sites, such as dry wells, ditches, or permeable retention areas.
R-9. Use a scientifically-based alternative management practice approved by the Director as specified by an enforcement letter.
R-10. Apply the pesticide with no use modification if none of the management practices are feasible, and the requestor submits and DPR approves a protocol for testing a new management practice.

The last two mitigation measures for both leaching and runoff conditions add flexibility to the regulations by promoting development of additional management practices.

In addition to the management practices for uses on agricultural crops, the regulations address use in recharge areas, canals and ditchbanks, roadside use, and wellhead protection. The structure is similar to the agricultural use in that, when feasible, a list of options is available to choose from. Complete information on the regulatory program is available at the DPR website at **http://www.cdpr.ca.gov/docs/gwp/index.htm**.

Summary
California regulations for protecting ground water from pesticide residues were revised in May 2004. At the heart of the regulations was the implementation of a spatial vulnerability assessment that identified areas of the state that are most vulnerable to pesticide contamination. Vulnerable areas are described by soil properties and depth to ground water data. Identification of specific soil properties lead to determination of pathways for movement of pesticides residues to ground water and a determination of whether they occur by either leaching or runoff processes. The 'Better Way to Protecting Ground Water' is allowing continued use of known ground water contaminants but under management practices that minimize their potential movement to ground water. In addition, a list of management options has been developed for each pathway to ground water, providing flexibility for the user to continue use in vulnerable areas.

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Table 1. Pesticide active ingredients known to contaminate ground water that are listed in Food and Agriculture section 6800(a). Some associated product names are indicated.

Active Ingredient	Product Name
Atrazine	**Aatrex ®**
Simazine	***Princep®***
Bromacil	Hyvar®, Krovar®
Diuron	Karmex®, Krovar®

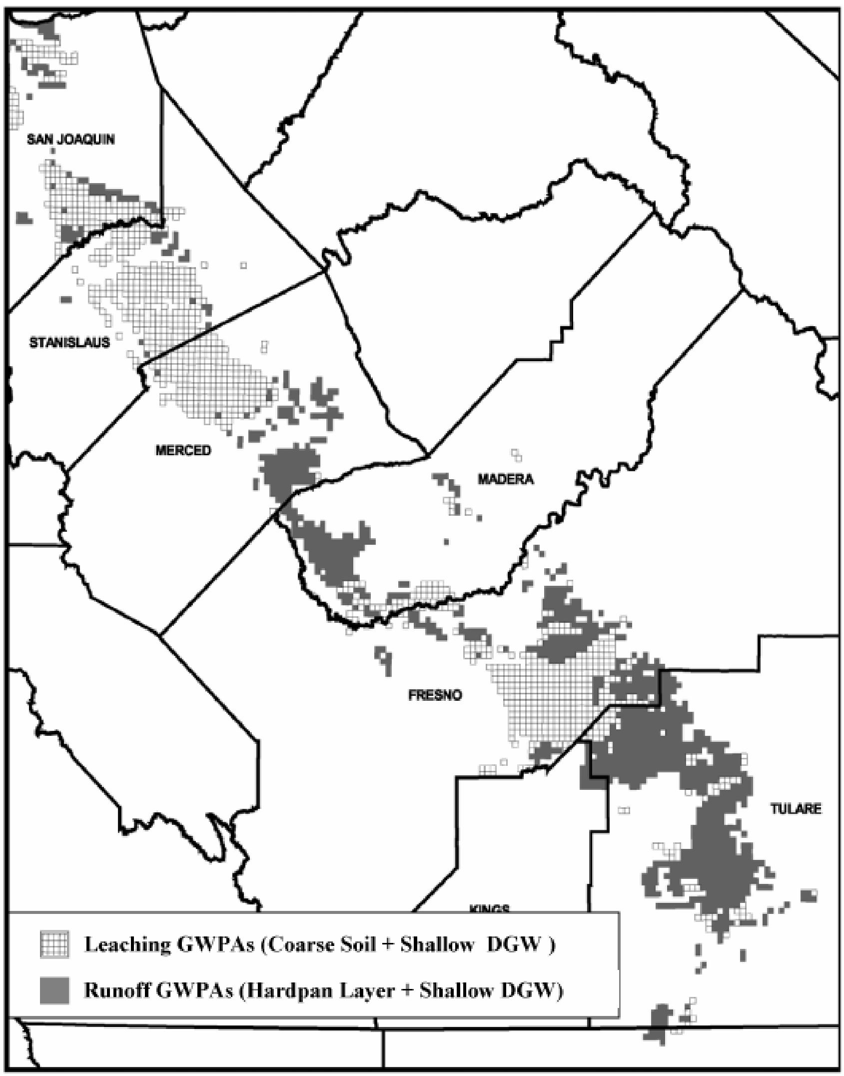


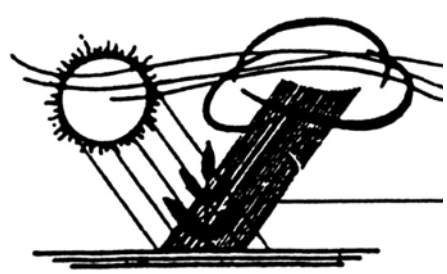
Figure 1. Location of leaching and runoff ground water protection areas (GWPAs) in the San Joaquin Valley. White sections with a gray outline are leaching GWPAs and solid gray colored section are runoff GWPAS.

Session VI

Managing Nutrients From Dairy Effluent

Session Chairs:

Charles Krauter, CSU Fresno



Using Nutrient Management to Improve Groundwater Quality Under Dairies: Case Studies

Marsha Campbell Mathews[1] and Thomas Harter[2]

[1]Corresponding author:
UC Cooperative Extension
3800 Cornucopia Way, Suite A
Modesto, CA 95358
Tele: 209-525-6800 FAX: 209-525-6840
e-mail: mcmathews@ucdavis.edu

[2]Dept. of Land, Air and Water Resources, University of California, Davis

Introduction

California's dairy herd of 1.5 million milk cattle produces large amounts of liquid and solid waste. Most of the state's dairy herd is located in the San Joaquin Valley. In this area, it is very common to house the milking animals in freestall facilities which have a flushing system for manure removal. With this system, the lanes are flushed with large volumes of water. The manure laden water is usually run through a separation system to remove coarse solids prior to being stored in a retention pond (commonly called lagoons) where it is recycled through the flush system and eventually applied to adjacent crop land.

Ideally, the nutrients in the animal manure are recycled through the crops grown on the dairy by applying the manure as a crop fertilizer, matching the nutrient application to the field with the nutrient uptake by the forage crops, which are typically a corn silage/winter cereal forage rotation. However, the liquid manure from the lagoons has traditionally been applied with minimal regard for the nutrient content of the material because a practical way of measuring the amount of nutrients being applied in the lagoon water has not been available. This misapplication of dairy lagoon nutrients. has been shown to result in contamination of groundwater in certain locations, especially in areas with a high leaching potential and shallow depth to groundwater (Harter et al, 2001, 2002).

Over the past few years we have developed a practical system using a nitrogen quick test, flow meter, and throttling valve that enables dairy producers to apply targeted amounts of lagoon nitrogen with much the same accuracy as commercial water run ammonia (Mathews, 2002). These tools allow the operator to inject into the irrigation water the amount of lagoon nitrogen that can be utilized by the crop before the next one or two irrigations at any one time. Lagoon water nitrogen is primarily in two forms, ammonium and organic (Mathews, 2001). The practice of applying specific small amounts of nitrogen in multiple applications relies on the principle that nutrients in applied manure will stay near the top of the soil profile when initially applied because the positively charged ammonium ions are attracted to negatively charged soil particles and relatively large particle sizes of the organic nitrogen hinders its movement through the soil.

After application, the ammonium form of nitrogen nitrifies to nitrate and the organic form of nitrogen mineralizes ultimately to ammonium, which in turn is nitrified. This nitrate form of nitrogen is negatively charged, does not adhere to soil particles, and is subject to leaching in subsequent irrigations. If the timing of the application rates are synchronized correctly to coincide with crop uptake, then most of the nitrogen that was applied will be taken up by the crop before the next irrigation event and thus not be subject to leaching.

The project reported here represents the first attempt to use the synchronized rate nutrient application technique on a commercial scale. The initial objectives of the study was to determine to what extent proper lagoon nutrient management could improve current concentrations of nitrate in shallow groundwater associated with some dairies. Since the study fields had had a prior history of excessive lagoon nutrient applications, there remained a considerable background of nitrogen in the soil that insulated against crop loss when nutrients have been under applied and also resulted in significant amounts of nitrate remaining in the soil at harvest. During the latter years of the project an additional location was added with the objective of confirming that lagoon water could be used as the exclusive source of field crop nutrients without any adverse impacts on shallow groundwater quality, and that yields could be maintained in the absence of soil nitrogen reserves.

General Setting

All three fields in these studied are located on the low alluvial plains and fans east of the San Joaquin Valley trough in the north-central part of the valley. The soils on the Hilmar area fields are loamy sand to sand with rapid drainage in the surface soil and low water holding capacity. The groundwater table is very shallow (6 – 10 ft.). The Modesto area field is somewhat heavier than the Hilmar site, with a sandy loam surface and loam to clay loam subsurface.

As on most dairies in this region, the two fields are used to grow two crops per year for silage, summer corn and a winter cereal crop. The fields are border check flood irrigated during the summer. Crop plantings and harvest dates vary from year to year. Corn is typically planted in late April through early June and harvested between mid-August and late September. Winter forage is planted in October and harvested in April. Surface water originating from the Sierra Nevada and distributed through the local irrigation district is used for irrigation water during the summer. Late fall irrigations and winter precipitation (annual average: 15 inches) provide moisture for the winter forage crop.

Fresh water applications in this area are typically 36 to 48 inches, and measured irrigation rates on these fields were within this range. Annual average crop water uptake is 27 inches (corn) and 12 inches (winter grains). Estimated net recharge rates under these fields are nearly two feet per year, including rainfall, and there is mimimal or no water leaving the field due to high soil water intake rates. Irrigation efficiencies of approximately 50% - 60% measured on these fields are similar to those observed elsewhere in the San Joaquin Valley (Meyer and Schwankl, 2000).

Methods & Results

1. Determine to what extent current concentrations of nitrate in shallow groundwater associated with some dairies can be improved by proper lagoon nutrient management.

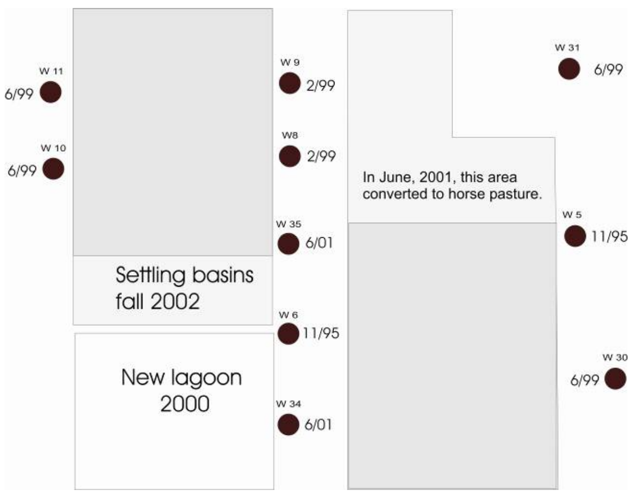


Figure 1 Approximate locations and date of first sampling for Hilmar location. Wells on left are downgradient of left field. Wells on right are upgradient of the right field and measure concentrations in the neighbors' field. Wells in upper center monitor the (new) pasture and the three lower center wells monitor the field on the right.

Two fields in the Hilmar dairy area, each originally about 15 acres, had shallow groundwater monitoring wells installed in 1993-94. Groundwater nitrate is determined from water samples taken at monitoring wells between and adjacent to the two fields on a quarterly basis. Beginning in 1996, the concentrations of nitrates in these wells were sampled for nitrates more frequently. In 1999 and again in 2001, additional monitoring wells were installed to provide replication and to compensate for wells that no longer monitored the cropped areas because some of the land area originally in the study eventually went out of production due to the construction of a new lagoon and settling basins on some of the west field land, and expansion of an irrigated pasture occurred on one end of the east field.

All monitoring wells are 25 feet deep for measuring water quality within the upper 15 feet of groundwater. Based on a simplified hydraulic analysis, groundwater sampled from these monitoring wells can be shown to originate predominantly from recharge that percolates from the two fields to the water table (Harter et. al. 2001).

Starting with November of 1995, we began estimating the amount of nitrogen being applied to the field in the forms of commercial fertilizer and lagoon ammonium and organic form nitrogen. This information was reconstructed from the growers records of how much the pond dropped during irrigation of a given field and estimating the concentration of the applied water, based on a few sporadic samples taken during this period. Yields and nitrogen uptake for years prior to 1998 were estimated based on subsequent years' yields and nitrogen concentrations because actual records were not available.

Starting with the 1998 summer corn silage crop, improved nutrient management practices were implemented where the amount of lagoon water nitrogen applied was controlled using a flow meter and throttling valve. Although results were promising, it was suspected that there was still a considerable amount of organic nitrogen in the soil remaining from previous years' overapplications, and that this was preventing a realistic assessment of yields and was contributing to groundwater nitrate concentrations that were still at more than double drinking water quality in the year 2000..

The project continued to monitor the metered application of lagoon nutrients for an additional four years. In most instances, the cooperating grower managed the irrigations, with project staff collecting supplemental information.

The concentration of nitrate in shallow groundwater upgradient of the fields has generally increased since 1999 (figure 2). This coincides with the installation of a transfer pipeline that was installed by the neighbor which allows lagoon water to be applied to the field immediately upgradient of the wells. Since that time, water in the upgradient wells has never returned to the lowest levels recorded in winter of 2001 and winter of 2002.

The east study field recorded concentrations of about 30 mg/L in mid winter of 2001. Dairy nutrient water was applied during the previous summer corn crop at a total nitrogen rate that was very close to crop removal. Commercial fertilizer had been applied to the winter crops in 1999 and 2000 because the system to apply metered amounts of lagoon nitrogen in the winter had not yet been installed and the grower wanted to avoid excessive applications. In late February, a single irrigation of nutrient water was applied for the first time on the winter crop. About 250 lbs/acre of total nitrogen was applied, of which 180 was in the ammonium (available) form and the rest was bound in the organic form. This amount was only slightly higher than what we expected would be needed to meet the needs of the crop. Crop production, however, was lower than expected and only about 60 lbs of nitrogen was taken off the field at harvest. Soil samples taken at the time of harvest showed about 60 pounds/acre of nitrate in the top two feet of soil, however fresh water irrigations had been applied on March 28 and again on April 17 so it is possible that much of the excess nitrogen could have already been leached out of the soil profile prior to the sampling at harvest. The June 5 well sampling increased from 29 to 46 mg/L just after the May 25 preirrigation, where 11.9 inches of water were applied. This was an unusually high amount of water applied at one time, because the pasture on the far end of the field was being irrigated at the same time and the water had to go over the study field before it reached the pasture at the far end. The field was later reconfigured so that the pasture and the field irrigated separately.

The corn was planted into moisture, according to standard practice, however the moisture at the time of planting was insufficient to carry the corn through to the normal date for first irrigation, normally about 30 days after planting with the corn at that time being about three feet tall. The corn was irrigated when it was only about a foot tall with fresh water. Soil samples taken immediately before and just after this irrigation confirmed that the 81 lbs/acre of nitrate nitrogen in the top foot of soil were reduced to 23 lbs N/acre (figure 3). Most of this was moved to the second and third foot of soil, apparently out of reach of the small root system of the young corn because the corn became chlorotic after the irrigation until additional lagoon nitrogen was added in the next irrigation. During the remainder of the 2001 corn season, 185 lbs lagoon ammonium N was applied and the 80 lbs/acre of organic form N was applied, a nearly optimum amount of nitrogen to apply to a normal corn crop. However, yield of the corn was less than expected, probably due to the early moisture stress and nitrogen deficiency, and only 165 lbs of nitrogen were taken off in the crop. Much of the excess nitrogen, especially the available form, was leached to the groundwater, as evidenced by soil samples taken just before and after the 8th irrigation, which showed a loss of 190 lbs/A of nitrogen. Nitrogen uptake by the maturing corn silage crop during the six day period between sampling dates was not measured, however it could certainly account for only a small portion of the difference.

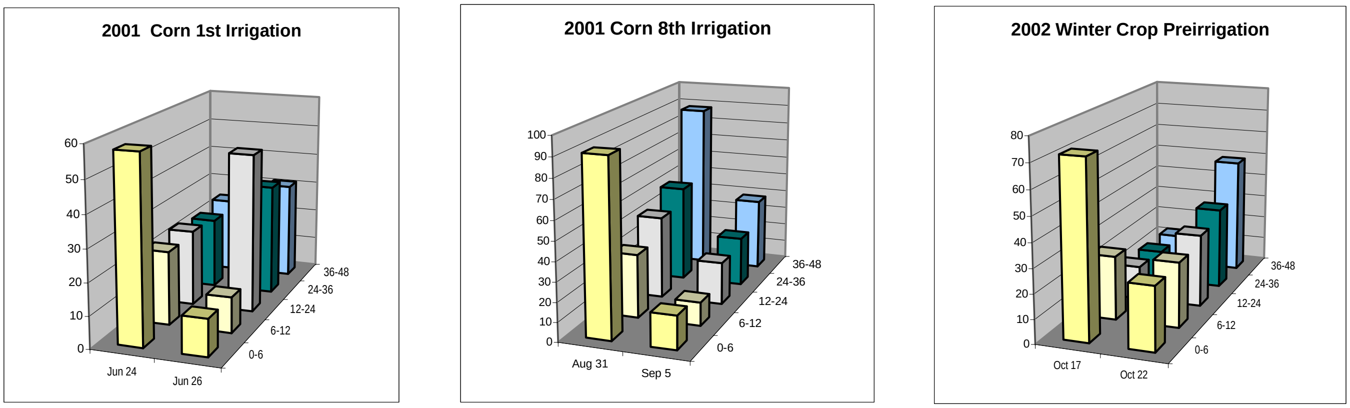


Figure 3. Pounds per acre of nitrate nitrogen by soil depth immediately before and soon after irrigation with fresh water. Hilmar, CA 2001

The overapplication of nitrogen in comparison to less than anticipated crop uptake, corresponds with the timing of the increased concentration of nitrate in the shallow groundwater associated with this field. Figure 4 shows the ten year nitrogen application and crop uptake history of this field, and the associated changes in concentrations in the shallow groundwater. In winter of 2002, the lowest groundwater N concentrations were recorded in early January and remained low the remainder of the winter season, where total nitrogen applications closely matched crop removal. In the summer season, while ammonium nitrogen applications were reasonable, the lagoon water was higher in organic nitrogen concentration than in the two previous years when the pond was brand new. The grower was uncomfortable with relying too heavily on the organic nitrogen to meet crop uptake, and only about 20 to 30% of the organic nitrogen was accounted for when determining application rates. This strategy has apparently resulted in increased nitrate in groundwater, apparently from mineralizing organic nitrogen, because the application rates of the available ammonium form have be less than crop removal in all years.

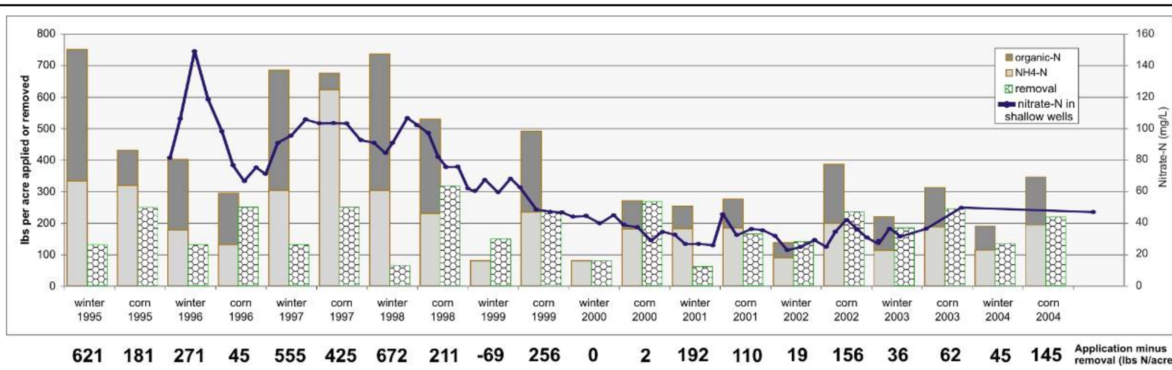


Figure 4. Nitrogen application and crop uptake and impact on shallow groundwater quality, Hilmar, CA 1995-2004 East field.

At the same time, corn yields have not returned to levels achieved during the early years of the project, when it is likely that large amount of mineralizing nitrogen for previous year's overapplications provided supplemental nitrogen. Figure 5 shows the correlation between the last 4 years of corn yields compared to the total amount of nitrogen applied. Yields improve as more total nitrogen is applied (r2 = .90). This implies that, although the groundwater is being adversely impacted by excess nitrogen, the crop itself is not getting enough to maintain optimum yields. The winter forage crop yields appear to be limited mainly by factors other than nitrogen availability.

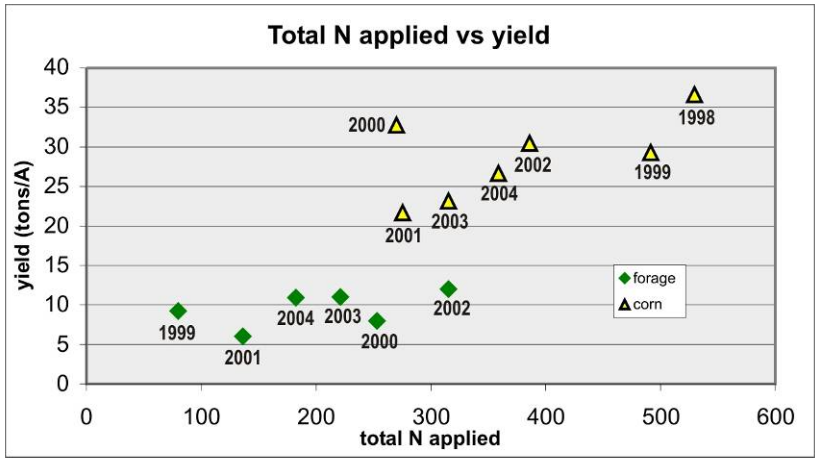


Figure 5. Total nitrogen applied and yield of winter forage and silage corn, corrected to 70% moisture, compared to total nitrogen applied. 1999 – 2004, Hilmar CA.

The West field at this location has historically been managed similarly to the East field. Groundwater monitoring wells were established in 1999 to provide replication for the data generated from the East field. The groundwater originating from the West field did not exhibit the steady decline during the winter 2000 season that was seen in the East field. This is not explained by the nutrient water application, however during this period this field at times received unmeasured amounts of overflow from a settling basin when the pump malfunctioned. The winter application of nutrient water was especially high in solids because it was one of the first fields irrigated after turning on the pump which drew from the bottom of the pond. The summer irrigations were also higher in the relative percentage of organic nitrogen than

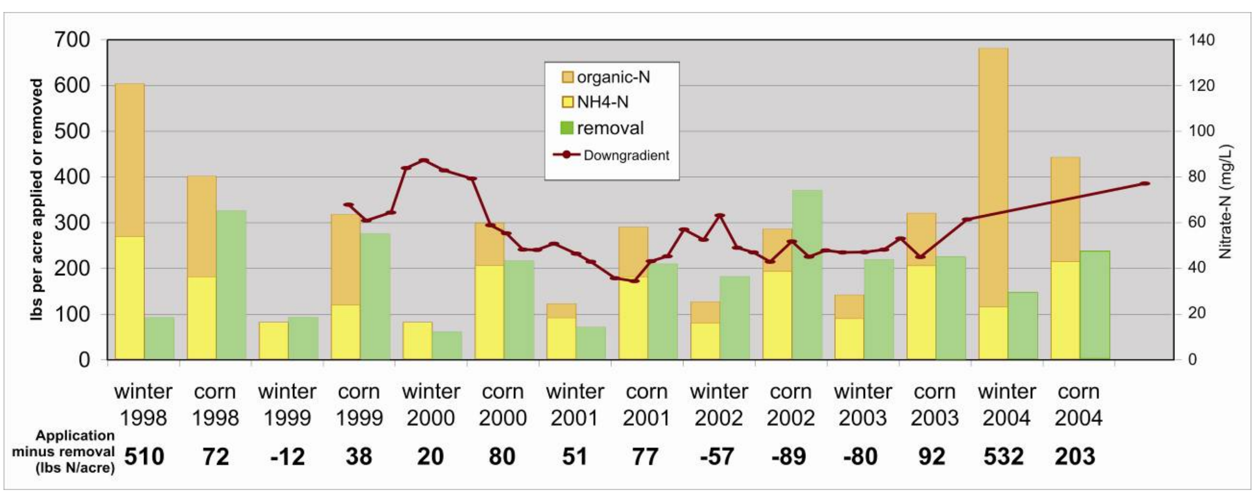


Figure 6. Nitrogen application and crop uptake and impact on shallow groundwater quality, Hilmar, CA 1995-2004 West field.

in previous years likely because the pond had been in service longer and more cows had been added to the dairy that utilized this pond. The most recent groundwater measurements from this field have been higher than in previous recent years. Data for the West field is still preliminary, and is presented in figure 6.

2. Confirm that lagoon water can be used as the exclusive source of field crop nutrients without any adverse impacts on shallow groundwater quality, and that yields can be maintained in the absence of soil nitrogen reserves.

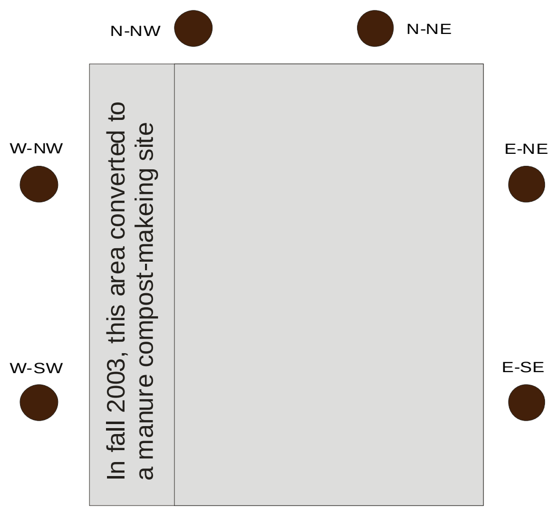


Figure 7. Approximate location of monitoring wells on a field near

A field associated with a diary near Modesto was converted from a walnut orchard into a forage field in the fall of 2001. During the previous at least 20 years prior, only one application of dry manure (applied during the year prior to the year the trees were removed) had been applied. Six shallow groundwater monitoring wells were installed on three sides of the field (figure 7). Initial groundwater concentrations were highest in the two wells immediately downgradient from a microsprinkler irrigated almond orchard. The almond grower indicated in an interview that he typically applies enough nitrogen to approximate nitrogen removed in the crop. The field was originally about 37 acres but in late 2003, 10 acres along the western edge were converted to a composting operation.

This field was flood irrigated as one check, with all valves open at one time. Since the run length was quite long (1585 feet) irrigation uniformity is presumed to be poor. Flow measurement was difficult on this field because the flow meter had to be mounted below grade on a pipeline that ran through an irrigated field. During and after irrigations, flooding in the vicinity of the mounting area made access to the meter difficult. Also, the pipeline configuration limited the amount that the flow could be throttled back without plugging the pipeline or causing the pump to shut itself off. In an effort to control application rates without having to throttle back the pump, on some of the latter irrigations the grower ran the lagoon water pump during only part of the irrigation.

The ratio of organic to inorganic nitrogen in this location was much higher, in general, than in the Hilmar location. The pond was often agitated in an effort to keep solids from accumulating in the pond, however, frequently there were large amounts of solids falling out of the mixed irrigation water and settling out near the upper end of the field. This could account for the increased nitrate concentrations that have been developing in the north and north-west wells (figure 8) compared to the downgradient well towards the bottom end of the field. Also there have been three poor crops: the first corn crop was nitrogen deficient during the 2002 season, especially at the beginning; the 2003 winter forage crop developed a severe case of leaf rust, and the 2004 sudan crop following corn could not be harvested due to early rains.

Applications of ammonium and organic nitrogen compared to crop uptake and its impact on groundwater quality for this field are shown in figure 9. In every case, the available nitrogen applied was less than the amount of nitrogen removed in the crop. Because we knew that much of the organic nitrogen would fall out at the head of the field, many of the particle sizes were large and unlikely to become available during the current crop season, and that the quick test did not accurately predict the amount of organic nitrogen in this particular pond, we were hesitant to allow for more than about 20% of the organic nitrogen to be available this season for the current crop. Clearly, this strategy was not protective of groundwater quality, nor was it particularly successful in optimizing crop production. The advantage to agitating a pond is to prevent the accumulation of solids on the bottom of the pond that will be stored from year to year and need to be applied at excessive rates when the pond is cleaned out. It is desirable to apply all the nutrients generated in a year in that year. However, it appears that this strategy results in excessive amounts of organic nitrogen being applied in a manner that is difficult to manage agronomically.

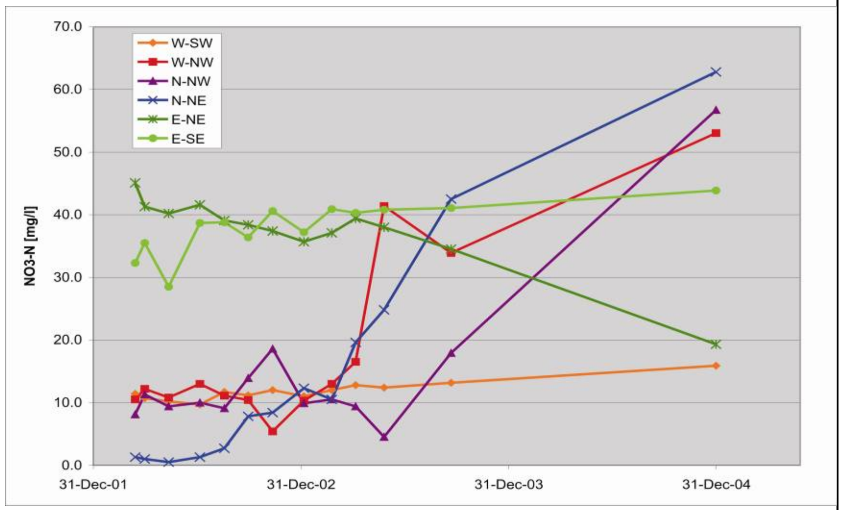


Figure 8. Nitrate concentration in shallow groundwater monitoring wells associated with a field with minimal previous history of manure application. Modesto CA, 2002 - 2004

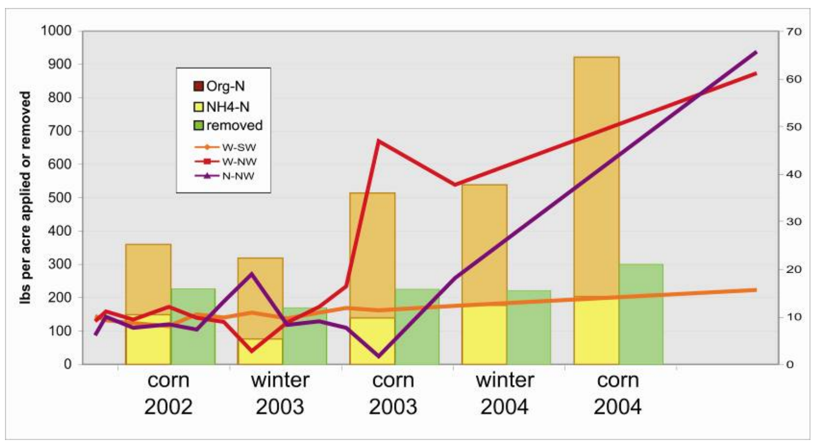


Figure 9. Nitrogen application and crop uptake with impact on shallow groundwater quality, Modesto, CA 2002-2004

The five- to six- fold increases in the nitrates in three of the wells over the course of the three years that the lagoon water has been applied in this location can therefore be attributed to several factors. These include less-than expected crop yields, the difficulty in capturing the mineralizing nitrogen when high amounts of organic nitrogen are applied, and the uneven distribution nutrients down the length of the field from both solids settling out at the head of the field and the uneven irrigation distribution uniformity due to excessive run lengths.

Conclusions

There are several significant implications of this study for Central Valley dairies. This study clearly shows that careful management of manure nutrients can significantly improve shallow groundwater quality, and many of the techniques and protocols to accomplish this have been developed in the course of conducting this project.

However, in carrying this study forward several years longer, it becomes evident that not only is it imperative that manure nitrogen applications be carefully controlled and managed but also that accomplishing this over a sustained period of time is very difficult. Even a single nappropriately applied lagoon water application can have fairly immediate significant impact on groundwater quality. Yields are difficult to maintain when a significant amount of nitrogen is in the organic form, while at the same time, allowing the organic nitrogen to accumulate in the pond over many seasons sets up a situation where this sludge must be disposed of all at one time.

Developing better methods than those that have been tested to date to apply dairy lagoon nutrients to farmed ground is imperative if groundwater quality is to be protected and in many cases enhanced from its current state. Needed techniques include methods of minimizing the amount of organic nitrogen in dairy nutrient water applied through irrigation systems, methods of minimizing leaching through inefficient irrigations, especially pre- and first irrigations, and methods keeping track of the amount and type of organic nitrogen applied and predicting when it will mineralize in order to optimize crop utilization and avoid the buildup of large amounts of leachable nitrate in the soil.

This project has been supported by grants from UC Sustainable Agriculture Research and Education Program, USDA NRCS EQIP, and the California Dairy Research Foundation

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Generalized Nitrogen Demand Curve for Small Grains

David M. Crohn, Associate Professor and Extension Specialist, Dept. of Environmental Sciences
University of California, Riverside, CA 92521
(951) 827-3333, David.Crohn@ucr.edu

Marsha Campbell-Matthews, Farm Advisor, University of California Cooperative Extension
3800 Cornucopia Way, Suite A., Modesto CA, 95358
(209) 525-6800, mcmathews@ucdavis.edu

Introduction

Small grains are frequently planted as winter crops in California. These crops may be fertilized conventionally or with organic fertilizers, such as dairy manures. The leaching potential of the nitrogen (N) in applied fertilizers can be reduced by timing the supply of plant available N (PAN) to coincide with crop uptake. For conventional fertilizers, this means supplying N at measured rates as the crop develops. For organic fertilizers, mineralization rates much be considered when deciding on application timing and rates (Crohn, 2006).

Regardless of the fertilizer used, delivering N efficiently to small grains requires a way to predict crop uptake over time. We have therefore developed an empirical model for estimating crop N uptake continuously over time where N is not limiting. The model was calibrated using field measurements of a number of small grains typical of Stanislaus County dairy operations. The model is easily calibrated to consider changing weather, farm soil conditions, and specific crop characteristics and therefore cannot be completely accurate.

Model Description

Crop N uptake is modeled using an *S*-shaped curve known as *logistic function*. To account for temperature effects, the model is determined as a function of growing degree-days (GDD) which are calculated as the sum of all degrees above 32°F throughout the growing season. N removal rates begin slowly, accelerate, and the decrease late in the season. Late season slowing may not be apparent if the crop is harvested before slowing is significant. The predictive equation was formulated using five parameters. Three determine the overall shape of the curve. The fourth, t_H, represents the GDD expected between planting and harvest while the fifth, C, is the N, in lb/ac, expected in the harvest.

Parameter Development

To develop parameters for winter grains, replicated samples from some 29 winter plantings were collected throughout several winter growing seasons between 1997 and 2002 from Stanislaus County dairies. Crops included various strains of wheat, triticale, rye, and oats. Three to four replications were included for each planting. Plants were harvested by collecting between 6 and 60 ft^2 per replication. Plants were clipped at the soil surface prior to jointing and at between ½ and 1½ inches after jointing. Early harvests (<24 in) were all carried out by hand. Some later harvests were collected using a sickle bar mower. For smaller samples, the entire amount was dried at 120°F until dry to estimate moisture. Subsamples were used for this purpose later in the growing season. Samples were ground to a 2 mesh using a Wiley mill and representative sub-samples were measured for total N by the DANR Laboratory using a combustion method (LECO FP528).

Shape parameters were fit to the model by minimizing the sum of squared error. Parameters were first developed for each considered crop, including Dirkwin Wheat (5 plantings), Swan Oat (6 plantings), T2700 Triticale (9 plantings), Cayuse Oat (5 plantings), Longhorn Wheat (2 plantings), and Ensiler Oat (1 planting). This generated six different *crop models*. After determining parameters for each crop separately, a *general model* was also developed by fitting the data from all selected grains simultaneously. The degrees to which the different crop models and the general model represented observed variance were then compared through their associated r^2 statistics. This was done by comparing the r^2 for each crop model (r^2 custom) to the r^2 the results when general model parameters were used to represent that crop (r^2 joint fn). An r^2 for the general model itself was also computed (r^2 all crops).

Results and Discussion

Although these crops develop differently, we found a single equation that adequately described N uptake by all grain crops when adjusted for local conditions using harvest time and yield N information along with local GDD data (Fig. 1). Because the model is intended to represent conditions where N is not limiting, data from four of the plantings were ultimately excluded from the study due to slow early development followed by rapid midseason growth, a growth pattern suggesting initial N deficiency followed by fertilization. One planting each for Dirkwin Wheat, Swan Oat, Longhorn Wheat, and Cayuse Oat, was excluded reducing the total number of plantings used to parameterize the model to 25.

Table 1 lists the r^2 values derived from the data. When parameters were generated separately for each crop (r^2 custom, data not shown), r^2 values were above 0.92 for all crops except Longhorn Wheat which had an r^2 of 0.83. The overall r^2 statistic for the model when parameterized using all crops was 0.91. When these parameters were used to predict uptake independently for each crop (r^2 joint fn), differences with the custom r^2 statistics were ≤ 0.01 in all cases. Because r^2 values were quite similar between parameters derived for individual crops and parameters derived from all crops, there is little justification for promoting crop-specific parameters and a single function can be used for all small grains.

The fits with the data were quite reasonable considering the environmental variability associated with measurements. Figure 1 compares selected measurements to predicted curves for four crops. Each curve uses the same set of shape parameters. Local conditions are represented by different values of C, the amount of N harvested with the crop, and t_H, the number of GDD between planting and harvest. This means that the shape of the curve can be determined by its endpoint.

Model Use

Growing degree-day data for many California locations are readily available through the UC IPM Online web site:

http://www.ipm.ucdavis.edu/WEATHER/ddretrieve.html.

Options for determining degree days should be: Fahrenheit, “Enter Lower”=0, leave “Enter Upper” blank, “Method of Calculation”=”Single sine”, “Upper cutoff method”=”Horizontal or none”, click on “Calculate.” This takes you to a weather station page where a location near or similar to the farm location should be selected. For a t_H value. the “Start date” should be the planting date while the "End date" should be the estimated harvest date. For various values of t, simply change the "End date" to dates during the growing season.

Estimates can then be made graphically with Fig. 2. To estimate uptake, find the adjustment factors associated with the anticipated harvest time, t_H, and the time, t, at which the cumulative N uptake is to be known. Divide the second adjustment factor by the first and then multiply by the N expected to be removed with the harvest. If C_t is the cumulative amount of N in the crop at time t (in GDD), then

$$C_t = (\text{lb/ac N removed in harvest})\left[\frac{\text{Uptake factor for } t}{\text{Uptake factor for } t_H}\right]. \qquad [1]$$

Example 1: Consider a crop to be harvested after 4000 GDD. If 300 lb/ac are expected to be removed in the harvest, how much N would the crop have taken up after 2500 GDD?

Solution: the Uptake factor at the harvest time of 4000 GDD is about 51. The uptake factor for the time of interest, 2500 GDD, is close to 34. Therefore:

$$C_{2500} = 300 \text{ lb/ac}\left[\frac{34}{51}\right] = 200 \text{ lb/ac}. \qquad [2]$$

Example 2: For this same system, how much N is removed between 1500 GDD and 2500GDD?

Solution: From Eq. [2], we know that cumulative removal at 2500 GDD is 200 lb/ac. The uptake factor at 1500 GDD is near 8.5.

$$C_{1500} = 300 \text{ lb/ac}\left[\frac{8.5}{51}\right] = 50 \text{ lb/ac}. \qquad [3]$$

Since 200 lb/ac – 50 lb/ac is 150 lb/ac, it is estimated that 150 lb/ac is taken up by the crop between 1500 GDD and 2500 GDD.

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Table 1. Statistical correlations when (1) the model is parameterized independently for each crop, (2) the model is parameterized simultaneously for all crops, and then applied to a particular crops. The overall r^2 for the model parameterized for all crops is 0.91.

	Dirkwin Wheat	Longhorn Wheat	Swan Oat	T2700 Triticale	Cayuse Oat	Ensiler Oat
Fitted Plantings:	4	2	6	9	4	1
r^2 custom:	0.96	0.83	0.92	0.92	0.93	0.97
r^2 joint fn:	0.95	0.82	0.92	0.92	0.93	0.97

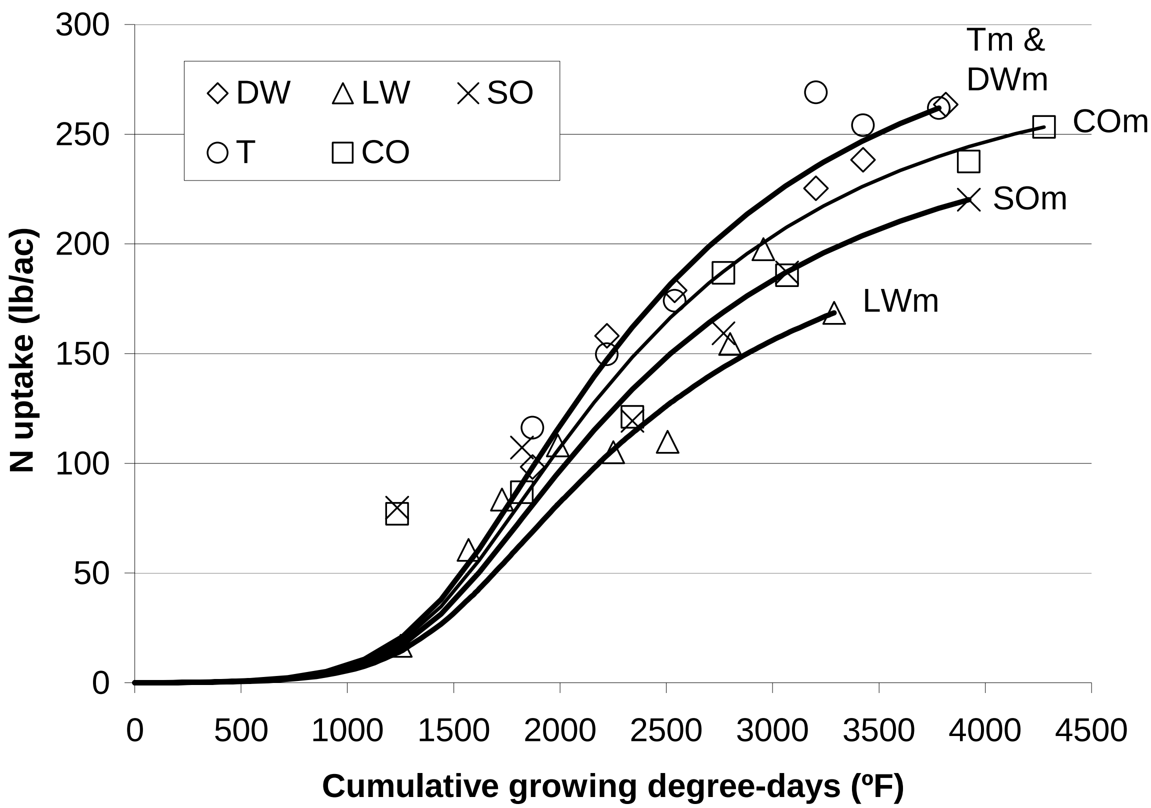

Fig. 1. Observed and model N uptake for selected experiments. Grains include T2700 triticale (T), Dirkwin wheat (DW), Cayuse oats (CO), Swan oats (SO), and Longhorn wheat (LW). Lines represent the model while points represent actual measurements. The T2700 triticale and Dirkwin wheat model lines are superimposed.

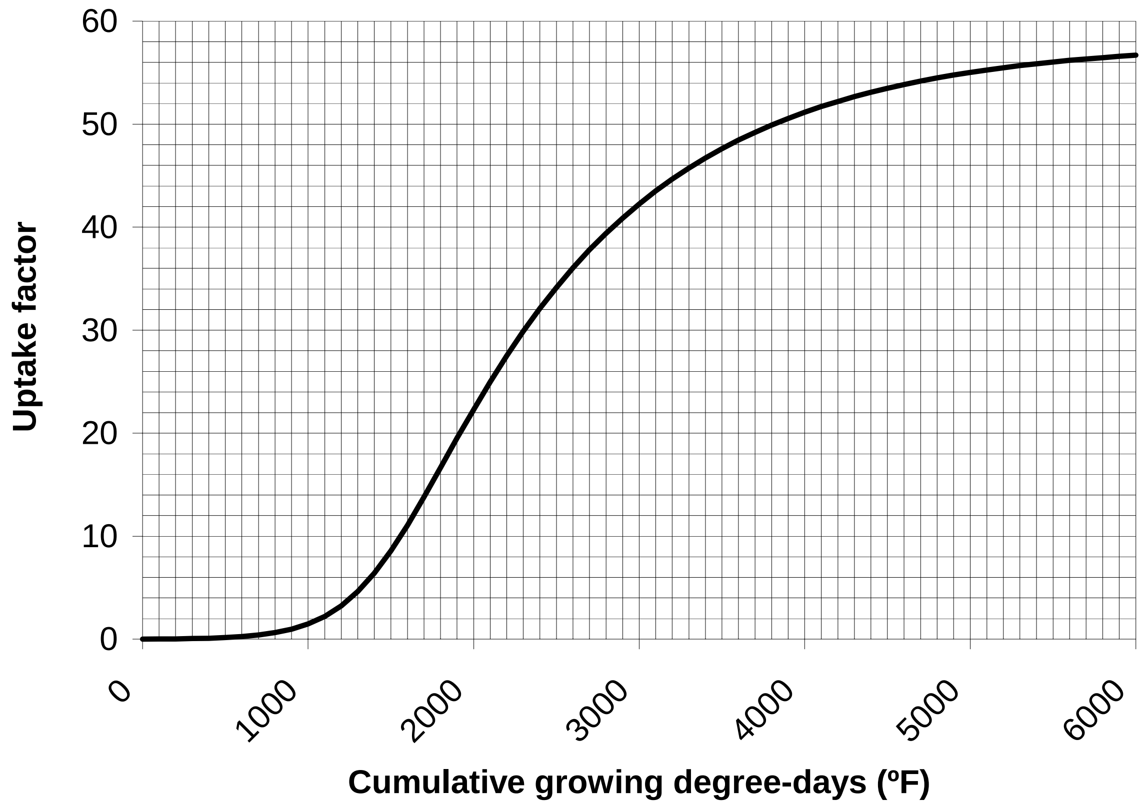

Fig. 2. Graph for estimating N uptake over time in small grains. To estimate uptake at a particular time, *t*, the uptake factor associated with time *t* must be divided by the uptake factor associated with the time of the expected harvest, t_H. The result is then multiplied by the N removed with the anticipated harvest.

Ammonia Emissions from Dairy Effluent Stream

Dave Goorahoo[1], Charles Krauter and Matt Beene
Center for Irrigation Technology & Plant Science Dept.,
California State University-Fresno. 5370 N Chestnut Avenue, Fresno, CA 93740.
Phone (559) 278-8448, FAX (559) 278-6033.
[1]dgooraho@csufresno.edu; [2] charles_krauter@csufresno.edu; [3] mattbeene@csufresno.edu

Introduction: In California, which is now the number one dairy producing state in the U.S. (CDFA, 2003), dairy manure is commonly handled as an effluent stream of liquid or slurry by means of a hydraulic flushing - lagoon storage - irrigation system. Alternative methods of treatment of the dairy effluent and their effect on crop nutrition are presented in a companion paper by Beene et al. (2006). Major problems associated with the manure management are high solids and nutrient contents of the effluent stream, and gas production during the decomposition of manure in storage and after field application. High solids content causes fast sludge buildup in storage lagoons, thus reducing the available storage volume, and when the effluent is applied to fields this can cause high solids loading to the soil hindering the crop seed germination and growth. High nutrient contents tend to cause overloading of land with nutrients, especially nitrogen and phosphates, causing contamination of surface and ground water resources.

Of the gases emitted, ammonia (NH_3) is of primary concern because of health, environmental and economic concerns. Ammonia is the dominant gaseous base in the atmosphere and a principal neutralizing agent for atmospheric acids. NH_3 and alkaline soil dust in the atmosphere may control the acidity of precipitation. Volatilized NH_3 may react to form ammonium nitrate or ammonium sulfate and thereby contribute to airborne particulate matter ($PM_{2.5}$). Nevertheless, NH_3 remains one of the most poorly characterized atmospheric trace compounds. This situation persists as a result of several factors: experimental difficulties associated with NH_3 measurements, rapid gas-to-particle conversion of NH_3 in the atmosphere, capacity of soils, organic matter, and vegetation to act as both sources and sinks for atmospheric NH_3, and variability in nitrogen fertilizer management and related NH3 emissions. Hence, as we attempt to ensure the sustainability of the dairy operations, there is a need to quantify the NH_3 emissions at dairies.

The Central San Joaquin Valley (SJV) of California with its growth of Concentrated Animal Feeding Operations (CAFO) and sprawling urban development is a paramount example of the serious problems in the United States of accommodating population growth in prime agricultural land areas (Mitloehner, 2005). Ammonia (NH_3) emissions from dairy effluent may be significant contributors to the SJV air problem. In this presentation, we begin with an overview of nitrogen (N) loss processes and focus on the factors affecting NH_3 volatilization. Then we discuss the process-based approach for predicting ammonia emissions from the dairy effluent stream. We conclude the presentation with an brief overview of our current research involving the use of two different ammonia sampling systems- filter packs and tunable diode lasers (TDL) (Fitz et al., 2003; Beene et al., 2002 & 2003; Carstensen et al., 2004) and the advancement in data analyses since the presentation last year by Goorahoo et al. (2005).

N Loss Processes: Essentially all of the nitrogen excreted in animal manure is contained in a variety of organic nitrogen compounds (EPA, 2004). If inorganic forms of nitrogen (ammonia, nitrites, and nitrates) are excreted, they usually are present in trace amounts. However, the conversion of organic nitrogen to inorganic nitrogen (mineralization) begins immediately after manure is excreted as indicated in a typical representation of the nitrogen cycle (Figure 1). Gaseous N losses involve complex processes mainly with NH_3 volatilization and denitrification. While volatilization is more prevalent with surface exposure of ammonia sources, such as a dairy lagoon and surface application of effluent onto fields, denitrification is associated with soil-incorporated N.

The nitrogen emissions that occur at dairy lagoons and land application sites are primarily emissions of ammonia (EPA, 2004). Most of these emissions occur from the ammonia which is present in the dairy effluent at the time of land application. A smaller and less significant amount of ammonia formed during mineralization may also be emitted. However, the rate of mineralization will be relatively slow because the organic nitrogen compounds remaining in the manure are most resistant to biodegradation. Therefore, manure that is collected and spread on the land immediately will contain a higher concentration of organic nitrogen than manure that has been stored for an extended period of time, such as settled solids in anaerobic lagoons (EPA, 2004). Although this organic N will eventually mineralize to NH_3, several transformations (e.g., fixation by clay minerals and organic matter, direct utilization by higher plants, and immobilization by soil microorganisms) limit emission potential (EPA, 2004).

Factors Affecting NH_3 Volatilization: Most of the livestock-derived NH_3 lost to the atmosphere originates from manure and slurry applied to the soil surface (McGinn and Janzen, 1998). The proportion of NH_3 lost, however, varies widely depending on the material applied and management practices. Thompson et al. (1990) reported that the total NH_3 loss from slurry applied to grassland was 1.5 times greater than when slurry was applied to bare soil. Forty to seventy five percent of the N in manure is present either as ammonium N or as urea and uric acid N which can readily hydrolyze to ammonium N (McGinn and Janzen, 1998). When left exposed to the atmosphere, much of this ammonium N can be lost as volatilized NH_3. These losses are affected by factors such as ammonium N content, manure pH, time of incorporation of manure into soil, drying rate, temperature, wind speed, and rainfall or irrigation occurring after application (Sommer et al., 1991 & 1993; EPA, 2004).

Process-based NH_3 Emissions Model: Figure 2 shows an example of one of the process based models developed by the EPA (2004) National Emissions Inventory (NEI) for NH_3 emissions from animal husbandry. In summary, the model considers each of the processes occurring on a typical dairy, and calculates the resulting ammonia emissions from each. By tracking the amount of manure through each stage at the farm and using mass conservation, the total ammonia emissions for each process and for the farm as a whole is estimated. The main processes treated in the model include the nitrogen excretion from the animals, animal housing, manure storage and land application of manure.

Current Research on NH_3 Emissions: Over the past five years we have been monitoring ammonia emissions from various agricultural operations in the San Joaquin Valley, California (Krauter, 2001; Krauter et al. 2002 & 2003; Potter et al., 2001). Last year, we presented an overview of research involving the use of two different ammonia sampling systems- filter packs and tunable diode lasers (TDL) (Goorahoo et al., 2005). Basically, the filter pack, sometimes referred to as a denuder, is a device that pulls air through a treated medium that changes the NH_3 to a solid. Glass filters are impregnated with 3% citric acid in 95% ethanol solution. The NH_3

forms ammonium citrate on the treated filter. In the laboratory, the micro-grams (*u*g) of NH_3 on the filters are determined by dissolving the ammonium in de-ionized water and measuring the concentration using Nessler reagent and a spectrophotometer. The TDL system measures gas concentration over an open path. It consists of an integrated transmitter/receiver unit and a remote, passive retro-reflector array. The transceiver houses the laser diode source, the drive electronics, the detector module, and microcomputer subsystems. The laser light emitted from the transceiver unit propagates through the atmosphere to the retro-reflector and returns to the source, where it is focused onto a photodiode detector. A portion of the laser beam is passed through an onboard reference cell to provide a continuous calibration update.

The filter pack method for collecting atmospheric NH_3 requires several hours to collect a sample in most instances (Figure 3). That time period is too long to characterize short term operations such as those at dairies where a process occurring over a few minutes may produce significant NH_3 emissions that would not be detectable over the long sampling period of the filter packs. However, the data collected with the TDL depicted the periods of relatively higher emissions occurring during the day and night times which generally go undetected with the filter pack sampling (Figure 4).

During the last year, in addition to inverse dispersion modeling using the EPA approved models we have attempted to use the method of moment (MOM) analyses to quantify the relative changes in NH_3 emissions as a result of management practices. In this approach, we curve fit the TDL data using Mathcad 2000 software as shown in Figure 5, and make the following assumptions: (1) that a constant area (fetch) is monitored by the TDL; and (2) the wind pattern is consistent. The n the following mathematical equations are applied.
The Zeroth moment, M0, represents the mass under curve and is given by:

$$\boldsymbol{Mo} = \int_{t=0}^{t=1} \boldsymbol{f}(\boldsymbol{t})\, \boldsymbol{dt}$$

The first moment, M1, is given by: $\boldsymbol{M}1 = \int_{t=0}^{t=1} \boldsymbol{t}\ \boldsymbol{f}(\boldsymbol{t})\, \boldsymbol{dt}$

And the mean concentration is concentration is calculated using: $\boldsymbol{Mean} = \frac{\boldsymbol{M}1}{\boldsymbol{Mo}}$

With a variance represented by the second moment, M2, as:

$$\boldsymbol{M}2 = \int_{t=0}^{t=1} \left(\boldsymbol{t} - \frac{\boldsymbol{M}1}{\boldsymbol{M}0} \right)^2 \frac{\boldsymbol{f}(\boldsymbol{t})}{\boldsymbol{M}0}\, \boldsymbol{dt}$$

Our analyses to date using the MOM approach have indicated that using the Mathcad curve fitting and method of moment analysis approach with acknowledgement of certain simplifying assumptions may be useful for comparing the relative amount of gas emitted over a given area covered by TDL path length. For the remainder of the project, we intend to collect TDL data and apply the MOM analyses for the lagoons, free-stall areas, and the fields following effluent application. In addition to the spatial measurements on the dairy, we will monitor for both diurnal and seasonal fluctuations in the emission of NH_3 in an attempt to quantify any temporal variations.

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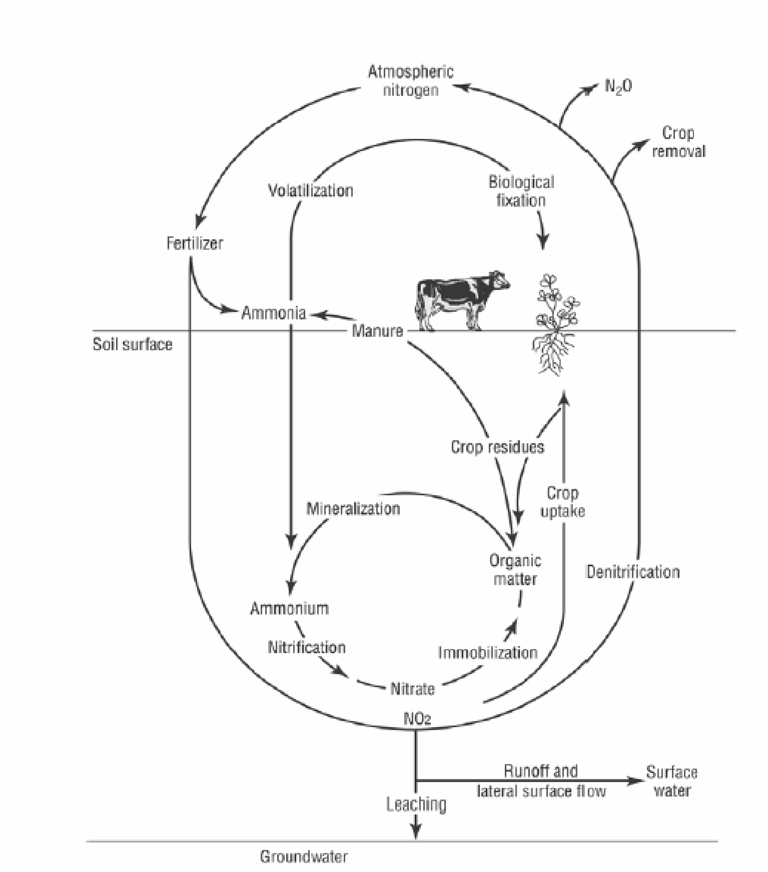

Source: Adapted from National Research Council 1993.

Figure 1: The Nitrogen cycle.

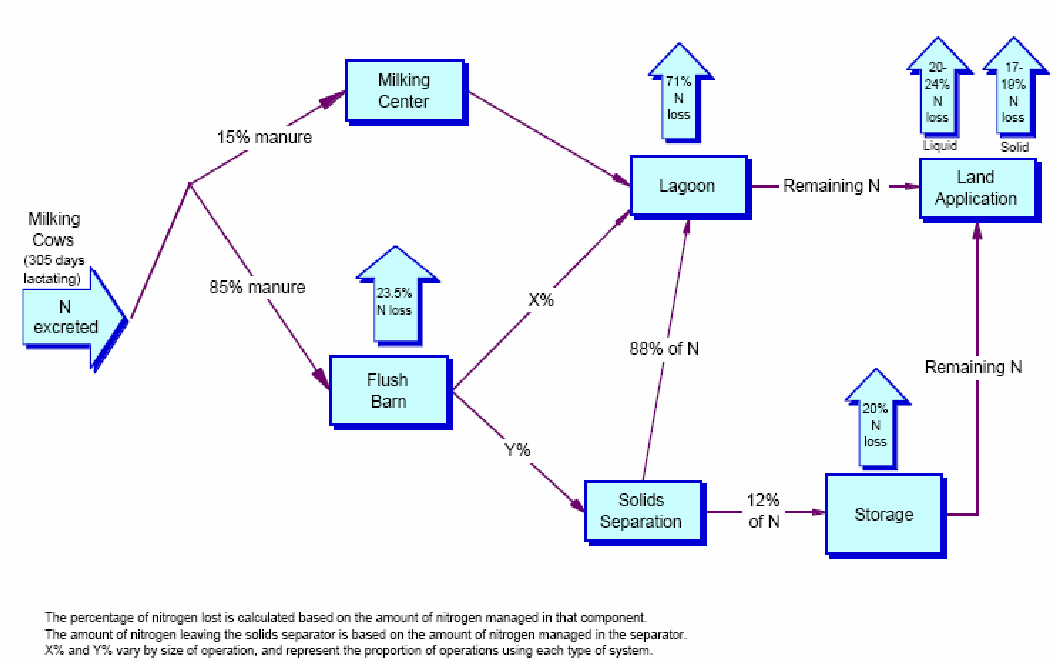

Figure 2: An example of one of the process based model for estimating N losses from a dairy flush barn developed by EPA (2004).

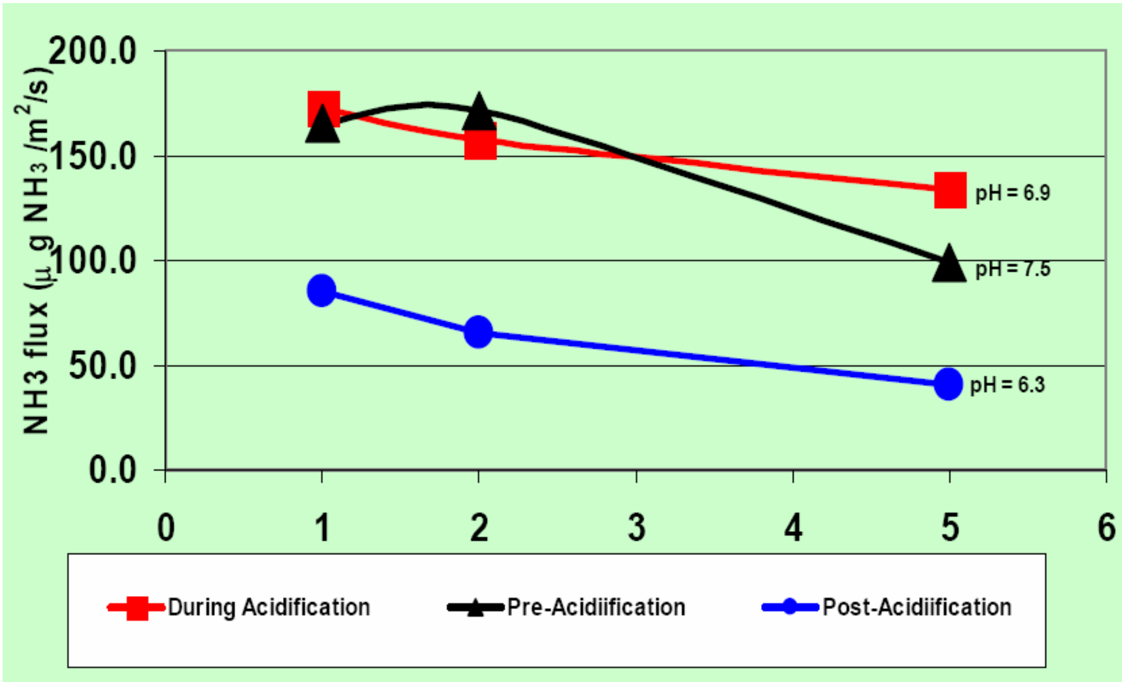

Figure 3: Ammonia fluxes measured with active denuder samplers before, during and after acidification of Lagoon at CSUF dairy.

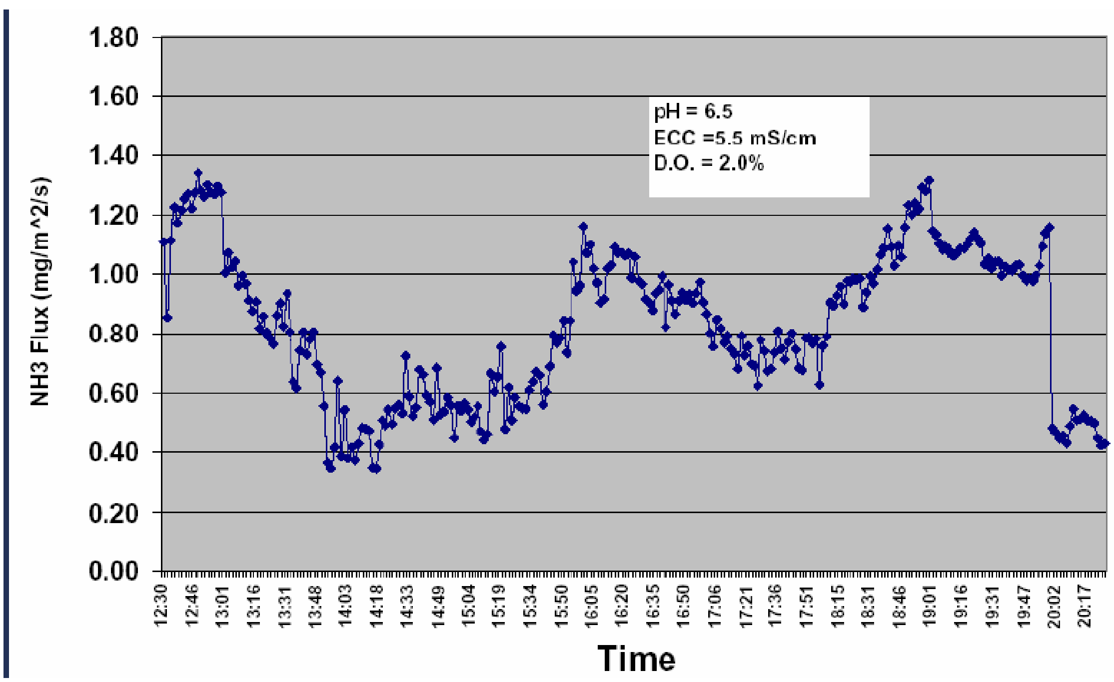

Figure 4: Ammonia fluxes measured with TDL during an 8-hours period of acidification of Lagoon.

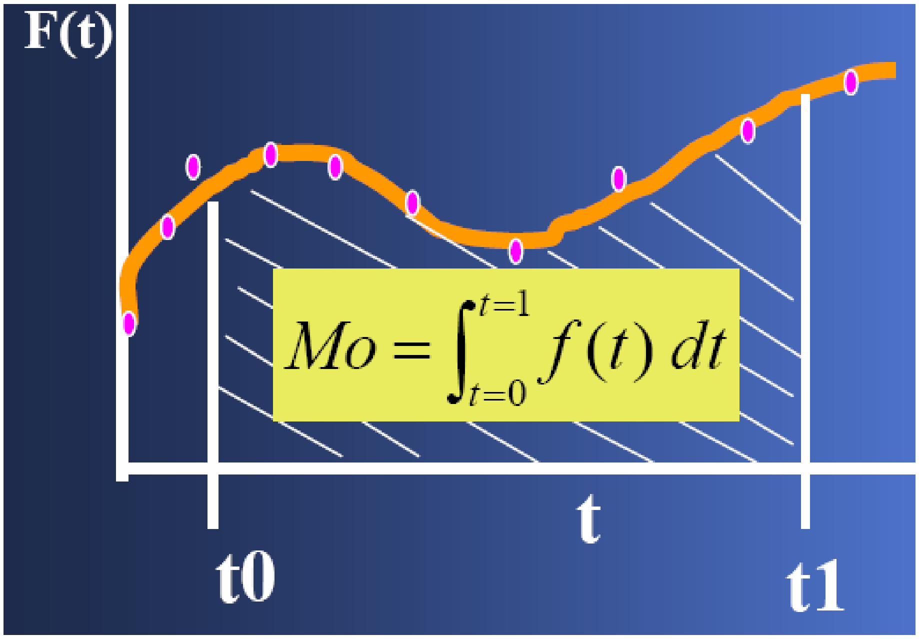

Figure 5: Schematic depicting the curve fitting of data and the application of area represented by the zeroth moment (Mo).

Treatment	Total x10^3	Mean x 10^3	Variance x 10^7
Pre acid	7.252	8.467	2.362
Acid	5.415	4.678	0.7771
Ratio of Acid: PreAcid	74.7	55.2	32.9
Relative change	**25.3**	44.8	**67.1**

Figure 6: Relative ammonia concentration values obtained using the method of moment (MOM) analyses for a lagoon subjected to acidification.

Methods for Treatment of Dairy Effluent and The Effect On Crop Nutrition

Matt Beene, Charles Krauter and Dave Goorahoo
Center for Irrigation Technology & Plant Science Dept.,
California State University-Fresno. 5370 N Chestnut Avenue, Fresno, CA 93740.
Phone (559) 298-6072 ext.215, FAX (559) 298-3576.
mattbeene@csufresno.edu

The highest value agricultural process in California is the use of a dairy cow to turn forage into milk. That process, like any other, is not completely efficient. In addition to milk, cows convert feed into manure, urine, digestive gasses, and more cows. The first two of these, manure and urine, are viewed in a number of ways. The dairyman sees them as waste to be removed from the dairy. The public and regulatory agencies see them as potential pollutants of air and water. Agronomists and soil scientists view them as valuable resources to be recycled for crop nutrition. Dairy operations have been evolving to meet each of these needs, ideally to the benefit of everyone.

There are approximately 2500 large dairies in the state and each must collect and deal with the solids and liquid that the cows produce. There are many different ways to accomplish that task and the particular method will often affect the volume, availability, and nutritional content of the manure to be used for crop nutrition. The combination of solids and liquid from the manure and urine produced by the dairy cows will be referred to as “dairy manure” for purposes of this discussion. There are several components of the diary manure that may or may not be separated from each other in the process of collection, treatment and disposal. These components are currently being evaluated by various regulatory agencies to determine the potential for water and air pollution and to evaluate different practices to minimize the environmental impact of dairy operations. Much of this work remains to be done and these regulatory agencies need input from agronomists to assist them in selecting management practices that reduce pollution while maintaining the value of the dairy manure for crop production.

Dairies can be classified by the different methods used to collect, treat and dispose of manure. There are three basic types of dairies with regard to method of manure collection and a variety of technologies to separate it into its components and treat them. In nearly every case, the treatment is completed by the application of solids or liquid to crop land where the organic matter can be mineralized and the plant nutrients released for crop uptake. The particular method of separation and treatment will affect the quantity and quality of the manure for use as fertilizer. This paper will address the different manure handling methods and the characteristics of the products of each with respect to crop fertilization and environmental impact.

The oldest and least common of the three basic manure handling systems used on California dairies is the open lot operation where the animals are kept in a large corral or pasture. The manure is deposited over the entire area, though it may be concentrated around shade structures, feeding and watering troughs. Periodically manure in the corral is scraped into a pile where it may compost or be hauled out to be spread. The liquid in the manure either evaporates or leaches into the soil prior to collection. This type of dairy operation is becoming less common for large operations since it affords the least opportunity to manage the manure.

The second manure management method is the free stall barn where the cows each have a stall that is elevated and lined with bedding. They can enter and leave the free stalls at will as they are fed and milked. The barns are usually long with a lane between the line of free stalls and the feeding area where forage is delivered by a truck. There is usually a corral adjacent to the barn that they are allowed to use in good weather. The feeding area is a long, sloped, concrete paved lane where the cows stand as the feed is delivered. A large percentage of the manure is deposited on this lane as the animals eat. The lane is flushed with a large head of water several times each day, often when the cows are being milked, to remove the accumulation of manure. The flush lane drains to a sediment trap where the mineral solids are settled out. After that, there are a variety of separation and treatment techniques that will be discussed in detail below. This free stall – flush lane dairy is the most common type of large dairy in the Central Valley. The frequent flushing of the area where the animals stand has numerous advantages for animal health and is an effective method of manure removal. The primary disadvantage is the large volume of water required. After some type of separation process, the liquid and remaining solids are usually stored in a single or a series of ponds called lagoons. Water is pumped from a lagoon for subsequent flushing and eventually is pumped onto cropland.

The third manure handling method is both an old technique, long used in small operations and the newest one for collecting manure without diluting it in flush water. Some operations that have been constructed with free stalls and flush lanes will scrape it into a pit or vacuum the fresh manure into a tank without adding water. This reduces the volume and requires much less area for the treatment process. It may also be combined with treatments such as digesters to generate methane or reduce air emissions by quickly removing the manure and treating it in an enclosed tank or chamber.

The free stall / flush lane dairy is the most likely type of manure handling system to be encountered by an agronomist who will need to factor the composition of the effluent into a crop nutrition program. The large volume of water from the flush system will be available to add to irrigation water, hopefully when it is needed by the crop. The solids from the flush may be available to spread prior to planting. The raw flush water from the free stall barns is generally 0.5% -2% solids. These solids are a mix of sediment, partially digested fiber and fine particles. Nearly all of the N and most other plant nutrients are in the organic, fine solids or dissolved in the water. The method of separation used at the dairy will determine how much of those solids are in the lagoon water and how much is separated out to be spread.

There are a number of methods used to separate the solids from the flush water. Most dairies have a sand trap or processing pit as the first step in managing the flush water. Soil tracked in from the corrals by the cows or sand, when it is used as bedding in the stalls, is removed in a settling basin before it can plug the screens or fill up lagoons that are difficult to clean. The remaining organic solids plus the liquid can be separated be further settling, floating, screens or a combination of these. The coarse, partially digested fibers are often removed from the flush water by a sloping screen. The flush water is delivered to the top of the screen runs down the surface. Water and fine solids pass through and are piped to the lagoon system while the coarse solids fall off the bottom or are scraped off and piled to dry. These fiber solids are primarily cellulose with very little value for plant nutrition. They are often returned to the corrals or free stalls for bedding where their absorbent qualities are useful. Some of these coarse solids will find their way back into the flush system and the rest will eventually be collected and spread on fields.

Screen separators generally pass most of the fine solids along with the water. The separation efficiency is usually no more than 35%. More efficient separation can be achieved with very fine screens, settling ponds or other structures where the flush water is held for sufficient time to allow the slow separation of the various components. This may be the initial lagoon, a large sloping slab or a shallow pit with perforated sides called a "weeping wall". The separation efficiency of these methods is generally greater than screens but they take up considerable area and require more labor to clear the separated solids from the structure. The coarse and fine solids tend to be mixed together from such a system which increases the significance of solids spreading for crop nutrition.

Some dairies with a need to use the coarse material for bedding and the fine material for nutrient recycling or those wishing to reduce the organic content of the lagoon water may use a combination of screens and settling to remove the coarse and fine solids separately. The resulting water is about 0.1% - 0.3% solids and will often support a bloom of photosynthetic bacteria that are able to thrive in the less anaerobic lagoon conditions. These lagoons often acquire a red or rose color and are reported to have less odor and, possibly, a reduction in other emissions. Use of water from these red lagoons will need to account for the decreased nutrient content. The need to increase the fraction of low concentration lagoon water in the irrigation stream is helped by the fact that these systems often hold a much larger volume of water in the larger lagoons.

While every dairy is somewhat different, it is possible to make some generalizations with respect to the quality and quantity of water and solids available for crop nutrition. The type of separation and lagoon systems found at a free stall / flush lane dairy can determine the manner in which the crop is fertilized. Table 1 is a summary of the dairy manure handling systems and the nutritional value of the water from them. A dairy with a single lagoon with a screen separator will keep most of the fine solids in the water where they will either settle in the lagoon as sludge that must be removed to be spread or kept in suspension by circulators to be pumped out with the water and mixed in the irrigation stream. The nutritional value of the water and fine solids will be high compared to other systems where the fine solids are more efficiently removed. A system such as this will provide a considerable amount of N and other nutrients in any irrigation. More efficient separation systems will provide less N in the irrigation and it will be primarily in the NH_4^+ form rather than the organic N from the fine solids. Those systems that separate the fine solids and allow their storage for later field spreading may afford the agronomist with more flexibility in the nutritional program. The NH_4^+ -N in the water may be sufficient to maintain fertility during the growing season without over fertilizing that can result in leaching losses. The stored solids can be spread as a pre-plant application where the slower release of N from the mineralization of the organic matter will be more effective.

The estimates in Table 1 are not accurate enough to be used for precise planning of a forage fertilizer program. They should only be used to make preliminary estimates for a fertility plan that should be based on an analysis of the nutritional content of the water and solids available from a particular dairy. These estimates only apply to free stall / flush lane dairies or those others that use a large lagoon to dilute the dairy manure. Open lot and the scrape or vacuum collection systems generally have much higher solids percentage and may not be suited to application through irrigation. Open lot dairies will usually spread the collected dry solids between crops and have very little water to deal with. The scrape and vacuum collection systems may apply the fresh dairy manure as a slurry or treat it in some type of anaerobic digester to convert some of the organic material to methane. The solid material from such a digester may have a high plant nutrition value similar to composted manure and can be used accordingly.

Table 1. Estimated Nitrogen content of Lagoon Water from a Free Stall Flush Lane Dairy

		Lagoon System			
Separation System	Separation Efficiency	Single Lagoon	Multiple In Series	High Volume Low Loading	Fine Solids Organic N (sludge)
Single screen or small pit	<40%	High	Medium	Low	most in lagoon
Multiple screens or pit + screen	30%-75%	Medium	Low	Low	50/50 lagoon/separated solids
Settling pond, Fine Screens, Pad, Weeping Wall, or Combination	>60%	Medium	Low	Low	most in separated solids

High = 8 – 15 lb. N per 1000 gallons. (1/3 NH_4^+, 2/3 organic N)
Medium = 4 – 8 lb. N per 1000 gallons. (1/2 NH_4^+, 1/2 organic N)
Low = 2 – 4 lb. N per 1000 gallons. (2/3 NH_4^+, 1/3 organic N)

Estimates and fractions based on data from Marsha Campbell-Mathews, UCCE, Stanislaus Co.
THESE ESTIMATES ARE NOT A SUBSTITUTE FOR EFFLUENT ANALYSIS

Poster Abstracts

Session Chairs:

Mary Bianchi, UCCE San Luis Obispo County

Effects of application timing and water chemistry on phosphate uptake efficiency for tomatoes grown on Tulare Clay loam.

Robert A. Blattler, Bruce A. Roberts, Brad Ramsdale, Clayton Morton (T-Systems International, Inc.)

Contact Name: Robert A. Blattler
Affiliation: Department of Plant Science, CSU Fresno,
Address: 2537 South Encina Street
City: Visalia
State: CA
Zip: 93277
Telephone: (559) 392-1700
Fax : (559) 734- 4875
Email: rblattler@sbcglobal.net

ABSTRACT:
Phosphorus is a major plant nutrient necessary for plants to complete there growth cycle. Soil chemical factors can inhibit phosphorus uptake and plant utilization. In the 2004 growing season tomato plants grown in the Tulare lake bottom showed a decrease in phosphate levels during the critical fruit fill stage. Tomatoes are a relatively new crop on these heavy soils. This area has shown a rapid increase in tomato acreage over the past five years. The main objectives of this project were to: 1) evaluate phosphate uptake and fruit yield from soil pH adjustments with drip applied irrigation water, and 2) compare timing of phosphate applications on plant growth, nutrient uptake and fruit yields. The trial was conducted in a commercial size field using standard equipment and the grower's drip system to apply treatments. The trial was set up as a modified split block design. Main treatments were irrigation water adjusted to pH of 6 and 7. The subplot treatments were a pre-plant application of 10-34-0 and a post plant application of 0-30-0 phosphoric acid. Irrigation water pH was adjusted by injecting sulfuric acid into the irrigation water prior to field application. Soil and tissue samples were collected biweekly to monitor soil phosphate and plant tissue levels. Daily monitoring of irrigation water was done by a hand held pH meter. Tomato fruit yield (T/Acre) were determined from hand harvested subplots and field scale machine harvests. Fruit quality determinations on Solids, pH and Color were made by the CA State Inspection Station, Lemoore, CA. Data collected is being analyzed for significant differences. Final results are presented on Phosphorus uptake and its effects on tomato yield and quality.

Nitrogen fixation by Central Coast winter cover crops: the story unfolds

Katie Monsen and Carol Shennan

Contact Name: Katie Monsen
Affiliation: UC Santa Cruz
Address: ENVS / ISB 413, 1156 High St.
City: Santa Cruz
State: CA
Zip: 95064
Telephone: 831-469-3095
Fax : 831-459-4015
Email: kmonsen@ucsc.edu

ABSTRACT:
Winter legume cover crops such as bell beans and woollypod vetch are commonly used to add nitrogen to organic vegetable production systems on the Central Coast. Accurate N fixation estimates by these legumes are crucial to determining whether the systems have an overall N excess, deficit or balance.
We used the $\delta^{15}N$ natural abundance method to estimate the percent of N derived from the atmosphere (%Ndfa). We planted vetch, bell beans and two reference species (oats and mustard) in replicated plots in five fields with a range of 1-7 yrs since last compost application and analyzed aboveground plant tissue for $\delta\,^{15}N$. Reference species $\delta\,^{15}N$ was negatively correlated with the number of years since compost application but there was no relationship between legume $\delta\,^{15}N$ and compost history. Additionally, there was no clear relationship between $\delta\,^{15}N$ of the legumes and integrated seasonal soil fertility using reference species biomass as a proxy. This indicates that the reference and legume species were accessing different pools of soil N, with the reference species taking up more available N from compost than the legumes. Estimates of %Ndfa varied substantially by field within a single farm. For example, vetch fixation estimates were 70 to 98% Ndfa with oats as the reference and bell bean estimates were 77 to 108% Ndfa with oats as the reference.
These data raise questions about whether a method that gives estimates over 100% is appropriate for estimating N fixation in these systems. The data also present a practical problem: how to develop N budgets for use by growers when fixation estimates vary by 25 to 30% for a single site.

Using Land Equivalency Ratio Analysis to Examine Synergistic Nitrogen Dynamics in a Wheat-Vetch Intercrop Produced for Fodder in California.

K.B. Koffler, T.J Krupnik, N. Kreidich, and S. Wiederkehr

Contact Name: K.B. Koffler
Affiliation: Department of Plant Sciences
Address: UC Davis, One Shields Avenue, Plant Sciences Dept, Mail stop 1, Plant & Environmental Sciences Bldg
City: Davis
State: CA
Zip: 95616
Telephone: 530-752-2023
Fax : 530-752-4361
Email: kbkoffler@ucdavis.edu

ABSTRACT:
This study provides preliminary results on the potential of an organic wheat-vetch intercrop system to produce a high protein content fodder, and is of particular interest to feed producers in California. We compared the biomass yield, N content, percent N and N-fixation of a wheat-vetch (*Triticum aestivum -Vicia villosa*) intercrop with monoculture plantings of each species. Our examination employed Land Equivalency Ratio (LER) analysis. LERs compare the productivity of intercrops with the yield of component species grown in sole stands. An LER value of > 1 indicates a beneficial intercrop interaction; an LER of < 1 denotes deleterious effects on intercrop productivity. Although we calculated the LER value for biomass of the intercrop at .99, the LER value for total N content was 1.3, indicating N over-yielding and increased protein production. Intercropped wheat had a significantly higher total N content ($p < 0.05$) and percent biomass N ($p < 0.05$) than wheat grown in sole stands, and the intercropped vetch derived a higher percentage of N ($p < 0.05$) from N-fixation than in monoculture. To obtain equivalent production of intercrop N from sole plantings, growers would need to cultivate 1.3 ha of either wheat or vetch monoculture at the same planting density. Our findings demonstrate a synergistic interaction whereby wheat N content and vetch N-fixation were increased. We surmise that these advantages resulted from complementary N use between wheat and vetch, wherein wheat drew more effectively from soil inorganic N pools, thus out competing the vetch and forcing it to fix more atmospheric N.

Phosphate Fertilizer Movement As a Result of High Frequency Micro-Irrigation

Rick Dal Porto[1], Charles Krauter[1], Dave Goorahoo[2], Bruce Roberts[1] and Sharon Benes[1]

Contact Name: Rick Dal Porto
Affiliation: Department of Plant Science, CSU Fresno[1], Center for Irrigation Technology[2]
Address: 2415 E San Ramon Ave, M/S AS72

City: Fresno
State: CA
Zip: 93740-8033
Telephone: (559) 278-2861
Fax :
Email: rjd16@csufresno.edu

ABSTRACT:
The use of fertigation for the application of phosphorus fertilizers has been limited by the perception that movement of PO_4-P in the soil profile may be insufficient to reach the active root system of the crop. The tendency of phosphorus to precipitate and clog emitters and nozzles represents another drawback on its use for fertigation. Two industry standards are used for phosphorus fertigation, phosphoric acid and monoammonium phosphate (10-34-0). Actagro (Biola, CA) has developed a phosphorus fertilizer formulation that may not precipitate as readily in soil and therefore, would be more available to plants than other existing materials. In this experiment, we applied three phosphate fertilizers at high rates (150 lb/A) using drip emitters to plots of bare soil in a randomized complete block design. The fertilizers applied were phosphoric acid, 10-34-0, and the Actagro phosphate blend. The phosphorus was applied through micro-irrigation lines followed by one-hour of irrigation after the fertigation. Subsequently, water was applied every Monday, Wednesday and Friday for 5.9 hours. The total irrigation events for the experiment were 45. Soil sampling was conducted after 2 days, 2 weeks, 1 month, and 2 months after the fertigation event. Soil samples were taken as a 12" x 12" x 1" section following each fertigation event. The soil section was then sub-divided into 16 squares (3" x 3" x 1" each). Samples were dried, ground and analyzed for pH and PO_4-P using the Olsen's method. While there appeared to be some indications that the organic-P material moved more readily than the other materials through the soil from the drip-tape emitter, there was no statistical proof. The variability in soil pH and pre-application P levels across the plots made statistical analysis very difficult.

Ryegrass Growth Curves and Nitrate Leaching Influenced by Nitrogen Rates

Ken Andersen and Roland D. Meyer

Contact Name: Ken Andersen
Affiliation: University of California, Cooperative Extension
Address: 5630 S. Broadway St
City: Eureka
State: CA
Zip: 95503
Telephone: (707) 445-7351
Fax : (707) 444-9334
Email: kandersen@ucdavis.edu; rdmeyer@ucdavis.edu

ABSTRACT:

Dairies are currently or have already developed nutrient management plans for the application of manure on crop and pasture lands. This study was initiated to develop ryegrass growth response curves to nitrogen (N), phosphorus (P) and potassium (K) applications. Applied urea-N rates were 0, 56, 112, 224, 336 and 448 kg ha^{-1} alone as well as 224-11-83, and 224-22-166 kg N, P, and K ha^{-1} to two field sites in 2003 with N split into 3 applications—mid March, June and August. In 2004, the 56 kg ha^{-1} rate was replaced with a 2 way split of 896, plus the addition of a 3 way split of both the 672 and 896 N rates (Dairy #1) and also a 2 way split of 672 kg N ha^{-1} rate (Dairy #2). The 2-way split of N applications was in mid March and July whereas P and K were applied only the first year. Irrigation or rainfall occurred within 1-2 days after fertilization and soil samples were taken 3-4 days later in depth increments of 0-15, 15-30, 30-60, and 60-90 cm from the 3 replications of the 0, 224, 448, 672, and 896 kg N ha^{-1} rate treatments 3 to 4 times per year. Between 8 and 12 forage harvests were taken from the two sites each of the two years. Yield responses were 4500 and 6000 kg DM ha^{-1} for the 448 and 672 kg N ha^{-1} rate in 2003 and 2004 respectively at Dairy #1 and 3500 and 4000 kg DM ha^{-1} for the 448 and 672 kg N ha^{-1} rate in 2003 and 2004 respectively at Dairy #2. Soil nitrate-N concentrations in the 60-90 cm depth seldom exceeded the 10-15 mg kg^{-1} level.

Planting Date & Density, Irrigation Management: Responses of Recent Upland varieties in the San Joaquin Valley of California

R.B Hutmacher[1], S.D. Wright[2], M.P. Keeley[1], G. Banuelos[2], B..H. Marsh[3], R.Delgado [1]

[1] Univ. California Shafter Res. Ext. Ctr. & Univ. CA Davis Plant Sci. Dept., [2] Univ. CA Cooperative Extension, Tulare, CA, [3] Univ. CA Coop. Ext., Bakersfield, CA & Shafter Res. Ext. Ctr., Shafter, CA

Contact Name: Robert B. Hutmacher, Extension Specialist
Affiliation: University of California Cooperative Extension, Shafter REC and UC Davis Plant Sci.
Address: 17053 N. Shafter Avenue
City: Shafter
State: CA
Zip: 93263
Telephone: (661) 746-8020 (office) (559) 260-8957 (cell)
Fax : (661) 746-1619
Email: rbhutmacher@ucdavis.edu

ABSTRACT:
A three year study was initiated in the San Joaquin Valley (SJV) to develop information on sensitivity of growth, lint yield and fiber quality responses to planting dates, planting density, and irrigation management practices in different Upland varieties, including comparisons of responses of non-Acala and Acala Upland varieties. Varieties represented a range of growth habits and maturity. The study was conducted at two locations for each year, one in a clay loam soil in Fresno County in the central SJV, the other in a sandy loam soil in Kern County in the southern SJV. Among the variables evaluated, the largest yield responses within any variety were planting date; with the earlier (April) planting dates consistently out-yielding May plantings. Planting density effects on yields were greatest in April plantings, where higher plant populations tended to reduce yields, particularly in the Acala variety. Under lower yield conditions or with later planting dates, higher plant populations generally had little impact or even slightly improved yields. Delayed irrigations, which produced moderate levels of plant water stress compared with standard irrigation practices, often produced slightly higher yields in the non-Acala varieties, but generally had no effect on yields (some numerically rediced slightly, but not significant) in the longer-season Acala variety. Most components of fiber quality were much more strongly affected by variety than by the range of management practices in this study. During multiple years of the study, however, there were tendencies for micronaire and fiber length to be significantly reduced by later plantings and the highest plant density.

Double-Row 30 Inch Versus Single-Row 30 Inch Beds in Cotton: Field Comparisons

Robert Hutmacher (UCCE Shafter REC and UCD Plant Sci.); Steve Wright (UCCE Farm Advisor-Tulare Co.); Ron Vargas (UCCE Farm Advisor – Madera and Merced Counties); Brian Marsh (UCCE Farm Advisor-Kern Co. and UC Shafter REC Supt.); Dan Munk (UCCE Farm Advisor-Fresno Co.); Mark Keeley, Raul Delgado (Shafter REC and UC Davis Plant Sci. Dept.), Gerardo Banuelos (UCCE-Tulare Co.); Tome Martin-Duval (UCCE – Madera Co.); Staff of Shafter and West Side REC

Contact Name: Robert B. Hutmacher, Extension Specialist
Affiliation: Univ. of California Cooperative Extension, Shafter REC and UC Davis Plant Sci.
Address: 17053 N. Shafter Avenue
City: Shafter
State: CA
Zip: 93263
Telephone: (661) 746-8020 (office) (559) 260-8957 (cell)
Fax : (661) 746-1619
Email: rbhutmacher@ucdavis.edu

ABSTRACT:
A multi-year trial was conducted to evaluate impacts of a change in cotton planting configurations on growth, yield potential and quality. Conventional cotton production in California typically uses 30, 38 or 40 inch beds, planted to a single line of seeds, typically at seeding rates resulting in 30,000 to 60,000 plants per acre. In an attempt to further decrease production costs, a variation of ultra narrow row production was initiated in the San Joaquin Valley. These efforts have been variously called the "California version of ultra narrow row" or "Double-Row 30 inch cotton". The planting configuration has been two seed lines of cotton, seven to ten inches apart, on a 30 inch bed. Many field evaluations were done in cooperation with western Merced County growers, and we also conducted trials at Shafter and West Side REC locations plus grower field sites in multiple SJV counties. Data from Merced County trial locations has shown economic savings for the double-30 inch planting system in reduced number of field tractor operations, fewer cultivations, and fewer openings and closings of irrigation ditches under furrow irrigation. With management approaches used with double-row 30 inch cotton at test sites, there were few significant differences (savings or extra costs) associated with fertilizer requirements, defoliation or harvesting costs (although harvests were slower in some cases). Overall conclusions include:
(1) Positive yield responses with double-row were most consistent in northern SJV sites;
(2) Double-row plantings did not consistently improve yields over single row at a wide range of other sites;
(3) There were indications that crop maturation with double-row plantings was earlier (2-5 days); and
(4) in small plot studies double-row yielded best at 50,000 to 70,000 plants/ac, while in large field studies, yield responses were less consistent within the range of populations tested.

Assessing vadose zone quality of lands receiving food-processing effluent waters.

Diganta D. Adhikari , Florence Cassel S. and Dave Goorahoo

Contact Name: Diganta D. Adhikari
Affiliation: Center for Irrigation Technology, California State University Fresno
Address: 5370 N. Chestnut Ave. M/S OF 18
City: Fresno
State: CA
Zip: 93740-8021
Telephone: (559) 278-5289
Fax : (559) 278-6033
Email: diganta@csufresno.edu

ABSTRACT:
Irrigation of fields with effluent from wineries allows for the beneficial reuse of nutrients and water, while utilizing the soil profile to treat the process water and prevent degradation of groundwater. However, some constituents may pass through the soil profile and detrimentally impact groundwater.

In Phase 1 of our research, the Center for Irrigation Technology (CIT) and the California water Institute (CWI) assisted the City of Fresno's Public Utilities in monitoring subsurface water quality at a winery stillage disposal site. The objective of the work with the City was to collect soil water (vadose zone) samples at 2 and 4 ft depth in stillage disposal areas and evaluate the concentrations of chemical constituents in those samples.
The major objectives of the 2nd phase of the project are: (1) to examine the effectiveness of Sudan grass and Elephant grass forages to act as scavenging crops for the organic and nitrogen loading from the winery stillage application; and, (2) to assess the ability of these crops to alleviate any soil salinity build up associated with the application of the winery stillage (Cassel S., 2005).
Analysis of soil solution samples collected from fields irrigated with winery stillage indicated that there is a high degree of spatial and temporal variability in the amount of total dissolved salts, total suspended solids, and inorganic nitrogen levels which is closely related to the hydraulic loadings and application cycles of the wastewater.

References

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Characterizing spatial variability of soil salinity in fields receiving winery wastewaters

Florence Cassel S., Diganta D. Adhikari, and Dave Goorahoo.

Contact name: Florence Cassel S.
Affiliation: Center for Irrigation Technology, California State University, Fresno
Address: 5370 N. Chestnut Ave., M/S OF 18
City: Fresno
State: CA
Zip: 93740
Telephone: 559-278-7955
Fax: 559-278-6033
Email: fcasselss@csufresno.edu

ABSTRACT
Irrigation of agricultural lands with food-processing wastewaters is a disposal technique that widely is practiced in California because it allows for the beneficial reuse of nutrients and water. However, excessive application of these waters can lead to subsurface water degradation and increase in soil salinity. The objective of the research was to assess the spatial variability of soil salinity in two fields planted with forage grasses (Sudan grass and Promor "A") and irrigated with winery wastewaters. Salinity mapping of the fields was conducted using the electromagnetic induction (EM) technique and soil sampling. Contour maps of salinity levels at different soil depths will be presented for both fields. The study showed that the use of the EM technique improved the knowledge of salinity variability across the fields and was a valuable tool for evaluating the long-term effects of winery wastewater application on soil salinity.

Lessons Gleaned from Hands-On Fertigation Training Workshops

Aziz Baameur & Michael Cahn

Contact Name: Aziz Baameur
Affiliation: UC Cooperative Extension
Address: 1553 Berger Dr. Bldg. 1
City: San Jose
State: CA
Zip: 95112
Telephone: 408-282-3127
Fax: 408-298-5160
Email: azbaameur@ucdavis.edu

ABSTRACT:
Irrigation uniformity is a prerequisite for fertigation. However, even a uniform irrigation system cannot compensate for a poor injection strategy and the resulting uneven fertilizer applications. We developed a hands-on training workshop that uses a demonstration drip system to teach these fertigation principles to growers, foremen and irrigators. In one exercise we inject food-grade dye mixed with liquid N fertilizer. The goal is to: 1. Compare the effects of fast and slow injections on fertilizer uniformity and travel time. 2. Compare the practice of shutting off the system once the fertilizer tank was empty, vs. that of flushing out the system for a time length equal to the dye travel time to the furthest point from the injection site. Participants collected water samples from the emitters at various locations in the field during the exercise and recorded when the dye appeared at their location.
The following were observed during the exercise:

1. The dye travel time was dependent on the flow of water in the drip tape and not on the rate of injection.
2. Midway through the injection, the fast injection showed intense color and high EC readings at the head of the field and clear solutions/low EC values at the end of the field. At the same time, the slow injection resulted in less difference in color/EC between the head and tail of the field.
3. When the irrigation continued for a period equivalent to the travel time, the color and EC readings were similar everywhere in the filed using both injection rates.
4. A rapid injection coupled with too much flushing would leach mobile nutrients, like nitrate, below the root zone and possibly contaminate ground water.

POSTER SUBMISSION

Water Quality Education for Irrigated Agriculture on California's Central Coast

Mary Bianchi, Julie Fallon (UCCE San Luis Obispo) Daniel Mountjoy (USDA – NRCS)

Contact Name: Mary Bianchi
Affiliation: University of California Cooperative Extension
Address: 2156 Sierra Way Ste C
City: San Luis Obispo
State: CA
Zip: 93401
Telephone: 805 – 781 - 5940
Fax : 805 – 781 - 4316
Email: mlbianchi@ucdavis.edu

ABSTRACT:
In addition to coastal waters in Southern San Luis Obispo and Santa Barbara Counties, California's Central Coast includes the Monterey Bay National Marine Sanctuary, the largest marine protected area in the USA, encompassing more than 5,000 square miles. Runoff water, lost from agricultural lands in coastal watersheds, may carry sediment, nutrient, and pesticide pollutants. Previously, the California Rangeland Watershed Program, developed by the University of California Cooperative Extension (UCCE), in partnership with the USDA Natural Resources Conservation Service (NRCS), created the Rangeland Water Quality Short Course to promote the development of individual water quality management plans. To date, more than 60 courses had been taught in 31 counties; water quality plans have been developed for 800 ranches representing 1.3 million acres.

Building on this success and to improve the availability and relevance of technical information to irrigated agriculture, UCCE and NRCS have adapted and are extending the Farm Water Quality Planning Short Course to irrigated agriculture producers on the Central Coast. Outreach to inform producers of the program is coordinated with the Agriculture Water Quality Alliance, and industry-led programs including the Central Coast Ag Water Quality Coalition, the San Luis Obispo/Santa Barbara County Watershed Coalition and the Agriculture Land Based Training Association. During the course, producers learn water quality regulations, techniques for self-assessment of nonpoint source pollution problems, sediment, nutrient and pesticide management goals, methods for recognizing practices that are already in place that protect water quality, management practices that may be selected based on local conditions and crop types, and practice evaluation methods. To date, 1511 growers in 7 Central Coast Counties from San Mateo, to Santa Barbara have participated in the 15-hour training on the development and implementation of farm water quality management plans, including five Spanish-language courses.

POSTER SUBMISSION

Title of Paper: Nitrate Leaching Losses Following a Single Irrigation Event
Authors: Marsha Campbell Mathews, *Farm Advisor, University of California*
G. Stuart Pettygrove, *Extension Soils Specialist, University of California*
Carol A. Frate, *Farm Advisor, University of California UCCE*
Alison J. Eagle, Josef Dvorak *UCCE*

Contact Name: Marsha Campbell Mathews
Affiliation: University of California Cooperative Extension
Address: 3800 Cornucopia Way, Suite A
City: Modesto
State: CA
Zip: 95358
Telephone: 209-525-6800
Fax : 209-525-6840
Email: mcmathews@ucdavis.edu

Abstract

Many forage crops on the eastern side of California's San Joaquin Valley are surface irrigated with volumes of water ranging from 3 to 8 or more inches of water applied in a single irrigation. It has been common practice to dewater dairy wastewater lagoons onto cropland in spring and fall preirrigations. Although sufficient nitrogen (N) to supply all the needs of the crop is likely applied at this time, supplemental nitrogen later in the season is often necessary to maintain production. To measure the amount of nitrate lost in a single irrigation event, soil samples were taken at 1 foot increments to a minimum of 3 feet immediately prior to and again as soon as reentry into the field was possible (usually 1-3 days) after 12 freshwater irrigations on nine sites ranging from sands to loam. An average of 117 lbs (40%) of nitrate-N (ranging from 8 to 445 lbs N/A) was not present in the root zone (top 3 feet) after a single freshwater irrigation event. An average of 123 lbs N/A of nitrate-N (67%) was lost from the top foot alone (range 46-458 lbs N/A). Interferences from crop uptake and mineralization are presumed minimal in most cases because of the short time between sampling dates and/or the absence of a crop. In light of this data, large single applications of N should be avoided, and nitrogen soil test results should be interpreted with caution.

Introduction

Soils on the eastern side of the San Joaquin Valley in California are often light textured and in some areas have a shallow water table. Groundwater in many areas has been severely impacted by nitrate, especially where dairies are concentrated. In this area nearly all forage fields are flood irrigated with water from an irrigation district, sometimes supplemented with pumped water. The amount of irrigation water applied is determined by the time it takes for water to reach the far end of the field. Typical amount of water applied are between three to as much as eight acre inches of water per acre. Options to reduce the amount of water applied are not easy or cheap to implement and therefore are limited with relatively low value forage crops. A common practice in the past has been to dewater dairy wastewater lagoons onto cropland in spring and fall preirrigations. Although excessive amounts of N in comparison to crop needs can be applied at this time, supplemental N later in the season is often needed in order to maintain production.

Methods

To determine the amount of N lost from the soil profile during an irrigation event, soils were sampled to a depth of three to four feet immediately preceding twelve freshwater irrigations on nine sites. As soon as it was possible to get back into the field, a second set of samples was taken. All soil cores were taken at least two meters from any previous core so as to avoid any influence from water moving laterally through the profile. Soil samples at each site were replicated from one to four times. Each soil sample was comprised of 6 to 8 one inch diameter cores, separated by depth, composited, and thoroughly mixed. Samples were kept refrigerated before and after extraction with 2 M KCl solution and the extracts were analyzed for nitrate and ammonium. The time interval between the before and after irrigation sampling dates was as short as possible to minimize the influence of mineralization and crop uptake. In most cases, the irrigation occurred within hours of the first sampling. The amount of water applied to the field was measured by inserting a hand-held Marsh-McBirney FloMate velocity meter down an air vent in the concrete pipeline. Applied water was calculated based on average velocity in the pipeline, pipeline diameter, irrigation run time and field acreage. Application rates of dairy lagoon water N (when measured) were determined using flows measured with an installed electromagnetic flow meter, and analysis of samples collected at the time of application.

Results

On every site and sampling date, nitrate was moved out from the surface layers of the soil to the lower depths. In all cases, the total amount of nitrate in the entire soil profile was less than was present prior to the irrigation. Losses from the top three feet ranged from 8 lbs N/acre to 445 lbs N/acre. Losses from the top foot ranged from 46 to 458 lbs N/acre (Table 1).

Conclusions and Practical Implications

- Loss of nitrate, presumably due to leaching, can be substantial from a single irrigation event.
- Even if the nitrate is not moved completely out of the root zone in a single event, leaching of nitrate from the surface layers during a pre-irrigation can move the N beyond the reach of seedling crops, setting up the potential to lose that N in subsequent irrigations.
- Nitrogen applied early in the season may not remain in the profile long enough for crops to utilize it. To minimize groundwater contamination, N should be applied in multiple small applications timed to coincide with anticipated crop utilization
- Preseason soil sampling for nitrate is not a reliable predictor of N availability for crop use where pre-irrigations are applied.
- Late season application of N may be needed to facilitate grain fill and green silage.
- If excessive amounts of N are applied during a pre-irrigation, a crop can still suffer N deficiencies later in the season.
- A small amount of N should be applied in the irrigation water if it is necessary to irrigate a very young crop.
- Growers who get excellent yields while using only unmeasured amounts of liquid or dry manure as a nutrient source are very likely applying excessive amounts of N.
- Post harvest soil sampling may not be a reliable method of determining if N application rates have been reasonable during the season.

Table 1

Nitrate-N in soil before and after freshwater irrigation, 2001 (lbs/acre)

	repli-cations per site	soil type	sampling season	ac-inches freshwater applied	1st soil sample date	irrigation date	2nd soil sample date	Recent nitrogen application history in lbs per acre. All are dairy lagoon source N (ammonium or organic form) except site 9, which is not not associated with a dairy	NO3-N top 1 ft		lbs/acre lost top 12 or 15"	% lost top 12 or 15"	NO3-N top 3 ft		lbs lost top 3 ft	% lost top 3 ft
									before	after			before	after		
Site 1	1	Madera sandy loam	1st corn irrigation	12.8	Jun 18	Jun 18	Jun 21	unmetered lagoon preirrigation	159	49	110	69%	186	86	100	54%
Site 2	1	Hanford sandy loam	1st corn irrigation	3.8	Jun 18	Jun 18	Jun 20	unmetered lagoon preirrigation	209	36	173	83%	281	113	169	60%
Site 3	4	Dinuba loamy sand	2nd corn irrigation	6.8	Jun 11	Jun 12	Jun 13	149 NH4-N, 159 Org-N in pre & 1st irrig	143	56	87	61%	255	147	107	42%
Site 4	4	Colpien loam	2nd corn irrigation	5 (est.)	Jun 24	Jun 25	Jun 29	unmetered lagoon preirrigation	804	346	458	57%	959	514	445	46%
Site 5	4	Dinuba fine sandy loam	1st corn irrigation	6.7	Jun 22	Jun 22	Jun 23	106 NH4-N, 24 Org-N in pre	169	26	143	85%	200	83	117	58%
Site 6	2	Delhi sand	1st corn irrigation	6.3	Jun 24	Jun 24	Jun 26	none in preirrig	81	23	58	72%	127	108	19	15%
Site 6	2	Delhi sand	8th corn irrigation	6.5	Aug 31	Sep 2	Sep 5	202 NH4-N, 158 Org-N in 6 split applications	124	29	94	76%	217	77	140	64%
Site 6	2	Delhi sand	preirrig for winter crop	6.8	Oct 17	Oct 17	Oct 22		98	53	46	46%	125	117	8	6%
Site 7	2	Delhi sand	8th corn irrigation*	5.6	Aug 31	Sep 2	Sep 5	198 NH4-N, 155 Org-N in 6 split applications	151	46	105	69%	270	99	172	64%
Site 7	2	Delhi sand	preirrig for winter crop	6.9	Oct 17	Oct 18	Oct 22		113	54	60	53%	164	109	55	34%
Site 8	2	Delhi sand	8th corn irrigation*	4.8	Sep 4	Sep 4	Sep 6	137 NH4-N, 253 Org-N in 6 split applications	132	65	67	51%	254	236	18	7%
Site 9	3	Tujunga loamy sand	1st winter crop irrig	5.5	Oct 19	Oct 19	Oct 22	60 lbs/A as Ammon Sulfate applied Sept 15	101	23	78	77%	141	91	50	35%
									average all sites & dates		120	65%			113	37%

*there was a maturing corn crop on the site at this time, and some umeasured N uptake occured

Notes

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California Chapter – American Society of Agronomy
2006 Plant and Soil Conference Evaluation

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Please complete and return this form to the registration desk or send it to the address below. Thank you for your assistance in completing this survey. Your responses will help us improve future Chapter activities.

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	Agree				Disagree
Conference fulfilled my expectations	1	2	3	4	5
Conference provided useful information	1	2	3	4	5
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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 Council 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

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