CONFERENCE PROCEEDINGS

2003
California Plant and Soil Conference

Agriculture in the Environment: Land, Air & Water Issues

California Chapter of the American Society of Agronomy

Co-sponsored by the California Plant Health Association

February 5 & 6, 2003

Doubletree Hotel
1150 9th St - Modesto, CA

WEDNESDAY, FEBRUARY 5, 2003

GENERAL SESSION

AGRICULTURE IN THE ENVIRONMENT: LAND, AIR & WATER ISSUES

Session Chair: **David Zoldoske,** CSU Fresno, Center for Irrigation Technology

10:00 Introduction – Session Chair

10:10 **Air quality and its impact on agriculture** – Bob Fletcher, Planning and Technical Support, California Air Resources Board

10:40 **Irrigated agriculture in the Central Valley and water quality regulations -** Dennis W. Westcot, Central Valley Regional Water Quality Control Board

11:10 **Agricultural land in California: Does it have a future?** - Henry Rodegerdts, Attorney at Law, California Farm Bureau Federation

11:40 Discussion

12:00 **California Plant Health Association Luncheon Speaker: How can farmers make their case to a doubting public?** Mark Grossi. Agricultural and Environmental Writer, The Fresno Bee

CONCURRENT SESSIONS

I. NUTRIENT MANAGEMENT: BASICS AND ADVANCES

Session Chairs: **Ben Nydam**, Dellavalle Laboratory, Inc. & **Sharon Benes**, Dept. of Plant Sciences, CSU Fresno

1:30 Introduction – Session Chairs

1:40 **Macronutrients: Changing strategies from not enough to too much** – D. William Rains, UC Davis, Dept. Agronomy and Range Science

2:00 **Micronutrients in California**- Roland D. Meyer, UC Davis, Dept. Land, Air and Water Resources

2:20 **Interpretation of soil and tissue analytical results**- Keith M. Backman, Dellavalle Laboratory, Inc.

2:40 Discussion 3:00 BREAK

3:20 **Soil test to predict nitrogen response in California crops** - William Horwath, UC Davis, Dept. Land, Air and Water Resources

3:40 **Efficient phosphorus management in coastal vegetable production -** Timothy K. Hartz, UC Davis, Dept. of Vegetable Crops

4:00 **Nutrient demand and fertilizer strategies: Lessons learned from boron -** Patrick H. Brown, UC Davis, Dept. of Pomology

4:20 Discussion 4:30 ADJOURN

II. PEST MANAGEMENT INNOVATIONS

Session Chairs: **Tom Babb**, CA Dept. of Pesticide Regulation and **Steve Kaffka**, UC Davis

1:30 Introduction: Session Chairs

1:40 **Mitigating orchard dormant spray runoff by alternative treatment timing; impact on target pest species and pesticide load** - Frank Zalom, UC Davis, Dept. of Entomology

2:00 **Toxicity of stormwater runoff after dormant spray application in a French prune orchard: temporal patterns and the effect of ground cover** - Inge Werner, UC Davis, School of Veterinary Medicine

2:20 **Run-off of pesticide from residential landscapes and mitigation practices** – J. Gan, UC Riverside, Dept of Environmental Sciences

2:40 Discussion 3:00 BREAK

3:20 **Aquatic weed control – Caulerpa** - Lars Anderson, USDA-ARS

3:40 **Seedling IPM in the Imperial Valley** - Steve Kaffka, UC Davis, Dept. Agronomy and Range Science

4:00 **Assessing dormant season OP use in almonds and prunes: Examples of using the Pesticide Use Report database** - Minghua Zhang, California Dept. of Pesticide Regulation

4:20 Discussion

4:30 ADJOURN

Poster Session and Wine and Cheese Reception will be held immediately following the afternoon session on Wednesday.

A coupon for a free drink is included in your registration materials.

THURSDAY, FEBRUARY 6, 2003

CONCURRENT SESSIONS

III. ORGANIC FARMING: TRANSITION AND PRODUCTION

Session Chairs: **William Horwath**, UC Davis and **Richard Smith,** UCCE Monterey County

8:30 Introduction – Session Chairs

8:40 **Impact of the new Federal rule on organic farmers -** Jane Sooby, Organic Farming Research Foundation

9:00 **Structure and development of California's organic production** - Sean Swezey, Director UC SAREP

9:20 **Organic education: concepts and examples** - Mark Van Horn, Plant Science Teaching Center & Student Farm, UC Davis

9:40 Discussion

10:00 BREAK

10:20 **Cover crop cultivar and planting density impacts on productivity, weed biomass and seed production in an organic system …** - Eric Brennan, USDA, Salinas

10:40 **Transition to organic production in cool season vegetables in Salinas** - Louise Jackson, UC Davis, Dept of Vegetable Crops

11:00 **Overview of organic milk production and the organic milk industry** - Tony Azevedo, Organic Valley Coop, Snelling

11:20 Discussion

IV. WATER QUALITY AND AGRICULTURE

Session Chairs: **Sharon Benes,** Dept of Plant Science, Fresno State and **Larry Schwankl**, UC Davis, Dept. Land, Air and Water Resources

8:30 Introduction – Session Chairs

8:40 **Implementing a TMDL for salt and boron in the lower San Joaquin River** - Eric Oppenheimer, Central Valley RWQCB

9:00 **The San Joaquin River dissolved oxygen TMDL - Source analysis and implementation plan development** - Mark Gowdy, Central Valley RWQCB

9:20 **Comprehensive Nutrient Management Plan: Content and policy** - Robert Fry, USDA-NRCS

9:40 Discussion

10:00 BREAK

10:20 **Merced County regulations for dairy management** - Jeff Palsgaard, Merced County

10:40 **Use of wetlands to treat winery effluent -** Heather Shepherd, Komex-H_2O Science

11:00 **Agricultural use of spent process water** – Nat B.Dellavalle, Dellavalle Laboratory, Inc.

11:20 Discussion

12:00 **CONFERENCE LUNCHEON**: Presentation of Honorees, Scholarship awards, Election of new officers

V. AIR QUALITY

Session Chairs: **John Beyer**, USDA-NRCS and **Charles Krauter**, CSU Fresno, Dept of Plant Science

1:30 Introduction – Session Chairs

1:40 **Air quality problems and regulations related to California agriculture - Past and present** - John Beyer, USDA-NRCS

2:00 **Air quality challenges for California agriculture – Present and future** – Matt Summers, California Dept. of Food and Agriculture

2:20 **PM_{10} emission factors for harvest and tillage of row crops** - Teresa Cassel, UC Davis, Crocker Nuclear Lab

2:40 **Atmospheric** a**mmonia profiles over various crops in the San Joaquin Valley -** Charles Krauter, CSU Fresno

3:00 Discussion

3:20 ADJOURN

VI. APPLICATIONS OF AERIAL IMAGERY

Session Chairs**: Dan Munk**, UCCE, Fresno County & **Jim Gregory**, Verdegaal Brothers

1:30 Introduction – Session Chairs

1:40 **Limitations and benefits of remote sensing -** John Ojala, USDA-ARS, Shafter

2:00 **Aerial imagery that links soil variability to poor crop performance -** Richard Plant, UC Davis & Dan Munk, UCCE Fresno Co.

2:20 **Using aerial images to make precision applications of soil amendments** - Jim Gregory, Verdegaal Brothers

2:40 **Practical applications of aerial imagery for vineyard management** - Ron Brase - California AgQuest Consulting

3:00 Discussion 3:20 ADJOURN

CONFERENCE PROCEEDINGS

2003
California Plant and Soil Conference

Agriculture in the Environment: Land, Air & Water Issues

California Chapter of the American Society of Agronomy

Co-sponsored by the California Plant Health Association

February 5 & 6, 2003

Doubletree Hotel
1150 9th St - Modesto, CA

TABLE OF CONTENTS

TABLE OF CONTENTS continued

TABLE OF CONTENTS continued

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
	Oscar E. Lorenz
1976	Donald L. Smith
1977	R. Merton Love
1978	Stephen T. Cockerham
1979	Roy L. Branson
1980	George R. Hawkes
1981	Harry P. Karle
1982	Carl Spiva
1983	Kent Tyler
1984	Dick Thorup
1985	Burl Meek
1986	G. Stuart Pettygrove
1987	William L. Hagan
1988	Gaylord P. Patten
1989	Nat B. Dellavalle
1990	Carol Frate
1991	Dennis J. Larson
1992	Roland D. Meyer
1993	Albert E. Ludwick
1994	Brock Taylor
1995	Jim Oster
1996	Dennis Westcot
1997	Terry Smith
1998	Shannon Mueller
1999	D. William Rains
2000	Robert Dixon
2001	Steve Kaffka

California Chapter of American Society of Agronomy

Past Honorees

Year	Honoree
1973	J. Earl Coke
1974	W.B. Camp
1975	Milton D. Miller
1976	Malcom H. McVickar
	Perry R. Stout
1977	Henry A. Jones
1978	Warren E. Schoonover
1979	R. Earl Storie
1980	Bertil A. Krantz
1981	R. L. "Lucky" Luckhardt
1982	R. Merton Love
1983	Paul F. Knowles
	Iver Johnson
1984	Hans Jenny
	George R. Hawkes
1985	Albert Ulrich
1986	Robert M. Hagan
1987	Oscar A. Lorenz
1988	Duane S. Mikkelsen
1989	Donald Smith
	F. Jack Hills
1990	Parker F. Pratt
1991	Francis E. Broadbent
	Robert D. Whiting
	Eduardo Apodaca
1992	Robert S. Ayers
	Richard M. Thorup
1993	Howard L. Carnahan
	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
1997	Jolly Batcheller
	Hubert B. Cooper, Jr.
	Joseph Smith

Year	Honoree
1998	Bill Isom
	George Johannessen
	Ichiro "Ike" Kawaguchi
1999	Bill Fisher
	Bob Ball
	Owen Rice
2000	Don Grimes
	Claude Phene
	A.E. "Al" Ludwick
2001	Cal Qualset
	James R. Rhoades
	Carl Spiva
2002	Emmanuel Esptein
	Vince Petrucci
	Ken Tanji
2003	Vashek Cervinka
	Richard Rominger
	W. A. Williams

California Chapter
American Society of Agronomy

2002 Board Members

EXECUTIVE COMMITTEE

President	David Zoldoske, California State University - Fresno
First Vice President	Casey Walsh Cady, California Dept of Food and Agriculture
Second Vice President	Ron Brase, California AgQuest Consulting
Secretary-Treasurer	Bruce Roberts, UC Cooperative Extension, Kings County
Past President	Steve Kaffka, UC Davis

GOVERNING BOARD MEMBERS

One-year term	Dan Munk, UCCE Fresno County
	William Horwath, UC Davis
	Sharon Benes, CSU Fresno
Two-year term	Richard Smith, UCCE Monterey County;
	Larry Schwankl, UC Davis
	Jim Gregory, Verdegaal Brothers
Three-year term	Tom Babb, California Dept. of Pesticide Regulation
	Bob Fry, USDA/NRCS
	Ben Nydam, Dellavalle Laboratory Inc.
Advisors	Walt Bunter, USDA-NRCS (retired)
	Dennis Westcot, Central Valley Regional Water Quality Control Board

2003 Honorees

Vashek Cervinka

Richard Rominger

W. A. Williams

Vashek Cervinka

Dr. Vashek Cervinka was born in Prague, Czech Republic, where he worked as a Research Scientist. After spending six years in Ghana, West Africa working on agricultural development projects and teaching agricultural engineering at the University of Ghana, he immigrated to the United States in 1968. He completed his graduate work in Engineering Systems in Agriculture at the University of California, Davis, in 1972.

From 1972 – 1997, Vashek worked at the California Department of Food and Agriculture (CDFA) where he focused on energy use in agriculture, developing new uses for agricultural products, and agroforestry research for the management of drainage water and salinity on irrigated farmlands. His work included the production of saline biomass on land affected by salinity. He was instrumental in the development of bio-engineering systems to grow salt-tolerant crops and harvest salt on irrigated farmland in the San Joaquin Valley. During his tenure at CDFA, Vashek worked under Director Richard Rominger where they began the long range planning efforts in the development of agricultural resources. He has received several awards that include CDFA Superior Accomplishment Award and Environmental Achievement Award.

After his retirement from CDFA in 1997, Vashek began working for the California Department of Water Resources continuing his work in the San Joaquin Valley to further develop, in cooperation with growers and government/university employees, the integrated on-farm drainage management system (IFDM).

Over the course of his career, Dr. Cervinka has also provided his volunteer technical assistance to many countries including Costa Rica, Tunisia, Uzbekistan, Armenia, and Australia where he assisted in the development of innovative farming systems to address resource management issues on salt-affected lands.

Dr. Cervinka lives in Davis and is involved in many community activities. He also manages a small farm in between Davis and Dixon with his wife, Claudette, and their family.

Richard E. Rominger

Mr. Rominger and family are fifth generation farmers in Yolo County. Mr. Rominger attained a Bachelor of Science in Plant Science from the University of California Davis majoring in Agronomy, Summa Cum Laude, in 1949. Mr. Rominger spent 20 years on the family farm before becoming increasingly active in local organizations and government. Richard Rominger has dedicated his entire life to the ideals and advancement of agriculture in California, United States and abroad.

In 1977, Mr. Rominger was appointed as Director (Secretary) of the California Department of Food and Agriculture. His accomplishments in the CDFA include establishing comprehensive pesticide regulations and establishing farmer market networks. During his tenure at the CDFA, he built successful relationships among farm groups, environmental organizations and the state government. Other accomplishments as Director of the CDFA included President, Western association of State Departments of agriculture; President, Western U. S. Agricultural trade association; Board of Directors, National Association of State Departments of Agriculture; member of trade promotion delegations to the European community and general Agreement on Tariffs and Trade (GATT); and headed California's agricultural delegation to the People's Republic of China. He continued to farm with his bother, sons and nephews while taking on these important duties.

In 1993, Mr. Rominger assumed the post of Deputy General in the United States Department of Agriculture. He served on a variety of committees and was responsible for the operation of one of the largest federal agencies. As the Chief Operating Officer his duties included management of traditional farm programs, conservation programs, domestic food assistance programs, research and education, agricultural marketing, international trade, forestry, rural development and food safety. He also served on the President's Council on Sustainable Development. In addition, he severed as Director of the National Emergency Management Team.

Presently, Mr. Rominger is actively involved in the farm community and continues his role in shaping the future of California agriculture. In particular, Mr. Rominger is playing a key role as advisor on production agricultural at the California to Cal. Polytechic St. Univ., San Luis Obispo, Cal. St. Univ., Fresno and the University of California campus's of Davis and Riverside. This is a particularly important role that will develop the future direction for the interaction of production agriculture and California's universities. The link between research, education and outreach will remain the critical factor that connects consumers and farmers and will lead to competitiveness in the global market place. Mr. Rominger is also a board member for the American Farmland Trust and the University of California Agricultural Issues Center.

Richard Rominger is truly a statesman and visionary who has played a critical role in guiding and shaping California agriculture at the local and national level. His vast contributions to agriculture cannot be easily measured, but it is certain that the agricultural community and consumers have benefited greatly from his achievements. Mr. Rominger continues to be a guiding light that will lead California agriculture to prosper and be competitive in today's challenging global markets.

William A. Williams

William A. (Bill) Williams was born in Johnson City, New York in 1922. He worked on farms growing up and attended Cornell University as an undergraduate where he studied soil science. His education was interrupted by the Second World War when served as an army artillery officer in the Pacific. After the war, he returned to Cornell to finish his BS degree and continued on to earn MS (1948) and PhD (1951) degrees as well. After graduating from Cornell, he joined the Agronomy and Range Science Department at U.C. Davis, where he spent the remainder of his career. He retired in 1992 after 43 years of service. He married Pat Williams in 1943 and they have had three children.

Dr. Williams was one of the best known and most productive agricultural scientists of his generation. He has published over 160 papers in scientific journals and texts, and numerous other agricultural publications. He has been the editor of the Agriculture Section of McGraw-Hill's Encyclopedia of Science and Technology from 1982 until 2002, supervising 5 major revisions and the production of an agricultural yearbook in all 20 years. He has received numerous competitive grants from the USDA, the National Science Foundation, and state agencies.

He is a fellow of the American Society of Agronomy, the Crop Science Society of America, and the American Association for the Advancement of Science. He has numerous received numerous awards including a Fulbright grant to teach at the University of Adelaide, Australia, a Rockefeller Research Grant in Latin America, a Kellogg Foundation International Teaching Program.

His research has been wide-ranging. He has worked extensively with forage physiology and forage production, rangeland species and management, crop production, particularly with sugarbeets, corn, and rice, but also including many other crops, and agricultural statistics. He was a pioneer in crop simulation modeling. His most recent contributions have been the development and release of two new Berseem clover varieties and a production manual. One of his most important contributions has been teaching undergraduate and graduate courses and mentoring of more than 50 graduate students, most of whom have themselves gone on to distinguished careers in the agricultural sciences.

Besides his contributions to the agricultural sciences and to California's agriculture, he has been active in supporting local and statewide organizations in the area of mental health. Together with his wife Pat, he has given generously of his personal time and resources to support Pine Tree Gardens in Davis, a home for those with debilitating forms of mental illness. In 2002, they were awarded the Davis Human Relations Commission's award for humanitarianism.

Winning Scholarship Essay

How Can Agricultural Scientists Best Assist Producers to Meet Higher Expectations of the General Public in the Area of Environmental Stewardship?

By

Freeman Barsotti, Soil Science Major
Cal Poly State University, San Luis Obispo

As science advances, the population grows and our resources become more scarce, the need to protect our environment becomes more and more evident. While the importance of protecting our resources is solidifying in the public's eye, carrying out the task is a much different story.

Working directly with customers at Farmers' Markets I have begun to understand some beliefs that the general public hold towards agriculture, producers and the environment. Concerns about pesticide pollution, over use of adequate water and poor treatment of field workers are often the basis for their comments. While in many cases I find these statements exaggerated, I am still able to see some of the public's perceptions on producers. My unique position also allows me to hear remarks from the other side, producers themselves. For the producers, pressure to raise environmental standards means more costly farming practices, which decrease their already dangerously thin profit margin. This gap of understanding between the publics' growing expectations in the area of environmental stewardship and agricultural producers' needs provides an opportunity to agricultural scientists everywhere.

Agricultural scientists who develop knowledge of environmentally conscious farming techniques, but also understand the needs of a business are the ones who can best assist producers in meeting higher environmental expectations. There are many opportunities for farmers to save money and become more environment/resource friendly. For example, much of the nitrate groundwater contamination is due to over irrigation causing the nitrate to leach down. With knowledge of this problem a simple change in irrigation scheduling could save the farmer money in fertilizer costs while creating a solution to the contamination. Another opportunity lies in the development of tail water return systems. Many farmers who furrow irrigate without the use of a tail water return system are wasting money on pumping and water costs while receiving poor distribution uniformity. With the knowledge that installing a tail water distribution system could pay for itself in saved costs within a decade, and with possible government aid in installing this water conserving system, most farmers would willing make the switch. Finally, a huge opportunity lies in the knowledge of sustainable agriculture. The development of beneficial insects and the use of rotating cover crops can provide farmers with cost cutting techniques that are more environmentally conscious.

In our economic structure, the key to change is increased profits. By providing producers with knowledge that they can increase their profits by changing their farming techniques in a more environmentally friendly way, the environmental standards in the agriculture industry will gradually increase. Whether it is knowledge concerning farming techniques, irrigation systems or even the possibilities of increased sale prices of growing organic crops, the possibilities are there, and the opportunities are awaiting agricultural scientists of the future.

Runner-Up Scholarship Essay

How Can Agricultural Scientists Best Assist Producers to Meet Higher Expectations of the General Public in the Area of Environmental Stewardship?

By
Danilu Ramirez, Crop Science Major
Cal Poly State University, San Luis Obispo

In today's world the general public is demanding food and fiber products that have been grown in environmentally safe conditions. Genetically modified crops and inorganic products are not in demand. As an agricultural scientist, I will work with the producer to promote the incorporation of an integrated pest management system in order to support environmental stewardship - currently a large concern for consumers. An effective integrated pest management system should focus on precise monitoring

Catching problems before they become serious and damaging is the key. By using scientific calculations from graphs that show the density and distribution of insect populations, a Pest Control Advisor can tell when problems will arise simply by analyzing data that states if a population is aggregate or regularly dispersed. There are cultural and biological control methods that can keep weed and pest problems under control. By following these techniques and others -that I am learning through my education at Cal Poly - I will be able to act as a PCA who uses critical thinking to limit the use of pesticides. This will save the producer money and possibly have the potential to increase sales of their products that will be favored by the general public.

Aside from taking actions that generate environmentally safe products, an additional step is to educate each producer. By holding seminars and continuing education meetings, the growers can become aware of updated statistics and new procedures that will positively have an effect on consumer satisfaction. Agricultural scientists are the most knowledgeable sources of information for producers to refer to. It is therefore, very important that they keep open communication with growers and others in the business of production. New techniques and strategies are being developed everyday. For this reason, agriculture is a field in which relaying updated information and new technology is critical for its survival and success. I am anxious to begin aiding in the education of producers, and through them, improve agriculture in all its aspects.

Irrigated Agriculture in the Central Valley and Water Quality Regulation

Dennis W. Westcot, Rudy J. Schnagl and Amanda E. Smith
Central Valley Regional Water Quality Control Board
3443 Routier Road, Suite "A", Sacramento, CA 95827-3003
Phone: (916) 255-3000; FAX

BACKGROUND

California Water Code Section 13260 requires persons discharging waste or proposing to discharge waste to submit a Report of Waste Discharge (ROWD). This ROWD is used by California's nine Regional Water Quality Control Boards to prepare waste discharge requirements (WDRs) that limit the discharges to the extent necessary to comply with applicable laws and regulations. The purpose of this regulatory program is to protect the beneficial uses of the waters receiving wastes.

If a Regional Board finds that it is not against the public interest, that Board may waive WDRs for individual dischargers or categories of discharges (Water Code §13269). In 1982, the Central Valley Regional Board (hereafter Regional Board) adopted Resolution No. 82-036 waiving waste discharge requirements (WDRs) for 23 categories of discharges. Irrigated lands generate discharges in two of these categories – irrigation return waters and storm water.

Resolution 82-036 included conditions necessary to receive a waiver of WDRs. Discharges of irrigation return waters must be "*Operating to minimize sediment to meet Basin Plan turbidity objectives and to prevent concentrations of materials toxic to fish or wildlife*." WDRs are waived for storm water "*Where no water quality problems are contemplated and no federal NPDES permit is required*."

The staff report developed in support of Resolution No. 82-036 indicated that the Board's Executive Officer would determine whether discharges pose a threat to water quality. If there is no potential to impact water quality, there is no requirement to submit a ROWD except in cases where it is determined that additional information is needed.

Irrigation return waters and storm water have been discharged from irrigated lands in the Central Valley for more than a century before the adoption of the Porter-Cologne Water Quality Control Act in 1969 (codified in California Water Code Division 7). Rather than require submittal of ROWDs, the Regional Board's program has focused on promotion of voluntary compliance with management practices that minimize discharges of pollutants. Where the Board determines that a threat to water quality exists, other regulatory actions have been used, including discharge prohibitions and regulation under WDRs. In the irrigation return water category, WDRs have been used to regulate evaporation basins in the Tulare Lake Basin and return flows from high selenium areas. A conditional discharge prohibition has also been utilized in regulating discharges from some irrigated rice acreage in the Sacramento Valley.

As a result of recent changes to California Water Code §13269, all waivers in place on 1 January 2000 expired on 31 December 2002 unless the Regional Board renews them. Any new waivers adopted by the Regional Board after 1 January 2000 must be reviewed at least every five years and the Board must require compliance with any conditions placed on a waiver.

NEW CONDITIONAL WAIVER

On 5 December 2002, the Regional Board adopted an updated 2-year conditional waiver. This waiver applies to persons who discharge irrigation return flows (both surface and subsurface drainage), storm water runoff and operational spills to surface waters of the state. For the purposes of this waiver, the term "irrigated lands" applies to lands where water is applied for the purpose of producing crops and includes commercial nurseries, nursery stock production and managed wetlands.

This new waiver applies throughout the Central Valley Region and sets forth two categories. One category applies to persons who discharge from irrigated lands and choose to participate in a group effort on a watershed level to comply with the conditions of the waiver. The second category applies to individual dischargers who do not choose to participate in a group watershed or subwatershed effort to comply with the conditions of the waiver. Persons that manage irrigated lands that do not generate discharges to surface waters do not need to seek coverage under the waiver. Regardless of which category a discharger falls under, the following requirements must be met:

(1) Discharges shall not cause or contribute to conditions of pollution or nuisance as defined in Section 13050 of the California Water Code; and

(2) Discharges shall not cause or contribute to exceedances of any Regional, State, or Federal numeric or narrative water quality standard.

Watershed groups will jointly conduct work to meet waiver conditions while the owners and operators of irrigated lands would conduct the farm-level efforts. There are specific deliverables and deadlines that must be met in order to qualify for the waiver of WDRs. The waiver includes the following conditions:

- Plans will be developed to address regional or on-farm water quality issues
- Monitoring will be conducted to assess water quality impacts of the discharges
- Management practices will be developed and implemented, as necessary, to meet applicable receiving water limits

The discharger is in compliance if they submit specific information and a water quality monitoring plan in accordance with specified timetables. Regardless of whether the discharger is participating in a watershed group or qualifies for the waiver on an individual basis, the focus is to obtain water quality monitoring and the develop and implement management practices that reduce discharges of waste.

WATERSHED GROUPS

Using a watershed group to address non-point source (NPS) discharges from irrigated lands is consistent with the State Water Resources Control Board's (SWRCB's) Plan for California Nonpoint Source Pollution Control Program. Presently, there are two cases of successful use of the watershed approach in the Central Valley Region. The Rice Pesticides Program, formed in response to fish kills and drinking water concerns related to five rice pesticides, has reduced pesticide levels due to active participation by farmers, County Agricultural Commissioners, University of California Cooperative Extension, the Rice Industry, Department of Pesticide Regulation, the Regional Board and other stakeholders. Stakeholder participation in the Grassland Watershed, including formation of a Joint Powers Authority, has helped reduce levels of selenium and other constituents of concern into the wetland supply channels. Both efforts were successful because of the efforts of active concerned stakeholders in each watershed.

The benefits of using a watershed approach include the following:

- **The group shares resources and costs.** Individual dischargers will not bear the burden of developing and funding an entire program on their own.

- **A relatively small number of monitoring sites can be used to characterize the discharge from a large area.** Well defined monitoring sites can provide much of the same information that would be gathered by monitoring tens of thousands of individual fields. Should water quality problems be found, monitoring can then be efficiently targeted to determine how problem discharges are related to specific management practices or cropping patterns within the watershed.

- **The impact on the availability of laboratory services will be manageable.** As samples will have to be analyzed by certified labs and it is unlikely that the existing labs would have the capacity to handle samples from tens of thousands of additional individual clients in a timely manner. Watershed groups should require fewer sample analyses overall and existing labs should be able to handle the modest increase in demand for services.

- **Technical information is disseminated to a large audience quickly and efficiently.** The group provides a forum for its members to share technical information rapidly. This should result in more dischargers adopting management practices proven at the local level to protect water quality.

- **Use of Regional Board resources is optimized.** Although a watershed approach will require significant staff involvement, overall such a program is expected to require fewer Regional Board resources than would be needed if individual WDRs were issued and individual ROWDs are processed.

- **Watershed groups represent a number of interests.** While the conditional waiver does not dictate which entities should be included in any watershed group, historically groups have found it beneficial to have representation from a range of individuals, organizations and agencies. These have included grower groups, local water agencies, Resource Conservation Districts, commodity organizations, environmental interests, and state and county governmental agencies.

- **Water quality improvements can potentially occur sooner and be more widespread.** Dischargers cooperating in a watershed approach will be able to focus their pooled resources on the priorities of their region. A watershed group can undertake large-scale improvement projects such as tailwater recovery or water treatment systems when these might not be feasible for the individual discharger.

- **The watershed approach is flexible.** This new program is expected to evolve as more information is gathered and water quality problems are discovered and addressed.

IRRIGATED AGRICULTURE IN THE CENTRAL VALLEY

There are seven million acres of irrigated agriculture in the Central Valley Region. It is the dominant land use on the valley floor and often irrigation activities dominate flow and quality of valley floor water bodies. Supply canals and drains make up a complex maze of constructed water bodies overlaying a natural drainage network. In many locations, the natural drainage courses have been integrated into the man-made system. Designed to deliver water and provide for drainage of irrigation return flows and storm water, these facilities have significantly altered the aquatic system. In 1992, with the help of over 340 water, drainage and reclamation agencies Regional Board staff identified more than 20,000 miles of waterways in the Central Valley dominated by flows related to activities on irrigated lands.

The survey was conducted using two special water body category definitions. Category (b) water bodies included natural water bodies, or segments thereof, that are dominated by agricultural drainage (irrigation return flows) and/or agricultural supply water. The second, Category (c) included water bodies, or segments that have been constructed for the primary purpose of conveying or holding agricultural drainage and/or agricultural water supply and were not natural water bodies that supported aquatic habitat beneficial uses. Category (c) water bodies also included drains constructed in normally dry washes and low-lying areas.

In the three hydrologic basins in the Central Valley, 160 Category (b) natural water bodies, comprising a total of 1,512 miles, were dominated by agricultural drainage and/or agricultural supply water. There were shown to be 6,291 Category (c) constructed agricultural channels with a total length of 19,812 miles. A summary of the information provided by over 340 agencies on agriculture-impacted waters is shown in **Table 1**. The practice of irrigation in the Central Valley and where surface runoff occurs, there is a significant potential to adversely impact water quality if pollutants are not managed at the farm level.

Table 1.
Summary of Channels Dominated by Agricultural Activities (CRWQCB, 1992)

Drainage Area	# of Agency Reports	Water Bodies Dominated by Agricultural Drainage (b)		Constructed Agricultural Drains (c)	
		# Water Bodies	Length (miles)	# Water Bodies	Length (miles)
Sacramento	93	68	541	2,485	5,160
San Joaquin	63	46	538	1,715	4,689
Delta	70	13	126	789	1,548
Tulare Lake	109	28	268	1,068	6,460
Foothills	24	5	39	234	661
Area Subtotal:	359	160	1,512	6,291	18,519
Major Waterways	5	0	0	28	1293
Total:	364	160	1,512	6,319	19,812

WATER QUALITY IMPACTS FROM IRRIGATION ACTIVITIES

The type and amount of wastes carried to surface waters by discharges from irrigated lands will vary by location as a result of irrigation method, rainfall amounts, crops grown, soil type, pesticides and fertilizers used, management practices and several other factors. The source of the pollutant also varies. Water quality impacts from irrigated agriculture could be related to one or more of three mechanisms:

- Waste constituents that are imported in or introduced into the irrigation water,
- Waste constituents that are mobilized by the practice of irrigation or storm water, and
- Waste constituents that are concentrated as a result of irrigation practices.

Surface water discharges from irrigated lands generally fall into two categories:

- ***Storm water*** runoff generally occurs during the winter and spring months and consists of rainfall that does not infiltrate into the soil. In the drainage courses, it is often commingled with runoff from other land uses besides agricultural lands.

- ***Irrigation return waters*** are defined as "*surface and subsurface water, which leaves the field following application of irrigation water*" (USEPA, 1997). Irrigation water is applied to cropland during the drier months of the year to meet crop water requirements and the return waters are often the only waters in some drainage courses during the summer and early fall months.

Irrigation return waters and storm water runoff from irrigated lands commonly carry higher levels of one or more constituents including sediment, pesticides, nutrients, salt, trace elements (such as selenium and boron) and temperature (Irrigated Agriculture TAC, 1994a). Discharges from an individual field have the potential to contain high enough levels of one of these constituents to cause violations of water quality objectives in smaller water bodies. Of equal concern however is the cumulative impact from numerous such discharges that can adversely affect larger water bodies, such as the Sacramento-San Joaquin Delta or its tributary rivers (CRWQCB, 2001).

The Regional Board has documented the impact to water quality from irrigation return flow and storm water through listing of impaired water bodies in conformance Section 303(d) of the federal Clean Water

Act. Many of these impairments are related to either irrigation return waters or storm water runoff that contains organophosphate pesticides, primarily diazinon and chlorpyrifos. For each of the impaired water bodies, the Regional Board is required to prepare a Total Daily Maximum Load (TMDL) to assign loads to various sources so that water quality objectives can be met in the future. More information on the TMDL Program can be found at http://www.swrcb.ca.gov/tmdl/tmdl.html .

EXISTING LAWS AND POLICIES

There are several laws and policies that apply to the two categories of discharges from irrigated lands.

Federal Clean Water Act (CWA) – There is a specific exclusion for irrigation return waters from the CWA National Pollutant Discharge Elimination System (NPDES) permitting program. Storm water from irrigated lands is also excluded from NPDES storm water permitting. Under the CWA, water quality impacts caused by discharges from irrigated lands are addressed by promoting the use of best management practices. The CWA requires the preparation of TMDLs for impaired water bodies, including those impaired by nonpoint sources such as irrigation return flows and storm water from irrigated lands. The TMDL process establishes load allocations for nonpoint sources of pollution but there are no implementation mechanisms under the CWA.

California Porter-Cologne Water Quality Control Act (Porter-Cologne Act)– This law provides the Regional Board with the authority to regulate discharges from point and nonpoint source discharges through the use of WDRs, the state equivalent to the federal NPDES Permit. The statutory mandate that WDRs be adopted, however, can be waived by a Regional Board "where such waiver is not against the public interest" (California Water Code §13269). The SWRCB and the Regional Board can also make their own investigations or may require dischargers to carry out water quality investigations and report on water quality issues (California Water Code §13267). A summary of the regulatory options available to the Regional Boards is summarized in **Table 2**

Water Quality Control Plans (Basin Plans) – These plans are adopted by the Regional Board pursuant to State and Federal law. The Porter-Cologne Act requires the adoption of a Basin Plan as the guiding policies of water pollution management in each region. A Basin Plan identifies the beneficial uses of waters and establishes water quality objectives to protect these uses. The Basin Plan also contains implementation, surveillance, and monitoring plans. The Basin Plans form the basis for water quality protection in the Region. The Basin Plan is implemented primarily through issuance of WDRs and NPDES permits. The Basin Plan for the Sacramento River and San Joaquin River Basins contains a specific control program for pesticides in irrigation return flows. Under this program, the Regional Board would hold hearings every two years to review the control effort and initiate appropriate regulatory response. This Basin Plan also contains specific water quality control programs for selenium and five pesticides used on rice fields. The Tulare Lake Basin Plan has sections specific to the construction and operation of evaporation basins.

Plan for California Nonpoint Source Pollution Control Program - This Plan is the SWRCB's policy for controlling nonpoint source pollution including discharges from irrigated land. This Plan was adopted to satisfy the requirements of the federal CWA and the Coastal Zone Reauthorization Amendments of 1990 (CZARA). While giving the Regional Boards the discretion to use the most appropriate approach for any specific case, it recommends consideration of three different tiers of regulatory effort:

Tier 1: Self-determined implementation of Best Management Practices
Tier 2: Regulatory-based encouragement of management practices
Tier 3: Effluent limits and enforcement

The plan also identified management measures for irrigation water management, pesticide management, erosion and sediment control and nutrient management for irrigated lands. These management measures are broad policy directives that are to be implemented statewide. An example of a management measure for irrigation water management states that (the State) promotes effective irrigation while reducing waste discharges to surface and ground waters. The broad policy directive, however, does not come with specific implementation measures. These must be crafted within the three-tier structure.

Management Agency Agreement between the State Board and Department of Pesticide Regulation (DPR) – DPR is the state agency with primary authority over registration and use of pesticides. This Agreement spells out how the SWRCB, DPR, Regional Boards and the County Agricultural Commissioners will deal with issues involving pesticides and water quality. In most cases, DPR and the County Agricultural Commissioners are given lead role in correcting any problems using the pesticide regulatory process before the Regional Board uses its authority under the Porter-Cologne Act.

California Environmental Quality Act (CEQA)- CEQA applies to discretionary activities proposed to be carried out by government agencies, including approval of WDRs and waivers of WDRs. Compliance is commonly achieved through the preparation of Environmental Impact Reports (EIR) or Negative Declarations. The Board's Basin Planning process has been determined to be functionally equivalent to completing an EIR.

BIBLIOGRAPHY

Cal EPA. 1997. California Environmental Protection Agency. *California Pesticide Management Plan for Water Quality.*

CRWQCB. 1982. California Regional Water Quality Control Board, Central Valley Region. *Resolution No. 82-036. Waiving Waste Discharge Requirements For Specific Types of Discharge*. Amended March 26, 1982.

CRWQCB.1992. California Regional Water Quality Control Board, Central Valley Region. *Staff Report: Considerations of Water Body Designations to Comply with the Provisions of the Water Quality Control Plan for ISWP.*

CRWQCB. 1995. California Regional Water Quality Control Board, Central Valley Region. *Water Quality Control Plan (Basin Plan). Central Valley Region. Tulare Lake Basin.*

CRWQCB. 1998. California Regional Water Quality Control Board, Central Valley Region. *Fourth Edition Water Quality Control Plan (Basin Plan). Central Valley Region. Sacramento River and San Joaquin River Basins.*

CRWQCB. 2001. California Regional Water Quality Control Board, Central Valley Region. *A Review of Options for Controlling Discharges from Irrigated Lands.*

CWA. 1972. *Federal Water Pollution Control Act of 1972.*

DPR. 1999a. California Department of Pesticide Regulation. *Summary of Pesticide Use Data Report Data 1999.*

DPR. 1999b California Department of Pesticide Regulation. *Enforcement Initiative.*

DPR. 2000. California Department of Pesticide Regulation. *Information on Rice Pesticides December 31, 2000*. Submitted to the CVRWQCB.

DPR. 2001. California Department of Pesticide Regulation. Surface Water Program Website. *http://www.cdpr.ca.gov/docs/surfwatr/programs.htm*

EPTC. 1999. Evaporative Ponds Technical Committee. *Evaporation Ponds*.

Grassland Basin Drainage Steering Committee 1999. *Rule Enforcing Selenium Load Allocation and Establishing a Tradable Loads Program for Water Year 2000.* Passed October 22, 1999.

Porter-Cologne. 1969. Porter-Cologne Water Quality Control Act of 1969. Assembly Bill 413.

SJVDP, 1990. San Joaquin Valley Drainage Program, *Fish and Wildlife Resources and Agricultural Drainage in the San Joaquin Valley, California, Volume I.*

SWRCB. 1999. State Water Resources Control Board. *SB 390 (Alpert) Water Quality, Permit Waivers. Chapter 686, Statutes of 1999*. 1999 California Legislation. Office of Legislative and Public Affairs.

SWRCB. 2000. State Water Resources Control Board *Plan for California's Nonpoint Source Pollution Control Program.* California Coastal Commission.

SWRCB. 2001. State Water Resources Control Board *Draft: Compliance Assistance Guidance (CAG) for Implementing the Plan For California's Nonpoint Source Pollution Control Program.*

TAC. 1994a. Technical Advisory Committee. *Irrigated Agriculture Report to The California State Water Resources Control Board.*

TAC. 1994b. Technical Advisory Committee. *Report of the Technical Advisory Committee for Pesticide Management.*

USBR. 1996. United States Bureau of Reclamation. *Compliance Monitoring Program For Use And Operation Of The Grassland Bypass Project.*

USBR. 2001.United States Bureau of Reclamation and San Luis & Delta-Mendota Water Authority *Grassland Bypass Project Final Environmental Impact Statement and Environmental Impact Report*.

USC. 1972. United States Code. *Federal Insecticide, Fungicide and Rodenticide Act. 7 U.S.C. s/s 136 et.seq*.

USEPA. 1997. United States Environmental Protection Agency. *Terms of Environment* Revised December 1997.

USEPA. 1999. United States Environmental Protection Agency. *EPA Major Environmental Laws: FIFRA.* Office of Public Affairs Region 5. *http://www.epa.gov/region5/defs/*

USGS. 1998. United States Geological Survey. Estimated Use of Water in the United States in 1995.

Table 2
REGIONAL BOARD REGULATORY AND ENFORCEMENT MECHANISMS

ACTION	DESCRIPTION OF ACTION	POTENTIAL USE
Basin Plan Amendment	The Basin Plan specifies the beneficial uses and water quality objectives for waters in the Region. It contains an implementation program for meeting the objectives.	The Basin Plan describes how the Board will address various categories of discharges. It already contains detailed descriptions of control programs addressing rice pesticides, selenium and evaporation basins. The plan can set timetables and establish a prohibition of discharge.
Watershed Management Plans	Stakeholders within a watershed, including representatives of the Regional Board, develop and implement a plan to protect water quality and achieve other goals such as enhancement of the fishery or flood protection.	Use of the watershed approach is part of the Regional Board's Strategic Plan. While it often involves coordinated cooperative efforts, it does not preclude the use of regulatory tools to control discharges. Plans developed through the watershed process can be incorporated into the Basin Plan or WDRs.
Waste Discharge Requirements	Individual Orders are issued to dischargers allowing discharge of specified quantities and qualities of waste to land or surface waters. The limitations placed on the discharge are designed to ensure compliance with water quality objectives in the Basin Plans and protect beneficial uses. To obtain WDRs, the discharger must submit a Report of Waste Discharge and the requirements of CEQA must be met. All dischargers must submit monitoring reports and most dischargers pay an annual fee.	The Board can use this approach to regulate any discharge to waters of the state. The discharger would be responsible for providing enough information regarding the chemicals and volumes to be discharged and receiving waters to allow preparation of a permit. Annual fees would cover staff costs and the discharger would cover monitoring costs.
General Waste Discharge Requirements	The Board adopts a general order setting limits that must be met by a specified type of discharger and assures compliance with CEQA. Individual dischargers submit a Notice of Intent to comply with the order in lieu of a Report of Waste Discharge	This type of Order could be used to regulate a category of dischargers or those dischargers that do not meet the conditions for a waiver of WDRs.
Areawide Waste Discharge Requirements	The Board may adopt an areawide strategy using either irrigation districts or return flow groups. These	Areawide WDRs were issued by the Board in the 1970's when the Clean Water Act required NPDES permits for irrigation

ACTION	DESCRIPTION OF ACTION	POTENTIAL USE
	permits set limits that must be met by a specified type of discharge along with a CEQA document addressing the permit.	return flows. The NPDES permits were rescinded when the law changed, but this approach could be used to address local water quality issues. The Board could rank the irrigation districts according to their impacts on water quality. The agencies that most degraded water quality would be issued WDRs first. The irrigation districts with lower list status, and thus less threat to water quality, would have a grace period to improve the quality of their irrigation return water and thus avoid WDRs. If irrigation districts issued WDRs demonstrated improvement of their irrigation return waters, their WDRs could eventually be withdrawn.
Waivers	The requirement to submit a ROWD or obtain a waste discharge requirement may be waived by the Board for specific discharges where such waivers are not against the public interest. Such waivers must be conditional and may be terminated at any time by the Board. (Water Code Section 13269)	Waiver conditions can require actions by the discharger such as compliance with specified management practices and submittal of monitoring reports. If the ROWD is not waived, the discharger must provide sufficient information to verify that waiver conditions will be met. If the discharge qualifies for a waiver, all or a portion of the filing fees can be refunded (Water Code Section 13260 (e)). That portion of the fees retained would cover review of the proposed discharge.
National Pollutant Discharge Elimination System (NPDES) Permits	NPDES permits are issued by the Board pursuant to the federal Clean Water Act. They are used to regulate discharges from point sources such as sewage treatment plants and stormwater to surface waters. As a result of 1977 amendments to the law, these types of permits are not applicable to nonpoint sources such as agricultural return flows. In California, the NPDES permits are also WDRs and serve the same purpose - to restrict the volume and concentration of waste discharged in order to ensure compliance with Basin Plan objectives.	This type of permit is routinely issued to point source dischargers. Federal laws and regulations do not allow issuance of NPDES permits for irrigation return flows or stormwater runoff from agricultural lands.
Memorandum of Understanding/Management Agency Agreements	The Board enters into an MOU or MAA with another agency to formally specify the relationship between the two organizations. The MAA often provides more detail and entrusts the other agency with	The State Board has already signed a MAA with California Department of Pesticide Regulation that addresses water quality issues related to pesticides. Additional MOUs/MAAs could be developed with other agencies.

ACTION	DESCRIPTION OF ACTION	POTENTIAL USE
	additional responsibilities with respect to water quality control efforts.	
Cleanup and Abatement Orders	This is an enforcement order that directs a discharger to clean up waste, abate the effects of the waste, or to take other remedial action. It can be issued by the Board or the Executive Officer to parties that have caused or threaten to cause a condition of pollution of nuisance. No CEQA document must be prepared prior to issuance of such an order.	This type of enforcement action is best applied to individual parties that are conducting activities that require prompt attention. The legality of applying this type of order to a class of dischargers (such as those parties discharging a specific pesticide) is questionable.
Cease and Desist Orders	This is an enforcement order issued by the Board to dischargers that are in violation or threaten to violate WDRs or discharge prohibitions. The order can direct the discharger to comply forthwith, comply in accordance with a timetable or to take preventative action to avoid threatened violations.	Under the present circumstances, this type of order would have limited use in the control of pesticides from nonpoint sources. The Board would have to have WDRs or prohibitions in place for this type of order to apply.
Prohibition of Discharge	The Board, in a water quality control plan or in WDRs, may specify certain conditions or areas where the discharge of waste, or certain types of waste, will not be permitted. (Water Code Section 13243)	This process would allow the Board to address a large number of discharges in any area. When adopted into the Basin Plan, other state agencies must operate in compliance with the prohibition (Water Code Section 13247), and thus would directly or indirectly assist in obtaining compliance.
Request for Technical Information	The Board may require any person discharging or proposing to discharge waste to furnish technical or monitoring reports.	This type of report could be used to obtain verification that dischargers are following specific management practices and/or obtain monitoring that verifies that water quality objectives are being met.

Macronutrients-Changing Strategies from not Enough to Too Much

D.W. Rains
Department of Agronomy and Range Science
University of California
Davis, CA 95616
Phone: (530) 752-1711, email: derains@ucdavis.edu

The last fifty years agriculture has contributed to an amazing increase in productivity, most of it coming from increase yields of major food and feed crops. Agronomically a considerable portion of this increase has been due to inputs of macronutrients in the form of fertilizers; primarily nitrogen and phosphorus with increasing interest and success with applications of potassium. This success has helped make agriculture one of the most important economic sectors in California with current gate receipts of $ 28 billion. The use of fertilizers has been so successful that it is considered routine and an essential component of maintaining economic viability of agriculture. The success of this practice, however, has come under increasing criticism. There is public concern that agriculture is not demonstrating the proper regard for the environment and one of the areas that is under scrutiny is in the management of fertilizers.

Concern for the environment has generated a large number of studies on the quality of both surface and groundwater. This concern arises from the fact that 90% of the rural population and 50% of the urban population depends on groundwater. In the last 30 years systematic sampling of waters expanded to include well waters and small streams throughout the US. This activity was reinforced by the Clean Water Act and in 1990 US-EPA completed a nationwide survey of frequency and concentration of nitrate and pesticides in drinking well waters. They reported that over 1,300 wells they sampled were contaminated with nitrate. From this subsample they estimated that over half the drinking water wells in the US had elevated nitrate levels. Only 2% of those wells (8,200), however, contain levels of nitrate exceeding the health safety standard of 45 ppm. The major concern was that these levels were increasing in well water, specifically in agricultural areas, a concern justified by the latest USGS survey. The public became aware of these findings and began to question what was being done which in turn moved this issue into the public/political arena. Politicians representing the affected areas pressured regulatory agencies. In 1998 a Clean Water Action Plan (CWAP) was formulated as part of the Clean Water Act. The CWAP provides a blueprint for restoring and protecting water quality across the nation. The CWAP describes over 100 specific actions to expand and strengthen protection of water quality.

In Europe there is a very active Council which reports to the European Union. It adopted the Nitrate Directive in 1991. The Nitrate Directive was charged with reducing water pollution caused or induced by nitrates from agricultural sources. There is no debate as to the responsibility of agriculture; the focus is on reducing the contribution from agriculture.

In response to CWPA the United National Strategy for Animal Feeding Operations (AFO) in cooperation with US EPA has developed a number of guiding principles. The highest priority is given to minimize water quality degradation and reduce the risk to environment and public health. This is a proactive approach to addressing the problem and will provide a leadership role in decision making related to the potential impact of their industry on the environment.

A number of other sectors in American agriculture are becoming proactive. In the midwest both Nebraska and Iowa are implementing regulation procedures for the reduction of N and P fertilizers. These states responded to information coming from studies on the expanding nitrate plume found at the outflow of the Mississippi River into the Gulf of Mexico (McIsaac, et al., 2002). This nitrate plume has continued to expand resulting in a 22,000 square kilometer dead zone. The excess nitrate flowing into the Gulf lead to an “algae bloom”, which upon decomposition created anoxia conditions resulting in the death of oxygen dependent organisms (Science, vol. 297, 2002).

Reports continue to identify nitrate as a potential health hazard. In addition to the recognized “blue baby syndrome” the University of Iowa Medical School has suggested that “even low level exposure to nitrate over many years could be problematic in terms of certain types of cancer”(Environmental News Network, 2001). They specifically identified bladder cancer as a high probability factor. These concerns generated a need for information on the extent of the contribution of agriculture to the flow of nitrate into waters. A four year study has been conducted to assess the nitrate leaching in a central Iowa field (Cambardella, et al., 1999). Results of this study quantify the contributions of a conventional farming system in the midwest to the appearance of nitrate in the surface and groundwater.

Phosphorus also reduces the quality of water. Although not considered a health hazard it does cause eutrophication of waters with all of the attendant affects. This macronutrient has become an increasing problem in areas where animal wastes are concentrated and is a particular concern in the areas surrounding the Chesapeake Bay. States adjoining the Bay have undertaken a number of programs to address this issue. Maryland has deployed a statewide, phosphorus site index as an agricultural management tool in attempts to reduce pollution from phosphorus (Coale, et al., 2002). Other states have proposed or implemented P indices, as a basis for distinguishing between P sources should there be potential runoff from agricultural activities (Sharpley, et al., 2002). Development of the indices provides critical information for regulatory agencies if or when regulation is imposed.

California is susceptible to similar concerns. A survey conducted from 1975 to 1987 sampled 38,144 wells in California. In this survey 10% of the wells sampled exceeded the maximum contamination level of 45 ppm $NO_{3.}$ (MacKay and Smith, 1990). More recent data from a USGS survey of wells in the Central Valley of California suggests that the number of NO_3 contaminated wells continues to increase. Point source pollution is more easily identified both in terms of contributor and in terms of amount. Crop production systems, however, are categorized as non-point source contributors and it is much more difficult, if necessary to develop regulatory approaches to deal with the situation. It becomes increasingly important for agriculture to recognize their part in this environmental issue and to become proactive in dealing with situation. A number of programs have been addressing this potential problem and various approaches have been instituted. Franco and Cady (1997) make a case for using a non-regulatory approach. This involves agriculture in assessing the current situation and developing information on the fertility management in existing cropping systems. As an example, a summary of the current status of N fertility management in cotton will be used as a case study in California. Data will be presented and suggestions on the use of this information in managing nutrient systems will be discussed.

References

Cambardella, C.A., T.B. Moorman, D.B. Jaynes, J.L. Hatfield, T.B Hartman, W.W. Simpkins and D.L. Karlen. 1999. Water quality in Walnut Creek watershed: Nitrate-nitrogen in soils, subsurface drainage water and shallow groundwater. J. Environ. Qual. 28: 25-34.

Coale, F.J., J.T. Sims and A.B. Leytem. 2002. Accelerated deployment of an agricultural nutrient management tool: The Maryland phosphorus site index. J. Environ. Qual. 31: 1471-1476.

Franco, J. and C.W. Cady. 1997. Preventing nitrate groundwater contamination in California: A nonregulatory approach. J. Environ. Qual. 10: 52-57.

MacKay, D. and L. Smith. 1990. Agricultural chemicals in groundwater; monitoring and management in California. J. Soil Water Conserv. 45: 253-255.

McIsaac,G.F, M.B. David, G.Z. Getner and D.A. Goolsby. 2002. Relating net nitrogen input in the Mississippi River Basin to nitrate flux in the lower Mississippi River: A comparison of approaches. J. Environ. Qual. 31: 1610-1622.
To phosphor

Micronutrients in California

Roland D. Meyer, Extension Soils Specialist
University of California—LAWR Dept.
One Shields Ave., Davis, CA 95616
Telephone: 530-752-2531 FAX: 530-752-1552
Email: rdmeyer@ucdavis.edu

Introduction

California has a wide range in soil, climate, geologic and topographic features which give rise to a large variation in plant concentrations of micronutrients. Micronutrients considered essential for plant growth and discussed in this presentation will include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). Other elements such as cobalt (Co) which is required by legumes for nitrogen fixation and selenium (Se) which is required by animals and humans will only be mentioned as they are influenced by other nutrients.

Discussion

Information regarding deficiencies and toxicities of each of the micronutrients will be presented with some indications of geographical locations in California where they might occur. This is not intended to be an exhaustive discussion because of the limitations of both space in the proceedings and time in the presentation.

Boron (B)

The state has a number of primarily intermountain locations in the north where deficiencies occur as well as a number of areas with toxicities of boron. Alfalfa is one of the major crops that respond to fertilizer applications and specifically if seed is produced. Forage yield is not as greatly influenced with applied boron as seed production for many legumes. Boron responses are much less likely for grasses but fruit trees such as apple can be expected to show considerable response. A number of fruit and nut trees grown in the sandy soils on the east side of the San Joaquin Valley have shown deficiencies. Fertilizer application rates are usually in the 1-2 pounds B per acre range but may be as high as 3-5 pounds B per acre for new stands of alfalfa or other permanent crops. Applying boron in bands near germinating seed or young plants should be avoided.

Toxicities can be expected in a number of areas such as the Cache Creek watershed, the Hollister area and a number of other areas in the Coastal valleys and alluvial fans into the San Joaquin Valley. Many of these and other locations have groundwater used for irrigation that have boron concentrations exceeding 1-2 ppm which present considerable challenges for growing different crops.

Chlorine (Cl)

Sufficient levels of chlorine seem to be present throughout the state so that few if any deficiencies have been observed. Far more likely are the situations where chloride concentrations in groundwater or other irrigation water, perched water tables or the lower part of the rooting zone of some of the tree crops result in toxicities. If adequate drainage can be established, chloride concentrations can usually be reduced with sufficient leaching provided that the irrigation water has relatively low chloride levels.

Copper (Cu)

Deficiencies of copper often occur in crops growing on high organic matter soils or in a few cases crops with an inability to secure sufficient copper from the soil. Many forage crops require low concentrations (2-4 ppm) for there own growth and maximum yield but contain much lower concentrations of 6-8 ppm than would be desirable for domestic and wildlife animals of greater than 10-12 ppm. Higher concentrations of copper are particularly desirable in forages for animals if molybdenum concentrations are equal to or greater than those of copper. It is less likely that animals consuming forages with a nearly 2:1 ratio of copper to molybdenum will have growth difficulties as compared to a ratio of 1:1 or greater molybdenum unless copper concentrations exceed 10-12 ppm.

Iron (Fe)

Deficiencies of iron as well as manganese and zinc are often observed in plants growing on soils having a pH of 7.5 or higher when the solubility of each of the three becomes much lower. These areas occur throughout the San Joaquin Valley, the Imperial Valley and many Coastal and other valleys located generally in the southern half of the state. Iron deficiencies may also occur in the North Coastal Range where heavy textured serpentine (high magnesium) derived soils are used for walnut, pear and wine grapes are grown. Iron chelates can be used to correct these deficiencies with soil applications or foliar applied solutions of ferrous sulfate may be used. Soil applications of several ferrous compounds have not been very effective. Bands of sulfuric and other acids and elemental sulfur which maintain a long-term acidified band in the soil have been the most economical and effective remediation treatments to alleviate iron deficiencies.

Toxicities of iron have not been reported in plants but excessive iron concentrations in irrigation water present plugging and other problems in drip and microsprinkler systems.

Manganese (Mn)

As mentioned previously, manganese deficiencies can be expected to occur on soils with a pH greater than 7.5. It can be expected it tree crops such as walnut growing in the San Joaquin Valley and some intermountain valleys where former lake beds have left salts after the water has evaporated. A rather common oats variety Cayuse often shows the grayish green upper leaves with mottling that are specific to manganese deficiency. In the case of soils growing oats showing the symptoms, ammonium sulfate at a rate of 50-75 pounds per acre placed with the seed at planting time will be more effective in increasing the manganese concentration of the leaves than manganese sulfate. The acidifying effect of ammonium sulfate in the seed zone will solublize sufficient manganese to meet crop need. As is the case with remediation of iron deficiency, bands of sulfuric and other acids and elemental sulfur which maintain a long term acidified band in the soil have been the most economical and effective treatments to alleviate manganese deficiencies in permanent crops.

Toxic concentrations of manganese in plants are rare but high concentrations in leaf tissues are somewhat likely to occur in drip irrigated permanent crops where the accumulated effect of years of ammonium or ammonium forming nitrogen fertilizers like urea applied to a small volume of the soil dramatically reduce the pH into the 4.0 range. This will maintain high soluble concentrations of manganese and aluminum that can and will often be taken up by the plant. Manganese concentrations in the leaves can often reach 600-800 ppm during the latter part of the growing season in crops like almonds both with no leaf toxicity symptoms. Leaf toxicity symptoms can be expected if concentrations exceed 1000 ppm.

Molybdenum (Mo)

Molybdenum is the only nutrient that becomes more plant available as the soil pH increases from the strongly acidic range (pH 4.0-4.5) to highly alkaline (> pH 8.0). Deficiencies can be observed in a number of intermountain valleys in Northern California as well as the west side of the Sacramento Valley. Increasing concentrations in most plant species and particularly legumes are normally observed when proceeding south in the San Joaquin Valley from near 1 ppm in the Sacramento area to greater than 10 ppm in the Bakersfield area. In addition to deficiencies of molybdenum in legumes, several vine seed crops have shown dramatic growth and seed yield responses to applied molybdenum. Applied fertilizer rates are generally less than one-half pound of molybdenum (~1 pound of sodium molybdate) per acre and often need not be repeated more than every 10 years because of the extremely low crop removal amounts.

Toxicities or excessively high concentrations (> 5-10 ppm) are seldom if ever observed in affecting plant growth but frequently diagnosed in animals (domestic and wildlife). This has been noted in the lower rainfall areas of Northeastern California, along the Eastern side of the Sierra's to as far south as the Mexico border and throughout the San Joaquin Valley. The rangelands of the Central Coast beginning near Salinas and south to the border with Mexico have reportedly had forages that have molybdenum concentrations in the 5-10 ppm range or higher. Soils that have been irrigated for a number of years usually contain much lower concentrations of molybdenum because it is leached to the deeper portions of the soil profile.

Nickel (Ni)

Deficiencies of nickel have not been identified in plants growing in California. It is more likely that plants, particularly legumes would have excessive concentrations. Excessively high concentrations of nickel are often present in plants grown on soils having serpentine parent materials that contain large amounts of the element.

Zinc (Zn)

Of all the micronutrients, the deficiency of zinc is more widespread geographically and across more crops than any other. It is more likely to occur in soils having a higher pH but also occurs where the topsoil, which contains most of the organic matter, has been removed in leveling operations. The interaction with phosphorus application which reduces plant uptake of zinc is perhaps the major reason for applying it in fertilizer bands for many field and vegetable crops. Many of the fruit and nut tree crops also show deficiencies of zinc so it is routinely applied as a foliar spray.

Toxicity of zinc to plants is rare if not impossible to observe.

Interpretation of Soil and Tissue Analytical Results

Keith M. Backman
Certified Professional Horticulturist
Dellavalle Laboratory, Inc., Hanford, CA

From a horticultural standpoint soils are a medium for the support of plants. Soils do not consume fertilizer and they are not sensitive to salts, extreme pH levels, and poor drainage. Without a designated crop or plant specie the evaluation of a soil analytical results is meaningless or detrimental. Thus, a soil that is excellent for alfalfa may be terrible for strawberries. That is not a problem with the analysis but is instead a challenge for the consultant interpreting the analytical data.

Soil Analyses – Nutritional Evaluation

Nutritional decisions based on soil analytical results are of most value for preplant decisions in a row crop or field crop situations. Because it is known that the seedling or transplant must begin it's season in the top 3 to 6 inches, an accurate evaluation of the nutrients present in the soil is a valuable tool.

Complications of the surface nutrient evaluation arise when trying to predict whether deeper soil nutrients will become available as the root system moves deeper into the soil. A row crop may eventually extract from the third foot while the same crop in a nearby location may never go beyond one foot in depth. To accurately asses this situation the consultant must have a good familiarity with the field being farmed or make a guess at the expense of the crop. After the initial soil test, plant tissue analyses should be used to measure the nutritional status of the plant. This allows the plant to report what it actually needs.

In perennial (long term) crops (such as alfalfa, trees, and vines) the importance of root depth is even more important. Many orchards (possibly 25% or more) have root depths of less than two feet. The complication for the consultant is that an equal number of orchards may have roots well beyond five feet. Thus, 100 ppm of soil potassium may be less than adequate for the shallow rooted orchard and 40 ppm may be more than adequate for the deeper rooted orchard! A consultant must estimate using available root zone knowledge or find out the real situation by taking a tissue analysis. Thus a knowledgeable consultant never uses a soil analysis of nutrients when tissue samples can be collected.

Soil Analyses – Salinity Evaluation

Sodic, saline, low-salinity, and acidic soil conditions need soil analyses to accurately asses the situation and to help prescribe a remedial program. The main concept to keep in mind is that you are trying to evaluate a 3-dimensional environment. Vertical differences in the soil test components are very important. Interpreting lab data based on a top foot sample is often a mistake, because salt loads in high boron, sodic, saline, and sodic-saline situations generally increases with depth. It is also important to note that lowest salt levels are generally at the point where irrigation water first touches the soil and higher levels can be expected at the end of the water movement. Knowing the characteristics down thru the soil profile is important to evaluate the situation and the soil amendments that may be required.

Alkali hazard is not decided by the soil. It is a plant based situation considering the salts found in the root zone. Establishing a soil amendment requires information regarding anticipated root depth, plant species, crop (i.e. raisin or table grape?), water quality, root stock choices, irrigation system, time frame, etc. For a salt tolerant plant, there may be no gypsum requirement to grow in an alkali soil.

Exchangeable Sodium Percentage (ESP)(a measure of alkali conditions)

Crop	Problems Above:
Wheat	12 meq/l
Cotton	10
Almonds	7
Turf	5
Wine Grapes	5
Table Grapes	3
Cherries	2

Salinity problems are more complex that just looking at the Total Salt level.
Calcium (Ca) + Magnesium (Mg) + Sodium (Na) = Total Salts (EC)
Soil amendments, such as gypsum, greatly increase the Ca level, which in turn increases the EC. Since the Ca is generally not toxic, the higher EC may not be a problem.

EC _ Soil Test Example:

Ca	Mg	Na meq/l	EC mmhos/l	
18.7	7.7	5.5	3.7	Satisfactory for most crops
5.5	1.7	8.8	1.5	Problematic for many crops

Making a salt reclamation recommendation is a two step process:
1) Application of the necessary soil amendment
2) Leaching the harmful salts away from the intended root zone

Without leaching the soil may be worse after an amendment application. It is important to remember that lateral leaching is as important to control as vertical leaching. Drip zones and berm situations can create an environment where an inappropriate irrigation technique can make the soil more toxic to the plant.

Tissue Analyses – Salt Toxicity
Salts accumulate in the plant tissue over time. Thus, a plant in a moderate salt situation may take several months before toxic levels to accumulate in its leaves. This leads to qualitative decisions by the consultant, who should realize that a high level late in the season may not be a problem but a medium level early in the season can be a severe warning.

Problem salts that should be monitored are Sodium (Na), Chloride (Cl), and Boron (B). Critical levels tend to be similar for sodium and chloride. Both tend to be indicators of a problem if levels exceed 0.3% in the leaf tissue, depending on time of year and crop. Salt tolerant crops tend to accumulate salts slower that their sensitive counterparts. Boron is a salt that fits into the nutrient and salt categories. Leaves containing over 80 ppm may indicate an approaching problem, subject to seasonal and crop variables.

Tissue Analysis – Nutrients

Chlorophyll is the "engine" of the plant. It uses sunlight to construct the energy components necessary for plant growth. Nutrients are required to enable the reaction to progress and provide the building-blocks for the construction process. When a deficiency occurs the system slows down and has problems. When nutrients are high growth tends to be somewhat "warped", creating several types of crop damage in addition to environmental risk and increased production costs.

Because chlorophyll is almost identical among plants (with only a few exceptions) many of the nutrient requirements for leaves are similar. For instance, zinc is deficient below 18 ppm, marginal from 19 to 22 ppm, and adequate above 23 ppm in walnuts, strawberries, and Bermuda grass! They all run on chlorophyll and the number of atoms per molecule is the same. Differences between zinc programs is often more a factor of timing, application technique, and dosages. Actually the critical level can vary during the season:

Zinc Example: For a peach orchard that receives a fall leaf-fall spray:

> 40 + ppm would be normal in the spring
> 25 ppm would be normal in July.
> 20 ppm would be normal in September
> (Like filling a fuel tank, at no time during the trip do you want to "run out". Watch the gauge to avoid surprises!)

Nitrogen control is a valuable tool to manipulate crop quality an harvest dates. Many fruit crops will provide the best size if nitrogen is adequate in the spring and low (not deficient) at harvest. High N levels at harvest will delay harvest date, sugaring, coloring, and sizing. Many crops (such as sugar beets, cotton, peaches, tomatoes) can have devastating problems with excessive N levels.

Nutrient applications should be planned so that foliage and crop do not suffer before an application is planned. Pre-emptive analyses and applications are designed so your "engine is running on all 8 cylinders" taking your crop to market. Waiting for visual symptoms of a deficiency is <u>unacceptable</u> in a competitive market!

It would take many pages and hours of time to discuss the intricacies of each nutrient on each crop. Nutrient critical levels are available for most plants to enable you to put the crop in the right "ballpark". With a little experience the crop can be fine-tuned and controlled to conform to the grower's needs. Taking the time to develop a good background with your target crops, or working with an experienced specialist, is valuable to the consultant and the grower.

Closing Comment

It is important that published critical levels for soil and leaf analyses be used as rough guidelines rather than finite critical levels. The average critical level developed for the average crop in the average state, used blindly, will produce an average quality crop with average production levels. Paying a little extra attention to the specific crop requirements will pay-off with dividends in quality and quantity.

Soil test to predict nitrogen response in California crops

William R. Horwath, Assoc. Professor of Soil Biogeochemistry,
Department of Land, Air & Water Resources, University of California, One Shields Avenue, Davis, CA 95616, (530) 754-6029, wrhorwath@ucdavis.edu

The need to estimate soil N mineralization has been recognized in prescribing N fertilizer recommendations. Excessive and or inappropriate application rates and timing of fertilizer and manure N have been implicated in high groundwater nitrate content in several regions of the state. In addition to groundwater concerns, fertilizer N from agricultural sources has been blamed for low dissolved oxygen content in surface waters. For example, hypoxia symptoms in the Gulf of Mexico and in the shipping canal of Stockton, California are thought to be caused by excessive fertilization practices in upstream agricultural lands. Research is needed to accurately quantify the availability of soil N and residual N from prior fertilizer applications.

Soil testing for nitrate and matching N application rates and timing to actual crop uptake have been commonly used practices. The testing for residual available soil N has been at best marginal in predicting fertilizer N application rates. The main barrier to progress is the uncertainty in determining the amount of soil N that will become available during the growing season. The uncertainty is associated with the lack of complete understanding of the factors that control mineralization of N from crop residues, soil organic matter, and organic amendments, such as manure.

The amount of total N found in the top 6 inches of most soil amounts to approximately 15 times the amount of N needed by crops to achieve maximum yield. Most of the N in soil (greater than 95%) is in organic form and unavailable for crop uptake (Stevenson 1994). The availability of soil N depends on microorganisms that decompose or mineralize organic soil N to mineral N before it can be available for crop uptake. Soil organic N is mineralized at a rate of from 2 to 5 % per year. The mineralized N would be sufficient for most crops to attain maximum yield. However, crop demand for N occurs in a narrow window of time about two months after planting, while the mineralization of soil N occurs throughout the year. Therefore, the synchrony between soil N mineralization and crop demand does not coincide.

Predicting the timing and amount of soil mineralization has been problematic. The inability to predict soil N availability has hampered our efforts to determine accurate fertilizer N recommendations. The problem is more acute in soils with a history, even one application, of organic amendment applications, such as manure, biosolids, and green manure from cover crops. The main obstacle in determining soil N mineralization is in identifying a specific fraction of soil organic N that affects crop responsiveness to N fertilization.

Better quantification of the N mineralization contribution in cropping systems would help minimize N losses to the environment and allow more accurate recommendations for fertilizer N applications. Surveys have shown that farmers are often reluctant to adopt improved N management practices that could lower the frequency of excess N application because they perceive a high risk of potential yield loss if these practices are implemented.

A common technique to estimate available soil and residual fertilizer N is the preplant nitrate test (PPNT). Magdoff et al. (1994), improved the PPNT by developing the presidedress nitrate test (PSNT). The PSNT determines available soil N within days of sidedressing fertilizer. Hartz et al. (2000) showed that the PSNT was effective at determining fertilizer N responsiveness in irrigated vegetable production in California. These studies also suggest that postponing the sampling for available soil N to when maximum N uptake occurs more accurately estimate crop N. The timing would be crop specific and may also depend on other factors such as soil moisture and temperature. However, in general soil nitrate tests are only marginally useful in predicting fertilizer N response. One main reason for the marginal utility of these methods is the need to soil sample at specific times and to obtain results promptly in order to accurately estimate fertilizer N application rates.

The limitation of testing for soil NO_3^- is related to the dynamic nature of the soil N cycle. The temporal nature of the available soil N negates the predictive capacity of the tests based solely on the amount soil NO_3^-. Therefore, in practice the PPNT and PSNT have only been marginally acceptable in assessing fertilizer N application rates. For example, Krusekopt, H. et al. (2002) found little correlation of PPNT to tomato yields. Similar observations have been found in cotton. Even though these results seem not to be promising, soil testing for available N is still considered the best option to determine sites where N fertilization will produce a yield response.

The ideal soil test will estimate the fraction of soil organic N that will mineralize. The approach would overcome the complications of deciphering the dynamics of the N cycle and other soil factors controlling the available soil N. Recent studies have shown that quantity of amino sugars may be useful to determine soils that are responsive to N fertilization (Khan et al. 2001). Amino sugars account for up to 25 to 45% of the total soil N. Amino sugars in soil N are primarily derived from bacterial and fungal sources. The size of the amino sugars pool will depend on the activity of these microorganisms. The activity of soil organisms depends on the availability of food or organic matter in the soil. The production (microbial growth) and subsequent deposition (microbial turnover) of amino sugars in soil is directly related to available soil N. The higher the available soil N pool, the more likely the amino sugar pool will also be high. The advantage of examining the amino sugar pool in soil is that this soil N fraction represents an integrative response describing microbial processes. Therefore, time of sampling is not as critical as for the PPNT or PSNT methods.

In recent reviews, the consensus opinion on the prediction of soil N mineralization and availability is that multiple soil tests may be needed to accurately predict crop N (Bundy and Andraski 1995). For example, a combination (two or more) of a soil nitrate measurement with a chemical extraction procedure could provide a more reliable assessment of the available N supply for crops. This approach is deemed necessary because of the dearth of information regarding what fractions of soil organic N are responsible for contributing to the mineralizable soil N. However, the use of multiple soil tests is complicated and not likely to be easily adopted by soil test labs. In addition, the complicated requirement to integrate the results of the methods into a simple prescription for N fertilizer application would not be easy for university and industry farm advisors. From a practical perspective, the fewer tests that are required to give reasonably accurate results would be highly desired.

References

Bundy, L.G., and T.W. Andraski. 1995. Soil yield potential effects on performance of soil nitrate tests. J. Prod. Agric. 8:561-568.

Hartz, T. K., W. E. Bendixen, and L. Wierdsma, 2000. The Value Of Pre-Sidedress Soil Nitrate Testing As A Nitrogen Management Tool In Irrigated Vegetable Production. HortScience 35:651-656.

Khan, S. A., R. L. Mulvaney and R. G. Hoeft. 2001. A simple soil test for detecting sites that are non-responsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65: 1751-1760.

Krusekopt, H, J. P. Mitch T. Hartz, D. May, E. Miyao and M. Cahn. 2002. Presidedress soil N testing identifies tomato fields not requiring sidedress fertilizer N. Hortscience 37: 520-524.

Magdoff, FD, D Ross, J Amadon. 1984. A soil test for N availability to corn. Soil Sci. Sco. Am. J.48:1301-1304.

Steveson, F. J. 1994. Humus Chemistry. Wiley Interscience, NY.

EFFICIENT PHOSPHORUS MANAGEMENT IN COASTAL VEGETABLE PRODUCTION

T.K. Hartz, Department of Vegetable Crops, University of California Davis, CA 95616,
(530) 752-1738 (phone), (530) 752-9659 (fax), hartz@vegmail.ucdavis.edu and
Cooperating personnel: Michael Cahn, UCCE and Misty Swain-Johnstone, NRCS

Introduction

Decades of heavy phosphorus fertilizer application to vegetable fields in the Salinas and Pajaro Valleys have resulted in substantially increased soil P concentration. Soil test P levels frequently exceed the threshold for expected crop response to continued P fertilization; however, many growers continue to apply P to such fields. While this generally does not cause agronomic problems, it may be a significant contributor to the undesirably high P concentration found in the Salinas and Pajaro River systems. Parts of both watersheds have been listed by the California EPA as 'impaired' for soluble nutrients, based on the prevailing Federal water quality standards. This project was undertaken to reevaluate the current P management recommendations for lettuce production in light of this potentially serious environmental problem.

Objectives

1) Develop efficient P fertilizer guidelines for coastal lettuce production
2) Document the relationship between soil characteristics, soil test P levels, and potential loss of P through in runoff.

Methods

To determine the current P status of agricultural land in the Salinas and Pajaro Valleys, soil from 30 fields, most in long-term vegetable rotations, was collected in spring, 2002 (Table 1). The fields, located in Monterey, San Benito, Santa Clara and Santa Cruz Counties, represented both conventionally farmed and organically managed land. These soils will be used in a study designed to correlate the soluble and total P concentration of runoff water (from rain or irrigation) with the soil test P value and soil hydraulic properties. The intent is to provide a simple system by which growers can rank their fields for P runoff potential, so that remedial actions can be targeted where they would do the most good.

Six trials were conducted in commercial lettuce fields in the Salinas Valley in 2002 evaluating whether P fertilization in fields with moderate or high soil test P levels actually affected crop productivity. The fields chosen varied from 54 – 171 PPM bicarbonate P (top 6 inches of soil, Table 2). Existing recommendations rank these field as moderate (fields 1 and 3) or high P availability (fields 2,4,5 and 6). A strong crop response to preplant P fertilization would not be expected, based on prior research with cool-season vegetables. In fields 3 and 5 the grower did not apply P fertilizer; we established 4 plots within each of these fields which received a preplant fertilization with 130 lb P_2O_5 / acre. In all other fields the growers applied P, and we established 4 plots per field in which this P application was skipped. The experimental design was randomized complete block, with each plot being 4 beds wide and 200 feet long. All data were collected in the middle 100 feet of each plot, from the middle two beds.

Plant P status was monitored by biweekly sampling through the crop season, including at harvest. Plots with and without P fertilization were photographed on a biweekly basis with a digital infrared camera; these images allowed calculation of the percent of ground covered by the plant canopy, an objective, non-destructive measure of plant vigor. Prior to commercial harvest, 30-40 whole plants per plot were selected at random and weighed to compared total plant biomass between treatments. Where practical, data on marketable yield and head size distribution was collected by working with the commercial harvest crew. Where that was not possible, selected plants were trimmed to simulate commercial harvest, and the marketable yield of the treatments were compared.

Results

The soils collected in the field survey ranged from 14 – 196 PPM bicarbonate extractable phosphorus, averaging 78 PPM (Table 1). To put these numbers into context, soils from the Sacramento Valley that have been farmed for an equivalent period of time typically range from 10-25 PPM bicarbonate P. The difference reflects the higher application rates, and more frequent application, of P fertilizers in the coastal valleys. Despite these high soil test P values, many coastal vegetable growers continue to apply P before each crop, and a substantial number also apply P in sidedressings.

In the first trial, planted in early April, significant response to preplant P was observed (Table 3). This was somewhat surprising, since the soil bicarbonate P level was 54 PPM, above the response threshold cited in most references. Early planting (cold soil temperature) was undoubtedly a factor, since P bioavailability is reduced at lower soil temperature. Field 2 was planted only a week later, but had substantially higher soil test P (124 PPM). As expected, production in plots in which preplant P was skipped was equivalent to the grower's standard P application. Fields 3 and 4 had intermediate soil test P levels, and neither showed significant crop response to P fertilization. Fields 5 and 6 also showed no crop response to P fertilization; not only did both fields have high soil test P, they were planted during the warmest part of the season.

In the first trial (the only responsive field) there was a consistent trend toward slightly smaller plants in the 0 P plots, based on the infrared camera images. These differences were apparent at thinning, and were maintained throughout the growing season (Fig. 1). Preplant P apparently functioned mostly to maximize early seedling growth; once a substantial root system was established, the field soils had sufficient P availability to maximize crop growth, and all plots grew at a similar rate. This implies that a low rate, at-planting P fertilizer application (a phosphoric acid overspray, for example) might provide the same crop response as a heavier preplant application. This would be environmentally desirable, since it would minimize further P loading in these soils.

P application had minimal impact on tissue P concentration in any field at any time in the cropping cycle (Table 4). Leaf P concentration was well above current sufficiency standards in both P treatments in all fields. This reinforces the conclusion that heavy preplant P application is not an efficient practice in soils with moderate to high soil test P levels. In several non-responsive fields, mid-season midrib PO_4-P concentration in plots with and without P was below commonly cited sufficiency levels (usually considered to be 2,000 – 3,000 PPM), suggesting that these standards need to be reevaluated.

In summary, soil P levels in the coastal vegetable production areas are high enough to potentially contribute to surface water quality problems. Continued P fertilization of high P soil is an inefficient practice, particularly for fields planted when soils are warm. Even for spring planted fields there may be a more environmentally benign, and more cost effective, approach than the conventional preplant application.

Table 1. Soil test bicarbonate P content (PPM) of survey fields.

Field	Location	Management type	Bicarbonate P (PPM)[z]
1	King City	conventional	14
2	King City	conventional	18
3	King City	conventional	30
4	Hollister	organic	33
5	Santa Cruz	organic	34
6	Salinas	conventional	36
7	Morgan Hill	conventional	40
8	San Juan Bautista	organic	41
9	Gilroy	conventional	42
10	San Martin	conventional	42
11	Gonzales	conventional	47
12	King City	conventional	54
13	King City	conventional	58
14	Salinas/Buena Vista	conventional	65
15	Gilroy	conventional	65
16	Greenfield	conventional	77
17	Salinas	conventional	78
18	Chualar	conventional	79
19	Greenfield	conventional	80
20	Salinas/Buena Vista	conventional	85
21	Morgan Hill	conventional	87
22	Hollister	organic	92
23	Gilroy	conventional	93
24	Soledad	conventional	95
25	Watsonville	conventional	124
26	Castroville	conventional	126
27	Chualar	conventional	149
28	Salinas	conventional	185
29	Santa Cruz	organic	188
30	Santa Cruz	organic	196

[z] top 6 inches

Table 2. Characteristics of the 2002 field trial sites.

Field	Location	Bicarbonate extractable soil P (PPM)[z]	Lettuce type	P application rate (lb P_2O_5 / acre)	Planting date[y]
1	Salinas	54	Head	59	April 3
2	Salinas	124	Head	60	April 11
3	Soledad	55	Romaine	130	May 11
4	Chualar	72	Head	42	June 12
5	Chualar	171	Head	130	July 15
6	Chualar	78	Romaine	72	July 26

[x] top six inches of soil
[y] date of first water

Table 3. Lettuce response to P fertilization.

Field	P treatment (lb P_2O_5 / acre)	% of plants marketable	Whole plant wt (lb)	Marketable plant wt (lb)	Boxes 24s / acre
1	0	81[z]	2.15[z]	1.46 [z]	847 [z]
	59	87	2.29	1.56	751
2	0	93	2.42	1.58	1020
	60	95	2.52	1.57	1018
3	0		1.55	1.07	
	130		1.65	1.08	
4	0	84	2.56	1.66	
	42	83	2.64	1.70	
5	0	75	1.55	1.06	
	130	77	1.56	1.08	
6	0		1.21	0.90	
	72		1.17	0.88	

[z] significantly different from the applied P treatment

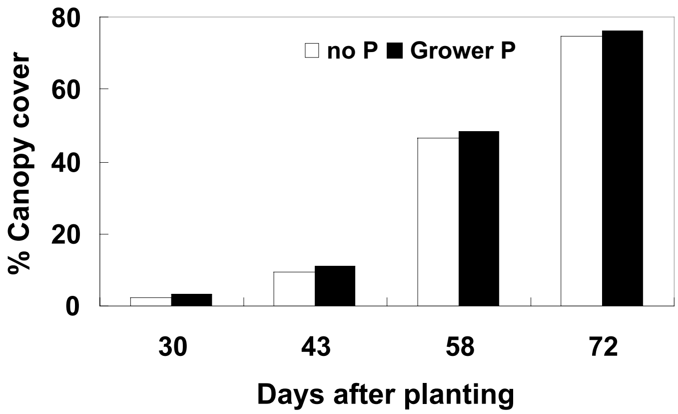


Fig. 1. Canopy cover development in field 1.

Table 4. Effect of P fertilization on lettuce tissue P concentration.

Field	P treatment (lb P2O5 / acre)	At thinning % leaf P	At heading % leaf P	At heading PPM midrib PO_4-P	At harvest % leaf P
1	0	0.42	0.43	1370	0.64
	59	0.42	0.43	1250	0.66
2	0	0.35	0.48	1620	0.68
	60	0.35	0.51	1600	0.71
3	0	0.39	0.37	840	0.38
	130	0.41	0.40	830	0.42
4	0	0.50	0.51	3480	0.78
	42	0.50	0.53	3440	0.81
5	0	0.54	0.44	2480	0.55
	130	0.59	0.49	2760	0.59
6	0	0.54	0.56	1430	0.56
	72	0.52	0.56	1490	0.56

Nutrient Demand and Fertilization Strategies:
Lessons Learned From Boron

Patrick H Brown, Department of Pomology,
University of California-Davis, CA, 95616
phbrown@ucdavis.edu (530) 752-0929

Abstract

In many regions of the world, growers and fertilizer manufacturers recommend the use of foliar fertilization to prevent short term or 'transient' deficiencies of micronutrients such as those that may occur during reproductive growth, or periods of peak demand. The fundamental nutritional physiology to support the importance of transient nutrient demand on yield, however, is scant and generally inadequate to predict or explain the usefulness of targeted foliar fertilizers.

Over the past 5 years we have conducted considerable research into the unique effectiveness of targeted boron (B) fertilization and have observed that foliar B applications frequently increase fruit set and yield if applied during reproductive growth. These responses are seen even in the absence of symptoms of B deficiency. Biochemical, isotopic and molecular experimentation demonstrate that a transient B deficiency is common during reproductive growth and that B plays a unique but poorly understood role in reproduction.

Whereas this research on B clearly demonstrates that transient micronutrient deficiencies occur and have important effects on tree yield, there is inadequate research to verify if transient deficiencies of other elements occur, or to determine if foliar fertilizers are the most efficient method of correction. Here we describe evidence that localized and transient B deficiency occurs and impacts yield, the implications of this research for other microelements is discussed.

1. Introduction

It is widely hypothesized that transient nutritional deficiencies occur as a result of limitations in uptake or restrictions in nutrient delivery during periods of peak nutrient demand. To address this issue many horticultural producers utilize foliar fertilizers since this allows for highly localized and specifically tailored nutrient applications that are not as easily provided using solid or blended products. This approach is particularly relevant for micronutrients.

Very little research is available, however, that demonstrates the value of foliar fertilizers and the role they play in ensuring continued nutrient supply during times of peak demand. In the following we describe the role of foliar B in addressing short term nutrient deficiencies in several crops and provide evidence that transient nutrient deficiencies are physiologically relevant. The historical, physiological and agronomic basis for the use of foliars is described and relevance to the broader field of fertilization is discussed.

Foliar fertilization has been used by fruit growers since the early 19th century (Gris, 1884) and has become an important management practice in all well managed orchard systems. The supply of nutrients by foliar fertilization, however, is expensive and therefore requires careful consideration of both the cost and the relative benefit over more conventional soil fertilizer applications. In general the supply of fertilizers to roots through soil applications is far cheaper and in many (but not all) cases results in a more efficient use of the applied nutrient (Weinbaum, 1989). Identification of the situations where foliar fertilization offers a specific advantage is critical to economic success and provides useful information on the relationship of demand to fertilization strategy.

A significant commercial justification for the use of foliar fertilizers is based upon the premise that foliar fertilizers offer specific advantage over soil fertilizers under certain conditions of high nutrient demand. Examples of conditions that prompt the commercial use of foliar fertilizers include periods of peak nutrient demand such as during rapid fruit growth, when nutrient demand can exceed nutrient supply even in a fertile soil or occasions when localized within-plant demand exceeds the capacity for within-plant nutrient redistribution.

Whereas the use of foliar fertilizers to overcome soil physical and chemical properties is well defined and many examples of its implementation are available, the use of foliar fertilizers to prevent or overcome transient deficiencies has received scant attention. Indeed there are very few research papers that clearly identify a critical but transient nutrient deficiency, and demonstrate that it can be best corrected through foliar fertilization. In spite of the lack of sound experimentation it is the purported effectiveness of foliar fertilizers at preventing and correcting transient deficiencies that is the basis for the sales of many commercial foliar fertilizers.

In the following, experimental evidence for the occurrence of transient nutrient deficiencies and their efficient correction by foliar fertilization is presented. The broader implications of these results as a rationale for the demand based use of fertilizers are discussed.

2. Materials and Methods

2.1 Response of Pistachio to foliar B.

In 1990-94 a large experimental site with potential B deficiency was established in mature Pistachio (*Pistacia vera* L.) cv. 'Kerman' trees growing in Yolo county, California, USA. In total over 1000 trees (tree spacing 5 x 6 m with 333 trees ha^{-1}) were utilized in this experiment. Treatments consisted of either 0, 12, 23, 35, and 47 g B per tree as Solubor ($Na_2B_8O_{13} \cdot 4H_2O$, containing 20.5% B) applied to the soil in November, or as foliar application of Solubor at four levels (0, 490, 1225, and 2450 $mg \cdot L^{-1}$ B) at a rate of 1000 L of water per hectare (equivalent of 0, 1.53, 3.82, and 7.64 g B per tree) by a tractor - mounted sprayer in January (late dormant spray) and again in July. A total of four fields were used (two foliar, two soil). In each field, the experiment was designed as a randomized complete block with 10 trees per replicate and five replicates per block. All treatments were bordered on all sides by two rows of untreated trees. In addition, a subset of trees (10 replicate trees per timing arranged in a completely randomized design) was utilized for the spray timing trial. In this site trees were sprayed with 490 ppm B at either of five dates, from late dormant through full leaf emergence. Total yield was determined on each tree and related to B application.

2.2 Response of Olive to foliar B.

In 1998 an orchard of bearing olive (*Olea europaea* L.) cv. 'Manzanilla' with July tissue B concentration of 17 ppm was selected in Butte county, California, USA. Experiments were conducted in both 1998 and 1999. The trees were planted at a density of 370 trees per hectare (Oroville). Boron as Solubor ($Na_2B_8O_{13} \cdot 4H_2O$), containing 20.5% B, was applied at four levels (0, 246, 491, and 737 $mg.L^{-1}$ B), at a rate of 935 L of water per hectare by a tractor - mounted sprayer. Boron was applied 3 weeks before anthesis on April 21, 1998 and May 1, 1999. The treatments were imposed in a randomized block of five adjacent trees within a treatment, replicated six times, making a total of 120 experimental trees per site. Single border trees separated the treatments and minimized the effect of cross-treatment contamination. The design was identical in both experiments.

On each replicate tree, five shoots in 1998 and twenty shoots in 1999, uniform in length and exposure with full floral differentiation (>95%), were selected before anthesis and tagged a few nodes above the shoot base. In 1998 all flowers on each tagged shoot were counted, in 1999 the total number of inflorescences was determined on each tagged shoot. For fruit set determination on each selected shoot, fruits remaining on the shoots were counted on ten consecutive inflorescences above the tagged point, and on five consecutive nodes. Fruit set was determined as the percentage of fruit remaining based either on total flower count (1998), or on inflorescence count (1999). For each treatment a total of 600 individual shoots i.e. 6000 inflorescences (ten inflorescences per shoot) were counted. At anthesis (May 10, 1998 and May 18-22, 1999) five uniform shoots per tree were detached and taken to the lab where the number of complete and incomplete inflorescences per shoot was counted and the number of perfect and imperfect flowers was recorded. 'Complete inflorescence' in this report is defined as an inflorescence with at least one single complete flower; 'incomplete inflorescence' means no single flower in an inflorescence is completely developed. The number of perfect vs. imperfect flowers was also counted on a single inflorescence arbitrarily chosen from the fourth node from the base of the detached shoot.

In 1998 each individual tree was harvested manually and yield and fruit size distribution was determined. In 1999, fruit set was determined from Sept 7 to Sept 13, and random fruit samples were taken for fruit size determination on November 12. Fruit size was determined according to commercial 'Manzanillo' olive grades (Sibbett et al., 1986). Due to excessive tree yield and consequently small fruit size, trees were shaken mechanically and yield was not recorded in 1999.

2.3 Transgenic manipulation of B transport in Tobacco (from Brown et al., 1999).

Three tobacco (*Nicotiana tabacum* L.) lines were used; SR1, wild-type tobacco; A4, tobacco transformed with the anti-sense gene construct for S6PDH; and S11, tobacco line transformed with the sorbitol synthesizing sense construct (Tao et al., 1995). A4 and SR1 served as controls. A4 and S11 are identical in all regards with the exception of the orientation of the S6PDH coding region with respect to the CaMV 35S promoter.

Homozygous seed of each tobacco line were germinated, then grown in vermiculite for four weeks with adequate supply of all nutrients including 0.05 ppm B. At four weeks, plants were transferred to hydroponic solutions with aeration (1/2 strength Hoagland solution (Hoagland and Arnon, 1950), minus B) and the following treatments imposed. 1), 0.05 ppm B, consisted of a continual supply of 0.05 ppm B in the rooting medium; 2), 0 ppm B, received no B in the rooting medium; 3) 'foliar' treated plants, received bi-weekly foliar applications of B to three mature leaves (described below) with no B supplied in the root nutrient medium.

At the time of foliar B application, the three mature leaves were immersed for 10 s in 100 ppm B solution as ^{10}B-enriched boric acid (99.43% ^{10}B: 0.57% ^{11}B) with 0.05% (v/v) L-77 as surfactant. Care was taken, so that contamination of B to the stem/petiole or drip of the B solution was avoided. The foliar B application was made three times**.** Boron analysis was performed by inductively coupled plasma mass spectrometry (Perkin Elmer-Sciex, Elan 500), as previously described (Brown and Hu, 1996). Plant appearance was closely monitored and eight weeks after transfer to hydroponic solutions, plants were harvested and growth, reproductive performance and tissue analysis for various parameters was performed. There were six replicate plants in each treatment group. Sorbitol production was determined by GC-MS (Greve and Labavitch, 1993) in mature leaf disks of all lines. Whereas significant sorbitol concentrations were detected in S11 (800 ± 100 nmol/g fresh weight), no detectable sorbitol could be found in either control (SR1) or antisense lines (A4).

3. Results:

3.1 Response of Pistachio to Foliar and Soil B:

Table 1 compares the effectiveness of soil B applications with respect to foliar B applications. It can be seen that soil applied B was most effective at raising tissue B levels. Plants supplied 170 to 227 g•tree^{-1} Solubor (35 to 47 g•tree^{-1} B) in 1990 had tissue B concentrations (in 1992) higher than trees that received foliar applications alone. Nevertheless, trees that received foliar B showed a positive yield response while those receiving soil B did not. This indicates that adequate leaf B status does not ensure optimal tree productivity. Apparently, foliar applications of B serve a unique role in enhancing pistachio fruit set.

Table 2 demonstrates that the most effective time for application of foliar B was the late dormant spray (immediately pre-anthesis) in which a yield increase of as much as 20% over unsprayed control trees were recorded. Later sprays effectively increased tissue B levels but did not increase fruit yield, though all B sprayed trees yielded more than trees not receiving supplementation. The effectiveness of early but not late B sprays, is evidence that B is critical for pollination or fertilization of pistachio flowers.

3.2 Response of Olive to Foliar B:

Foliar B application immediately pre-anthesis significantly altered the ratio of perfect to imperfect flowers, increased fruit set (results not shown) and increased final yield (Table 3). Soil B status did not influence the response of plants to foliar B (results not shown).

3.3 Transgenic manipulation of phloem B transport and its effect on susceptibility to B deficiency in tobacco.

Following removal of B from the growth medium, significant flower abortion and subsequently reduced seed production occurred in both wild-type and antisense tobacco plants (in which B is immobile), demonstrating that a brief deficiency of B can have a profound effect on flowering (Fig. 1). The application of foliar B had no beneficial effect on these plants. Tobacco plants with the capacity to transport B in the phloem to the flowers (transgenic) did not exhibit rapid flower abortion and in all cases produced significantly more seed than plants with limited phloem B mobility (Fig 1). With the application of foliar B, the transgenic tobacco performed equally to the control plants receiving root B indicating that the capacity to effectively use foliar fertilizers can entirely replace the need for soil B supply. The reduced seed set in the transgenic tobacco grown for an extended period in 0 ppm B is a consequence of the depletion of all remobilizable B and the ultimate occurrence of B deficiency throughout the plant.

4. Discussion:

The results of experimentation in both Pistachio and in Olive as well as many other reports in the literature (Nyomora et al., 1997; 1999 and references therein) demonstrates that foliar B application can result in correction of an apparent deficiency that is not responsive to soil B application nor easily indicated by leaf B concentrations. This is most apparent in pistachio where foliar B fertilization applied pre-anthesis increases pollen germination, reduces blanking and non-splits (results not shown) and consequently increases yield. This stimulation occurs even in trees with summer leaf B concentrations in excess of 150 ppm, indicating that there is a specific requirement for B in the developing flower. Foliar applications are the most effective method to ensure adequate B for the flowers. Soil applications of B are effective at raising leaf B levels but are not as effective as foliar sprays at increasing yield since B availability from soil is apparently not coincident with reproductive demand.

The apparent superiority of foliar B can best be explained as a consequence of a transient inadequacy in B supply to the reproductive tissues from the soil. This may occur as a consequence of low root activity in cool soils, high B requirement in developing flowers, or low transport of B to the reproductive tissues. All of these explanations suggest that transient deficiencies of B can occur and they may not be efficiently corrected by soil fertilization. To our knowledge this is the clearest example of a transient nutrient deficiency and a justification for application of foliar fertilizers.

The suggestion that the phloem immobility of B greatly enhances susceptibility to transient limitations in supply of B from the soil was verified using a novel transgenic approach. In tobacco plants in which phloem B mobility was enhanced through introduction of the gene for sorbitol synthesis, the susceptibility of these cultivars to B withdrawal from the soil solution was greatly reduced. These transgenic tobacco were also capable of obtaining their B requirements solely through foliar fertilization. Phloem immobility clearly contributes to plant susceptibility to transient nutrient deficiencies.

The results provided here, clearly demonstrate that transient micronutrient deficiencies occur and can be important determinants of yield. The evidence also suggests that foliar fertilizers can on occasions, be uniquely effective at correcting these deficiencies. Based upon these results, we conclude that transient deficiencies of B may occur as a consequence of a combination of spatial and temporal variations in plant nutrient demand and supply, and will be influenced by the relative mobility of the B in the plant.

Though these results demonstrate the occurrence of transient nutrient deficiencies of B and provide a biological justification for the use of foliar B, they do not predict plant response to other foliar fertilizers.

Whereas there is no shortage of literature assessing the relative effectiveness of foliar and soil fertilization, essentially none of this experimentation is based upon the definition of a period of plant phenology in which a specific transient nutrient deficiency was observed, predicted or effectively corrected. Further research must be conducted to determine if transient deficiencies of other nutrients occur and if targeted fertilizers can play a unique role in their correction.

Currently the targeting of fertilizers to correct nutrient deficiencies during periods of peak demand, is not adequately based upon any available scientific experimentation (with the exception of the B specific results presented here). The development of fertilization strategies that are clearly based upon actual (and temporally specific) nutrient demand will result in the greatest degree of fertilizer use efficiency. The adoption of demand driven fertilizer strategies, however, will be driven by cost, the availability of high quality research information and the value of the crop, nevertheless this paradigm should remain central to all aspects of plant nutrition research.

References

Brown P.H. and Hu H. 1996 Phloem mobility of boron is species dependent. Evidence for phloem mobility in sorbitol rich species. Ann Bot **77**: 497-505

Brown P.H., Bellaloui N., Hu, H., and Dandekar A. 1999 Transgenically enhanced sorbitol synthesis facilitates phloem boron transport and increases tolerance of tobacco to B deficiency. Plant Physiology 113:17-20

Greve C, and Labavitch J.M. 1993. Cell wall metabolism in ripening fruit. V. Analysis of cell wall synthesis in ripening tomato pericarp tissue using a d-[U-13C]glucose tracer and gas chromatography-mass spectrometry. Plant Physiol **97**: 1456-1461

Gris E. 1884. Nouvelles experiences sur l'action des composes ferrugineux solubles, appliqués à la vegetation et specialement au traitement de la chlorose et àla denilite des plantes. Comp. Rendes. (Paris) 19:118

Hoagland D.R., and Arnon D.I. 1950. The water-culture method for growing plants without soil. California Experiment Station Circular 347. The College of Agriculture, University of California, Berkeley, CA

Nyomora A.M.S., Brown P.H., and Freeman M. 1997. Fall foliar-applied boron increases tissue boron concentration and nut set of almond. J. Amer. Soc. Hort. Sci. 122:405-410.

Nyomora A.M.S., Brown P.H., and Krueger B. 1999. Rate and time of boron application increase almond productivity and tissue boron concentration. HortScience 34:242-245

Sibbett, G.S., Ferguson L., Anderson D., Freeman M.W., and Welch. G. 1986. Timing Manzanillo olive harvest for maximum profit. California Agr. 40:19-22.

Tao R., Uratsu S.L., and Dandekar A.M. 1995. Sorbitol synthesis in transgenic tobacco with apple cDNA encoding NADP-dependent sorbitol-6-phosphate dehydrogenase. Plant Cell Physiol 36: 525-532

Weinbaum S.A. 1989. Foliar nutrition of fruit trees, pp81-100. In Nuemann, P.M. (ed). Plant growth and leaf applied chemicals. CRC Press. Boca Raton.

Table 1. Influence of B application on yield, bud and July leaf B of pistachio

FOLIAR ($mg \cdot L^{-1}$ B)	YIELD (kg in-shell splits/tı	$mg \cdot kg^{-1}$ B Buds	Leaves (July
0	8.6	35	170
490	10.0*[z]	37	185
1225	11.8**	39	171
2450	9.5	41	210
SOIL ($g \cdot tree^{-1}$ B)			
12	8.6	35	172
23	8.6	38	189
35	9.1	44	201
47	9.5	50	219

[Z]*, ** significantly greater than control at 0.05, and 0.01%, respectively.

Table 2. Effect of application date of foliar B (1225 $mg \cdot L^{-1}$ B) on yield and lea Pistachio

APPLICATIO DATE	GROWTH STAGE	YIELD[1] (kg)	LEAF B (JUL $mg \cdot kg^{-1}$
28-Feb	Late Dormant	64**	188
19-Mar	Early Bud Breal	52	188
3-Apr	Flowering	54	187
17-Apr	Leafing Out	51	256**
8-May	Fully Leafed Ou	52	468**

** significantly greater than control at 0.01%

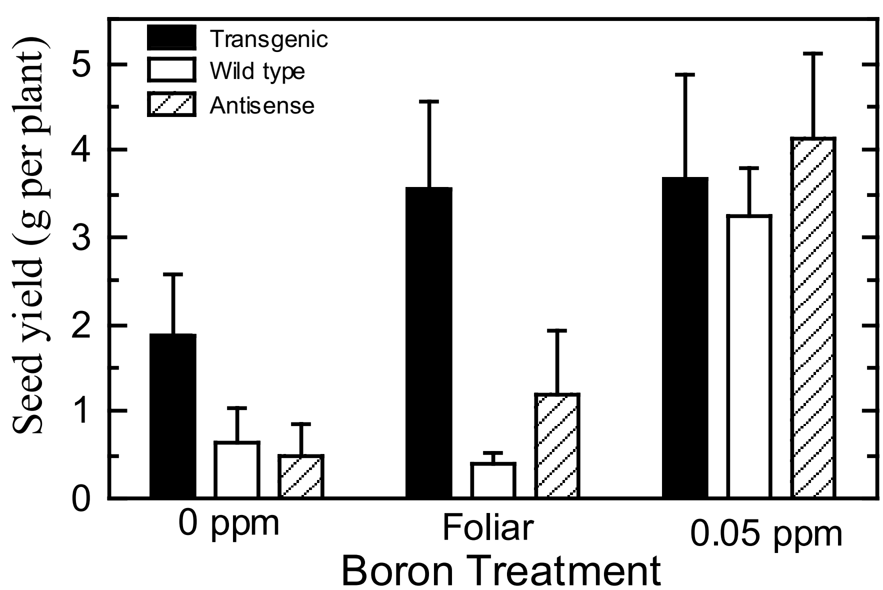
[1]All yields are fresh weight of fruit per tree.

Table 3. Influence of pre-anthesis foliar B on olive reproduction[z].

	1998	1999	
B spray rate ($mg.L^{-1}$)	Imperfect flowers	Imperfect flowers	Yield (kg/tree)
0	55 a[y]	49 a	12.6 b
246	35 b	38 b	14.9 a
491	33 b	40 b	17.8 a
737	48 a	47 a	13.5 b

[z]Applications were only effective pre-anthesis
[y]Within a column values followed by different letters differ significantly at $p < 0.05$ by Fisher's LSD.

Figure. 1. Seed yield of tobacco lines (transgenic, wild type, antisense) grown for 28 days with adequate B then transferred to either 0 ppm B, 0.05 ppm B supplied to the roots, or 100 ppm B supplied to three mature leaves. Seed yield was determined 56 days after transfer to treatment solutions. Values represent mean +/- standard error of six replicates.



Mitigating Orchard Dormant Spray Runoff by Alternative Treatment Timing; Impact on Target Pest Species and Pesticide Load

Frank G. Zalom[1], Michael N. Oliver[1], Inge Werner[2], Linda A. Deanovic[2], Tom Kimball[2], Barry W. Wilson[3], John D. Henderson[3], and Wes W. Wallender[4]

[1] Statewide IPM Project and Dept. of Entomology, University of California, Davis, CA 95616, USA
[2] Aquatic Toxicology Program, Dept. Anatomy, Physiology and Cell Biology, School of Veterinary Medicine, University of California, Davis, CA 95616, USA
[3] Dept. of Animal Science & Dept. of Environmental Toxicology, University of California, Davis, CA 95616, USA
[4] Dept. of Land, Air and Water Resources, University of California, Davis, CA 95616, USA

Correspondence to: Frank Zalom, Phone: 530-752-3687, Fax: 530-752-1537, Email: fgzalom@ucdavis.edu

ABSTRACT

Dormant spraying with an organophosphate insecticide in combination with horticultural mineral oil has been a standard practice of California tree fruit and nut growers since the 1970s. Concern for organophosphate runoff into surface waters has led to the need for effective alternatives as well as preventative best management practices to mitigate potential runoff. The efficacy and runoff of diazinon applied earlier than normal in the dormant season was studied in comparison to more typical treatment timings in the winter of 2001-02. Results indicated that control of the San Jose scale, *Quadraspidiotus perniciosus* (Comstock), and the peach twig borer, *Anarsia lineatella* Zeller, was not significantly different (P>0.05) between treatment timings. Average diazinon concentrations in runoff water were lower (3.60 ppm) in the early treatment timing than in the middle (11.46 ppm) or later (31.32 ppm) treatment timings. Earlier treatment timing holds promise for mitigating runoff of organophosphate insecticide applied during the dormant season while maintaining effective control of target pests.

INTRODUCTION

Dormant spraying is a practice that involves the application of insecticides or fungicides to dormant orchards (trees that are not leafed out) between the months of December and March depending on crop (Zalom 2002). Diazinon, an organophosphate insecticide, has been one of the most widely used dormant spray pesticides for controlling a variety of economically important pests in most California orchard crops since the 1970s. Dormant spraying with organophosphates and horticultural mineral oil has been advocated by University of California scientists as part of an IPM strategy which is both effective and preferable in terms of worker exposure, residues and impact on natural enemies of pests to multiple in-season insecticide applications for controlling the same suite of insect species (e.g. Rice et al. 1979, Barnes et al. 1991). Other broad spectrum insecticides including carbamates and synthetic pyrethroids are also registered for use on most orchard crops. The pyrethroids esfenvalerate and permethrin did not become widely used as dormant spray insecticides until the mid-1990s (Epstein et al. 2000) due, in part, to the relatively low cost of the organophosphate insecticides and concerns for secondary spider mite outbreak following their application (e.g. Bentley et al., 1987, Zalom et al. 2001). Their increased use has been due both to increased cost of organophosphate insecticides and water quality concerns.

Diazinon has been found in surface waters of California's Sacramento and San Joaquin River watersheds at concentrations toxic to the cladoceran *Ceriodaphnia dubia* (Kuivila and Foe 1995, Werner et al. 2000). In 1998, the State of California placed the Sacramento and San Joaquin Rivers and their delta on the Clean Water Act 303(d) list of impaired waterways due, in part, to elevated levels of diazinon and chlorpyrifos. Urban runoff, orchard dormant sprays and other agricultural uses have been implicated by agencies monitoring water quality as sources (e.g. Domalgowski et al. 2000, Foe and Sheipline 1993, US Geological Survey 1997).

In 1997, a multidisciplinary team of UC research and extension scientists began to study alternative practices intended to mitigate the effects of dormant season organophosphate used in orchard crops (Zalom et al. in press, Werner et al. 2002). Their research was preceded by identifying and contrasting efficacy of alternatives to the use of organophosphate dormant sprays as well as preventative best management practices (BMPs) that could reduce or eliminate offsite movement into surface waters. The alternatives were identified through an extensive literature review, and submitted as a final report to the State Water Resources Control Board (Zalom et al. 1999). Further elaboration of alternatives has been achieved through a stakeholder driven process by members of the Sacramento River Watershed Group.

One example of a potential mitigation measure for organophosphates applied to orchards in the dormant season is earlier treatment timing. It is presumed that drier soil conditions and lower probability of storm occurrence which are typical earlier in the dormant season of most years would facilitate water infiltration and reduce runoff for some time after a dormant spray is applied. However, the timing at which dormant sprays are applied may also impact their efficacy against target pest species. This study describes research intended to test the hypotheses that acceptable pest control efficacy and reduced pesticide runoff would result from earlier dormant season applications.

MATERIALS AND METHODS

Efficacy against target pests: Studies to determine the effect of dormant season treatment timing on efficacy were conducted in 2001 and 2002 in an almond orchard east of Waterford in Stanislaus Co., in 2001 in an almond orchard near Cortez in Merced Co., and in 2002 in the French prune orchard in Sutter Co. which also served as the site for the runoff study described below. The Stanislaus Co. orchard was divided into plots of ~500 trees. Four treatments, each replicated three times, were assigned to the plots in a randomized complete block design. The treatments were 7.0 l/ha diazinon with 56.1 l/ha of horticultural mineral oil and 467.3 l/ha of water applied on either December 18, 2000, January 6, 2001, or January 30, 2001 and untreated. Treatments the following year were 4.7 l/ha Chlorpyrifos 4E with 37.4 l/ha of horticultural mineral oil and 50 g/ac of water applied on either December 13, 2001, January 7, 2002, or January 30, 2002 and untreated. The Merced Co. orchard was divided into 9 plots. Three treatments, each replicated three times, were established in a randomized complete block design. The treatments were 7.0 l/ha diazinon with 56.1 l/ha of horticultural mineral oil and 934.7 l/ha of water applied on December 18, 2000 or January 6, 2001 and untreated. Treatment in the Sutter Co. orchard are described below.

San Jose scale, *Quadraspidiotus perniciosus* (Comstock), adult males and their parasitoids were monitored using San Jose scale pheromone traps (Trece Inc., Salinas, CA, USA). Both the trap and the lure were changed every four weeks. Two of the traps were placed in trees in the center row of each treatment replicate at a height of about 2 m by mid-March. The number of San Jose scale males on the pheromone traps were determined in the laboratory using a dissecting microscope, and scale parasites, if any, were recorded. The number of San Jose scale males per pheromone trap were summed for the first generation to provide an estimate of population densities present (Badenes-Perez et al. 2002). At the Stanislaus Co. site, peach twig borer, *Anarsia lineatella* Zeller, density in each treatment replicate was assessed by randomly collecting 25 watersprouts from trees near the center of each plot and returning them to the laboratory where the flagged shoot tips were dissected to determine if the flagging was due to peach twig borer, the oriental fruit moth *Grapholitha molesta*, or the fungal disease brown rot. Because the trees were relatively tall and not very vigorous, watersprouts were used for this assessment as there were insufficient numbers of new shoots on which to evaluate shoot strikes. Treatments were compared by one-way analysis of variance for densities of each insect species, and if significant treatment means separated by Fisher's Protected LSD.

Runoff measurements: The experiment was carried out in a mature French prune orchard planted on berms at the Half Moon Orchard, located near Sutter, Sutter Co., California. Treatments were 4.7 l/ha of diazinon with 28.0 l/ha of horticultural mineral oil and 934.7 l/ha of water applied on either January 12, 2002, February 2, 2002, or February 22, 2002, using the grower's commercial airblast sprayer. Each treatment timing was replicated 3 times in a randomized complete block design. The size of each treated block was 10 rows wide by the entire length of the tree row (over 100 trees). An autosampler unit (Zalom et al. 2002 in press) was set up in the row middle at the center of each of the 9 treated areas, and placed 50 m from the upslope end. The row middle was blocked at its uppermost end by a diversion dam made of soil to preclude inadvertent entry of water onto the row middle being sampled from an external source.

Immediately following each significant storm event, runoff volume was recorded from the flow meter through which all water leaving a plot was diverted by the sampler unit. At the same time a composit water subsample was taken from each plot for diazinon analysis and bioassay. The composit sample came from a covered Nalgene® collection tank that contained approximately 1% of the diverted runoff. These samples were collected in washed glass jars, and kept cool until they could be returned to UC Davis where they were frozen at -20^{o}C until they were analyzed. Water samples from rows that had yet to be treated served as controls for those that were previously sprayed.

RESULTS AND DISCUSSION

Efficacy against target pests: A significant difference (F=4.391, P=0.0419, df=3,8) in San Jose scale males captured in pheromone traps and proportion of peach twig borer shoot strikes (F=11.147, P=0.0004, df=3,8) was observed between treatments in the Stanislaus Co. orchard in

2001 (Table 1). Although there was no significant difference between diazinon treatment timings, there tended to be more peach twig borer shoot strikes on the trees that were treated earlier during orchard dormancy. No significant difference (F=1.139, P=0.3809, df=2,6) in San Jose scale males captured in pheromone traps was observed between treatments in the Merced Co. orchard. However, the mean (± SD) number of male scales trapped in the early diazinon treatment (81.2±27.1) was only about 60% that of that observed in the late diazinon (132.8±60.9) and untreated (131.8±49.6) plots.

A significant difference (F=6.259, P=0.0171, df=3,8) in San Jose scale males captured in pheromone traps was observed between treatments in the Stanislaus Co. orchard in 2002 (Table 2), confirming the 2001 results. No significant difference (F=1.193, P=0.3662, df=2,6) in mean (±SD) San Jose scale males captured in pheromone traps was observed between treatment timings in the Sutter Co. orchard (early = 41.0±20.7; middle = 21.0±5.6; late = 30.3±17.2).

Table 1. Total San Jose scale males per trap during the first flight and proportion peach twig borer shoot strikes per plot collected May 5, Stanislaus Co., 2001

Treatment	San Jose scale Mean± SD	Peach twig borer Mean± SD
Untreated	641.7± 176.4 b	0.217± 0.047 b
Diazinon mid-December	351.7± 63.7 a	0.073± 0.042 a
Diazinon early January	335.0± 85.4 a	0.067± 0.021 a
Diazinon late January	308.3± 155.1 a	0.037± 0.006 a

Column means followed by the same letter do not differ significantly (P>0.05) by Fisher's Protected LSD.

San Jose scale parasitoids were not found on pheromone traps in either the Stanislaus Co. or Sutter Co. orchards, but both *E. perniciosi* and *Aphytis* spp. were counted on the pheromone traps in the Merced Co. orchard. Figure 1 presents the

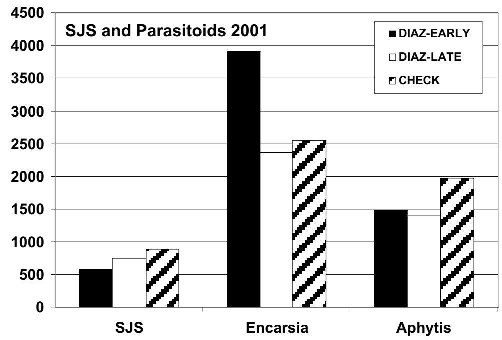
Table 2. Total San Jose scale males per trap during the first flight, Stanislaus Co., 2002.

Treatment	Mean	± SD
Untreated	225.3	± 114.7 b
Diazinon mid-December	26.0	± 10.4 a
Diazinon early January	54.7	± 36.7 a
Diazinon late January	70.7	± 26.6 a

Means followed by the same letter do not differ significantly (P>0.05) by Fisher's Protected LSD.

total number of San Jose scale males, *E. perniciosi* and *Aphytis* collected. While no significant difference (P>0.05) was found between treatment, the total number of *E. perniciosi* was greater in the plots sprayed earlier with diazinon as opposed to those plots sprayed later or untreated, corresponding to the number of male San Jose scales captured in the first flight.

Figure 1. Total number of San Jose scale males, *Encarsia perniciosi* and *Aphytis* spp. per San Jose scale pheromone trap captured for the first two flights of 2001 (n=3 replicates with 2 pheromone traps per replicate) in the Merced Co. orchard.



Runofff measurements: The rainfall pattern was somewhat atypical of California's central valley in the winter of 2001-02. Heavy rains occurred earlier than normal, primarily from November through early January, unlike more typical winters when major rainfall events occur during January and February. The first rainfall event following application of the diazinon treatment sufficient to produce runoff occurred on March 11 (3.75 cm), and this followed smaller rainfall events on March 6 (1.88 cm) and March 8 (1.25 cm). Cumulative rainfall following each diazinon treatment until March 11 when runoff occurred was 10.35 cm, 8.43 cm and 4.75 cm for the early, middle and late treatment timings, respectively.

Runoff volume from 8 plots (one autosampler malfunctioned) during the March 11 rainfall event averaged 3291.5 l as measured by our autosamplers. Average diazinon concentrations in the composite water samples averaged 3.60 ppb, 11.46 ppb and 31.32 ppb for the early (n=4), middle (n=2) and late (n=3) treatment timings, respectively, supporting our hypothesis that organophosphate concentrations are lower in runoff collected from the earlier treatment timing. It is possible that ground residues of diazinon from earlier spray applications infiltrate into the soil as a result of smaller storm events and are less available to become a component of runoff that results from later and larger storm events when the soil is more likely to be saturated.

In summary, acceptable control of San Jose scale and peach twig borer, two of the major target pests of dormant season organophosphate sprays, can be achieved at earlier diazinon or chlorpyrifos treatment timings. Trends clearly exist for the diazinon concentrations and toxicity to *C. dubia* (not presented here) to be lower for runoff from plots treated earlier versus later in the season. While promising, additional questions involving the use of earlier treatment timings need to be resolved. Among these, rainfall patterns occurring during this period were somewhat atypical and the runoff study should be repeated during winters with more typical rainfall patterns. In addition, concern exists for the potential of water stressed trees to be “burned” as a result of the application of the horticultural mineral oil that is a recommended component of dormant sprays.

Acknowledgments: The authors thank Half Moon Orchards, Sutter Co., for permission to use their orchard for the runoff study, the UC Statewide IPM Project for providing administrative support for Calfed grant no. B-81609 which funded much of this work, and Gary Obenauf which provided considerable logistical support through his Calfed Project.

REFERENCES

Badenes-Perez FR, Zalom FG, Bentley WJ (2002) Are San Jose scale (Homoptera: Diaspididae) pheromone trap captures predictive of crawler densities? *Jour. Appl. Entomol.* 126: 1-6.

Barnes MM, Barnett WW, Bentley WJ, Curtis RK, Hoy MA, Rice RE, Weakley CV, Zalom FG (1991) Entomology. pp. 48-91, *In* Barnes MM, Barnett WW, Kester DE, Micke WC, Teviotdale BL (tech. coord.). Integrated pest management for almonds. Univ. Calif. Div. Agric. Natural Resources Publ. 3340.

Bentley WJ, Zalom FG, Barnett WW, Sanderson JP.(1987) Population densities of *Tetranychus* spp. (Acari: Tetranychidae) after treatment with insecticides for *Amyelois transitella* (Lepidoptera: Pyralidae). *Jour. Econ. Entomol.* 80: 193-200.

Domalgowski JL, Knifong DL, Dileanis PD, Brown LR, May JT, Conner, V, Alpers CN (2000) Water quality in the Sacramento River Basin, CA, 1994-98. US Geologic. Surv. Circ. 1215. 24 pp.

Epstein L, Bassein S, Zalom FG (2000) Almond and stone fruit growers reduce OP, increase pyrethroid use in orchard dormant sprays. *Calif. Agric.* 54(6): 14-19.

Foe CG, Sheipline R (1993) Pesticides in surface water from applications on orchards and alfalfa during the winter and spring of 1991-92. Staff report. Central Valley Regional Water Quality Control Board, Sacramento, CA, USA

Kuivila KM, Foe CG (1995) Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco Estuary, California. *Environ Toxicol Chem* 14:1141-1150.

Rice RE, Hoyt SC, Westigard, P (1979) Chemical control of male San Jose scale (Homoptera: Diaspididae) in apples, pears, and peaches. *Can. Entomol.* 111: 827-831.

US Geological Survey (1997) Transport of diazinon in the San Joaquin River basin, California. U.S. Geological Survey Open-File Report 97-411, National Water Quality Assessment Program, USGS, Sacramento, CA, USA.

US Environmental Protection Agency (1994) Short-term methods for estimating the chronic toxicity of effluents and receiving water to freshwater organisms. Third edition, EPA-600-4-91-002, U.S. EPA, Washington DC, USA

Werner I, Deanovic LA, Connor V, De Vlaming V, Bailey HC, Hinton DE (2000) Insecticide-caused toxicity to *Ceriodaphnia dubia* (Cladocera) in the Sacramento-San Joaquin River Delta, California, USA. *Environ Toxicol Chem* 19: 215-227.

Werner I, Deanovic LA, Hinton DE, Henderson JD, De Oliveira GH, Wilson BW, Krueger W, Wallender WW, Oliver MN, Zalom FG (2002) Toxicity of stormwater runoff after dormant spray application of diazinon and esfenvalerate (Asana) in a French prune orchard, Glenn County, California, USA. *Bull Environ Contam Toxicol* 68:29-36.

Zalom FG (2002) Dormant sprays. pp. 204-206, *In* D. Pimentel, ed. Encyclopedia of Pest Management. Marcel Dekker, Inc. New York.

Zalom FG, Oliver MN, Hinton, D (1999) Alternatives to chlorpyrifos and diazinon dormant sprays. California State Water Resources Control Board, Final Report. 26 pp.

Zalom FG, Oliver MN, Wallender WW, Werner I, Wilson BW, Krueger WH, Angermann BT, Deanovic LA, Kimball TS, Henderson JD, Oliveira GH, Osterli P. Monitoring and mitigating offsite movement of dormant spray pesticides from California orchards. *Acta Horticulturae* (in press).

Zalom FG, Stimmann MW, Arndt TS, Walsh DB, Pickel C, Krueger WH (2001) Analysis of permethrin (*cis*- and *trans*- isomers) and esfenvalerate on almond twigs and effects of residues on the predator mite *Galendromus occidentalis* (Acari: Phytoseiidae). *Environ. Entomol.* 30: 70-75.

Toxicity of Stormwater Runoff after Dormant Spray Application in a French Prune Orchard (Glenn County, California): Temporal Patterns and The Effect of Ground Covers

Inge Werner[1], Linda A. Deanovic[1], Tom Kimball[1], Barry W. Wilson[2], William Krueger[4], Wes W. Wallender[5], Michael N. Oliver[6] and Frank G. Zalom[6]

[1]Aquatic Toxicology Program, Dept. Anatomy, Physiology and Cell Biology, School of Veterinary Medicine, University of California, Davis, CA 95616, USA
[2]Dept. of Animal Science & Dept. of Environmental Toxicology, University of California, Davis, CA 95616, USA
[4]Cooperative Extension Glenn County, University of California, PO Box 697, County Road 200 East, Orland, CA 95963, USA
[5]Dept. of Land, Air and Water Resources, University of California, Davis, CA 95616, USA
[6]Statewide IPM Project and Dept. of Entomology, University of California, Davis, CA 95616, USA

Correspondence to: Inge Werner, Phone: 530-754-8060, Fax: 530-752-7690, Email: iwerner@ucdavis.edu

ABSTRACT

Organophosphorous (OP) insecticides, especially diazinon and chlorpyrifos, have been routinely detected in surface waters of the Sacramento and San Joaquin River watersheds, coincident with storm events following their application to dormant orchards during the winter months. Preventive best management practices (BMP) aim at reducing pesticide runoff into surface waters. For example, more hydrophobic pyrethroid pesticides are believed to bind to organic matter and soil and thus remain in the orchard. Also, various types of ground cover vegetation are believed to increase the soil's capacity for water infiltration, thus preventing storm runoff from orchards. To measure the effectiveness of these BMPs, storm runoff was collected in a California prune orchard (Glenn County, CA) during several subsequent rain storms in the winter of 2001, after two insecticides (diazinon, esfenvalerate) were applied to different orchard sections. Bare soil and 3 different cover crops were tested for their effect on runoff and toxicity to standard bioassay and California resident species. Acute toxicity was tested by exposing larval fathead minnow (*Pimephales promelas*), larval rainbow trout (*Oncorhynchus mykiss*), midge larvae and two cladocera species (*Ceriodaphnia dubia, Simocephalus vetelus*) to runoff water samples. Ground covers significantly reduced runoff volume, but toxicity in runoff samples was not significantly affected. Whereas runoff from esfenvalerate sprayed orchard sections was less toxic to waterflea than runoff from diazinon sprayed section, esfenvalerate runoff was highly toxic to fish larvae. No fish toxicity was detected in storm runoff collected one month later, but invertebrate toxicity remained high.

INTRODUCTION

Stormwater runoff has been identified as a source of toxicity and a major water quality problem in agricultural and urban areas in California's Sacramento and San Joaquin River watersheds (e.g. Foe and Sheipline 1993, US Geological Survey 1997). During the winter rainy season, when dormant sprays are applied to stonefruit and almond orchards, organophosphate pesticides (OPs), in particular diazinon and chlorpyrifos (Lorsban®) were repeatedly shown to be present in surface waters at concentrations toxic to the cladoceran *Ceriodaphnia dubia* (Kuivila and Foe 1995, Werner et al. 2000). In 1998, the State of California placed the Sacramento and San Joaquin Rivers and their delta on the Clean Water Act 303(d) list of impaired waterways due, in part, to elevated levels of diazinon and chlorpyrifos. State Water Quality Plans have now been implemented by regulatory agencies to prevent movement of OPs into surface water, and growers have reduced OP application.

As a consequence, the use of other pesticide alternatives such as pyrethroid insecticides has increased dramatically (Epstein et al. 2000). Storm runoff of pyrethroids is believed to be minimal due to their hydrophobicity thus reducing pesticide impact on surface waters, but Werner et al. (2002) showed that storm runoff collected in an orchard sprayed with esfenvalerate (Asana®) was highly toxic to both *C. dubia* and fathead minnow larvae (*Pimephales promelas*). As a continuation of that study, we investigated the persistence of storm runoff toxicity from orchard sections sprayed with esfenvalerate or diazinon, collecting water samples during several consecutive rainstorms in the winter of 2000/2001. In addition, we re-examined the influence of ground covers on the toxicity of runoff samples.

MATERIALS AND METHODS

Experimental Design: Experiments were carried out in a French prune orchard at the Talbot – Vereschagin Ranch, Glenn County, California. Dormant sprays were applied to 42 orchard rows. Rows 1-8, 21-25, and 38-42 were unsprayed. Rows 9-20 were sprayed with diazinon, and rows 26-37 were sprayed with esfenvalerate using 0.1 L/m^2 (100 gallons/acre) of diazinon and esfenvalerate solutions. Diazinon 4EC was applied at a concentration of 200.9 g/L active ingredient (3 pints Diazinon 4EC per 100 gallons) and Asana XL was applied at 6.2 g/L active ingredient (9.8 oz Asana XL per 100 gallons). The orchard was sprayed on 20 January 2001. Storm runoff samples were collected using one half gallon glass jars (grab samples, diazinon – esfenvalerate comparison) or by autosampler (composite samples, ground cover comparison) on 25 January and 20 February 2001. Ground covers were compared with regard to their efficiency to reduce diazinon toxicity in orchard runoff. Four different cover crops were tested in three replicate rows each: (1) no cover (bare), (2) perennial sod (sod), (3) clover and (4) resident vegetation (RV).

Toxicity Testing: Mortality was recorded after 96 hours for larval fathead minnow (*Pimephales promelas*), larval rainbow trout (*Onchorhynchus mykiss*), and midge larvae (*Chironomus riparius*), and after 48 hours for two waterflea species (*Ceriodaphnia dubia, Simocephalus vetelus*) according to US EPA protocols (US EPA 1994). If 100% cladocera mortality occurred within 24 hours, dilutions of the respective water sample were tested to determine the lowest observed effect concentrations (LOEC) and the no effect concentrations (NOEC). Toxicity was defined as a statistically significant difference ($p<0.05$) between water sample and laboratory control. Bartlett's test for homogeneity of variances was performed on all fish mortality data.

When variance was homogeneous, data were compared to controls using analysis of variance and Dunnett's mean separation test. If variance was not homogeneous, data were transformed to relative ranks and analyzed using analysis of variance and Dunnett’s mean separation tests. *C. dubia* and *S. vetelus* mortality data were compared to controls using Fisher's exact test.

RESULTS AND DISCUSSION

Toxicity of January Storm Runoff: Orchard runoff samples collected 25 January 2001 from sections treated with esfenvalerate were highly toxic to fathead minnows and rainbow trout (Fig. 1). Fish mortality in water samples from diazinon treated rows and from unsprayed rows with resident vegetation was not significantly different from control survival.

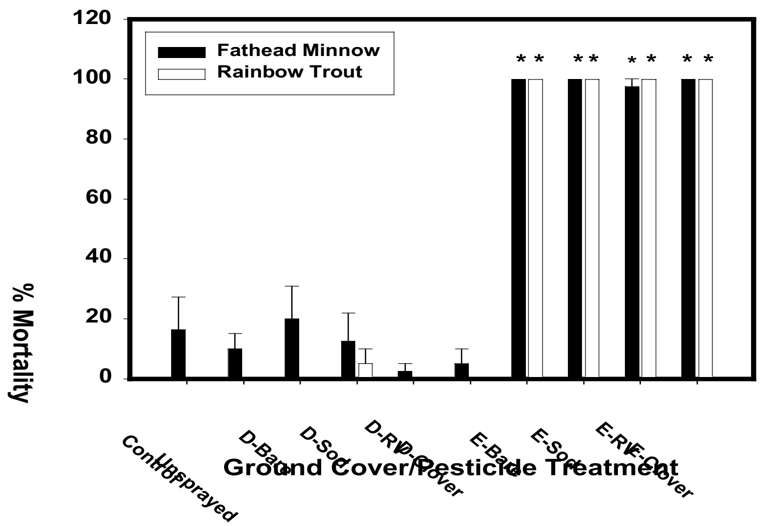


Figure 1. Percent mortality of fathead minnow and rainbow trout larvae when exposed for 96 hours to January orchard runoff (n=4). *= (p<0.05) significant increase in mortality compared to laboratory controls.

Runoff was extremely toxic to waterflea (*C. dubia*; Table 1). Table 1 shows the dilution factors needed to reach lowest observed effect concentrations (LOEC) and no observed effect concentrations (NOEC) using mortality as a test endpoint. Runoff samples collected 25 January 2001 from rows treated with diazinon were 40-80 times more toxic to the cladocera species than runoff from the esfenvalerate treated orchard sections. Runoff from esfenvalerate treated rows was still toxic after a 25-fold dilution with laboratory control water, whereas 1000 to 2000-fold dilutions of diazinon runoff were necessary to reach the *C. dubia* LOECs. Spray drift was likely responsible for the toxicity seen in samples collected in unsprayed orchard rows.

Table 1. Toxicity of runoff samples from diazinon and esfenvalerate sprayed orchard sections: LOEC and NOEC of orchard runoff samples for *C. dubia* and *S. vetelus* (48-hour test).

Runoff Sample	**C. dubia** Jan 2001 NOEC/LOEC (dilution factor)	Feb 2001 NOEC/LOEC (dilution factor)
Unsprayed	40/20	10/5
D-Bare	1000/500	400/200
D-Sod	2000/1000	200/100
D-RV	1000/500	200/100
D-Clover	2000/1000	200/100
E-Bare	25/12.5	5/2.5
E-Sod	25/12.5	5/2.5
E-RV	25/12.5	5/2.5
E-Clover	25/12.5	5/2.5

Toxicity of February Storm Runoff: Orchard runoff samples collected on 20 February 2001 did not cause significant fish mortality within the test period. Similarly, toxicity to waterflea was considerably reduced in the February samples (Table 1). Waterflea toxicity of runoff from diazinon and esfenvalerate sprayed sections was reduced by a factor of 2.5-10 (diazinon) and 5 (esfenvalerate), respectively. February runoff samples from esfenvalerate sprayed sections were significantly more toxic to midge larvae than samples from diazinon sprayed sections (Fig. 2).

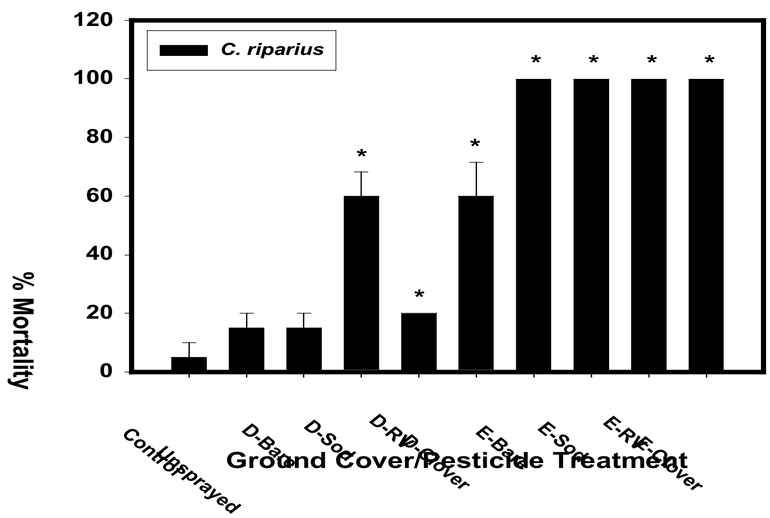


Figure 2. Percent mortality of midge (*C. riparius*) larvae when exposed for 96 hours to February orchard runoff (n=4).
*= significant ($p<0.05$) increase in mortality compared to laboratory controls.

Table 2. The effect of ground covers on toxicity of runoff samples to cladocera (*C. dubia*, *S. vetelus,* 48-hour test): average LOEC and NOEC and standard errors (n=3) of 1% composite runoff samples.

Sample	**C. dubia**		*S. vetelus*	
	Jan 2001 LOEC ± SE (dil.factor)	Feb 2001 LOEC ± SE (dil.factor)	Jan 2001 LOEC ± SE (dil.factor)	Feb 2001 LOEC ± SE (dil.factor)
D-Bare	588 ± 118	43 ± 16	667 ± 222	15 ± 3
D-Sod	500 ± 250	50 ± 0	286 ± 187	12.5 ± 0
D-RV	476 ± 248	43 ± 16	214 ± 81	13.6 ± 8
D-Clover	370 ± 93	43 ± 16	429 ± 162	12.5 ± 7

Ground Covers: A significant influence of ground covers on the toxicity of runoff samples was not evident (Table 2), although runoff samples from rows with bare soil were generally more toxic than runoff from rows with ground covers. However, runoff volume was significantly reduced by about 50% in orchard rows with ground cover, irrespective of the type of vegetation, when compared to bare ground (Fig. 3; Zalom et al., in press).

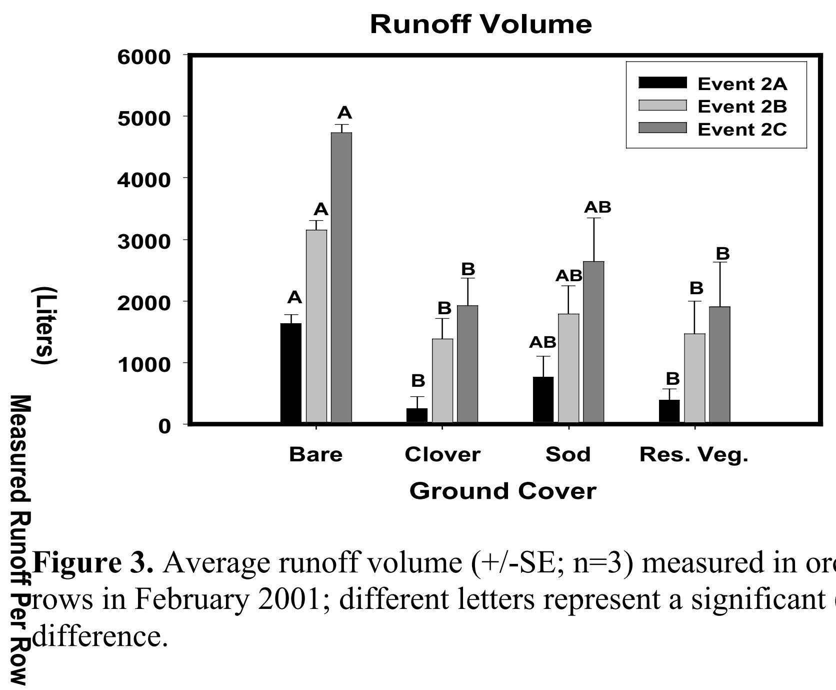


Figure 3. Average runoff volume (+/-SE; n=3) measured in orchard rows in February 2001; different letters represent a significant ($p<0.05$) difference.

For the study presented here it is important to note that the sampling design was aimed at examining a “worst case scenario”. Orchard runoff samples were collected directly in the orchard, and neither the influence of soil type on runoff nor the distance of the orchard from nearby surface waters was measured. Acute toxicity of orchard runoff from esfenvalerate treated sections was alarmingly high for fish larvae, but was reduced to zero about one month after application. Runoff samples from esfenvalerate treated sections were significantly less toxic to waterflea than those from diazinon treated rows, but toxicity persisted throughout the study. February storm samples from esfenvalerate sprayed rows were still highly toxic to midge larvae, another important prey species for larval fish. A quantification of hydrological parameters is clearly needed for a more realistic assessment of what proportions of the runoff and pesticides may be discharged into a nearby water body.

Acknowledgments: The authors thank the Vereschagin family for permission to use their orchard, and the field crew of the UC Davis Aquatic Toxicology Laboratory for their hard work. We acknowledge David Hinton who was co-investigator on the contract and helped to initiate this study. This project was funded through Calfed grant no. B-81609.

REFERENCES

Foe CG, Sheipline R (1993) Pesticides in surface water from applications on orchards and alfalfa during the winter and spring of 1991-92. Staff report. Central Valley Regional Water Quality Control Board, Sacramento, CA, USA

Kuivila KM, Foe CG (1995) Concentrations, transport and biological effects of dormant spray pesticides in the San Francisco Estuary, California. *Environ Toxicol Chem* 14:1141-1150

US Environmental Protection Agency (1994) Short-term methods for estimating the chronic toxicity of effluents and receiving water to freshwater organisms. Third edition, EPA-600-4-91-002, U.S. EPA, Washington DC, USA

US Geological Survey (1997) Transport of diazinon in the San Joaquin River basin, California. U.S. Geological Survey Open-File Report 97-411, National Water Quality Assessment Program, USGS, Sacramento, CA, USA

Werner I, Deanovic LA, Connor V, De Vlaming V, Bailey HC, Hinton DE (2000) Insecticide-caused toxicity to *Ceriodaphnia dubia* (Cladocera) in the Sacramento-San Joaquin River Delta, California, USA. *Environ Toxicol Chem* 19: 215-227

Werner I, Deanovic LA, Hinton DE, Henderson JD, De Oliveira GH, Wilson BW, Krueger W, Wallender WW, Oliver MN, Zalom FG (2002) Toxicity of stormwater runoff after dormant spray application of diazinon and esfenvalerate (Asana) in a French prune orchard, Glenn County, California, USA. *Bull Environ Contam Toxicol* 68:29-36.

Zalom FG, Oliver MN, Wallender WW, Werner I, Wilson BW, Krueger WH, Angermann BT, Deanovic LA, Kimball TS, Henderson JD, Oliveira GH and Osterli P (in print). Monitoring and mitigating offsite movement of dormant spray pesticides from California orchards. *Acta Horticulturae.*

Run-Off of Pesticide from Residential Landscapes and Mitigation Practices

J. Gan[1*] and C. Wilen[2]

[1]Department of Environmental Sciences, University of California, Riverside, CA 92521
[2]University of California Statewide Integrated Pest Management Program and UC Cooperative Extension, San Diego, CA 92123
(909) 787-2712; Fax (909) 787-3993;jgan@mail.ucr.edu

Abstract

Recent monitoring studies show that the majority of urban streams in the U.S. are contaminated by pesticides, and the contamination is primarily a result of urban runoff. Implementation of risk-reduction measures, however, is hampered by the lack of an understanding of the interaction of urban landscape planting systems with pesticide behavior. We investigated the effect of landscape plantings on the persistence of two commonly used herbicides, 2,4-D and dicamba. The herbicides exhibited greatly different persistence in the different planting systems. In the 0-10 cm surface layer, the half-life of 2,4-D was 31 d in soil under trees, which was about 20 times longer than in soil planted with turf grass (1.6 d). The half-life of dicamba was much longer in soil under a tree canopy (149 d) than in a mulched soil (7.9 d). This study suggests that landscape planting practices can modify the chemical and biological activities of soil, which in turn may affect pesticide persistence and hence the runoff potential. Such information may be used for developing landscape systems that are resistant to pesticide runoff, thus alleviating water quality impact by pesticides used by homeowners.

Introduction

In the U.S., home lawns occupy 20-25 million acres or 8-10 million ha. The total area of environmental horticulture in California was estimated to be 1.4 million acres. Residential landscapes serve as the direct target of pesticides applied to home lawns and gardens and the first-tier buffer for pesticides applied to structures. However, pesticide use in residential settings has apparently led to contamination of urban streams. For example, surveys by the U.S. Geological Survey (USGS) have shown that 99% of the tested urban streams contain at least one pesticide, with 70% containing 5 or more pesticides (*1*). The presence of pesticides at trace levels may cause short or long-term impairments to aquatic ecosystems, such as toxicity to aquatic organisms (*2*). Runoff of pesticides resulted in the establishment of diazinon and chlorpyrifos TMDLs for San Diego Creek in Orange County, CA (*3*).

Currently little is known about the behavior of pesticides in the heterogeneous residential landscapes. Because pesticide movement in urban settings is driven by stormflow, the runoff potential is related to pesticide persistence. Planting practices can modify a soil's chemical and biological properties. The objectives of this study were to evaluate the interaction of planting with soil chemical and microbial reactivity, and the effect on the persistence of two common herbicides, 2.4-D and dicamba. The results from this and similar studies may be used for identifying high-risk landscape systems, and for developing mitigation practices to reduce pesticide runoff to urban streams.

Experimental

Soils. Soil samples were collected from a field located at the Agricultural Experiment Station on the campus of University of California in Riverside, CA. The field consisted of plots with different planting covers that were established in 1995. The soil was a Hanford fine sandy loam. The planting systems included Bradford pear tree, "shortcut" tall fescue grass, mulches (chipped tree branches and leaves), and a low growing ground cover. Soil was collected from the 0-10 cm layer using a hand auger. Chemical and physical properties of these soils are shown in **Table 1**.

Table 1. Selected properties of soils for the various landscape systems

Soil	OM (%)	Clay (%)	Silt (%)	Sand (%)	CEC (meg/100g)	pH
	Surface soil (0-10 cm)					
Tree	0.35	10	24	66	6.3	5.4
Grass	0.82	9	24	67	7.7	6.7
Ground cover	1.16	8	26	66	8.4	6.3
Mulch	1.95	8	24	68	10.7	6.9

Degradation Experiments. Degradation of 2,4-D and dicamba in the different landscape soils was determined by incubating spiked soil samples at 20ºC. The initial soil water content was 8% (w/w). The initial herbicide concentration was 2.0 ppm. At different times after treatment, replicate samples were removed and extracted with methanol. Analysis of 2,4-D and dicamba in extracts was carried out by HPLC.

Enumeration of Herbicide Degraders. In a separate experiment, the population density of 2,4-D degrading microorganisms was determined in the surface soils using the most probable number (MPN) method (*4*).

<u>Results and Discussion</u>

Effect of Planting on Soil Organic Matter Content. The different planting covers over a period of about six years caused significant differences in soil organic matter content (OM) (**Table 1**). While the OM in the soil from the tree plots remained essentially unchanged, soils from the turfgrass, ground cover, and mulch plots showed 170, 280, and 550% increases over the original level, respectively. Because soil organic matter plays a critical role in soil microbial ecology and hence in the degradation of many contaminants, it may be expected that 2,4-D and dicamba would be degraded at different rates in the different soils.

2,4-D Persistence. Significantly different degradation patterns were observed among the different soils (**Table 2**). The most rapid degradation occurred in the turfgrass soil, the half-life of 2,4-D was only 1.6 d. The half-life in the ground cover (3.9 d) or mulched soil (3.7 d) was slightly longer. The half-life of 2,4-D in the tree soil, at 30 d, was the longest among all the soils. The persistence of 2,4-D therefore followed an order of tree soil > ground cover soil ≈ mulch soil > turfgrass soil. It may be envisioned that if a rain storm occurred following 2,4-D treatment, the potential for the herbicide to move in storm runoff would increase in the order of turfgrass soil < mulch soil ≈ ground cover soil < tree soil.

Table 2. Rate constants and half-lives of 2,4-D in various landscape soils

Soil	k (day^{-1})	$T_{1/2}$ (day)	R
	Surface (0-10 cm)		
Tree	0.0226	30.7	0.97
Grass	0.4256	1.6	0.97
Mulch	0.1851	3.7	0.96
Ground cover	0.1798	3.9	0.99

- *Mitigation implication* 1: With its large biomass and dense, fibrous root system and its ability to quickly degrade 2,4-D, turfgrass may likely act as a "filter" for 2,4-D and similar pesticides. Grassed strips may therefore be placed on the border of residential landscapes to reduce pesticide runoff.
- *Mitigation implication 2:* Conversely, 2,4-D applied to exposed soil surfaces such as in areas around trees or bushes may be highly susceptible to runoff, and pesticide application in these areas should be avoided when possible.

Dicamba Persistence. In the surface soils, the fastest degradation occurred in the mulched soil, which was followed by the ground cover soil and then the turfgrass soil (**Table 3**). The half-life of dicamba in the turfgrass, mulch and ground cover soils ranged from 7.9 to 19.6 d, which was much longer than that for 2,4-D in the same soils (1.6-3.9 d). The overall ranking of dicamba persistence was tree soil > turfgrass soil > ground cover soil > mulch soil. This order was different from that for 2,4-D, indicating that there were different predominant factors in the degradation of 2,4-D and dicamba in the landscape soils.

Table 3. Rate constants and half-lives of dicamba in various landscape soils

Soil	K (day^{-1})	$T_{1/2}$ (day)	R
	Surface (0-10 cm)		
Tree	0.0047	147	0.95
Grass	0.0354	19.6	0.99
Mulch	0.0873	7.9	0.98
Ground cover	0.0620	11.2	0.98

- *Mitigation implication 3:* The much longer persistence in the tree soil suggests again that dicamba applied on exposed soil such as in the area around trees or bushes may represent an increased runoff risk and such applications should be discouraged.
- *Mitigation implication 4:* The overall longer persistence of dicamba than 2,4-D implies that different pesticides may have different runoff risks. The use of persistent products should be reduced or avoided during the raining season when surface runoff is more frequent.

Role of Soil Chemical and Microbial Reactivity. Excellent correlation was found between the degradation rate of dicamba and soil OM (R = 0.98). This dependence suggests that the different plant covers altered soil OM and hence the degradability of dicamba. The population of 2,4-D degrading microorganisms was estimated to be 2,300, 230,000, 49,000, and 13,000 cells g^{-1} soil. Regression analysis showed that there was a linear relationship between the number of 2,4-D degraders in the soil and the degradation rate constant k (d^{-1}) (R = 0.94). This suggests that the different plant practices played a selective role in soil microbial ecology, which led to the different degradability of 2,4-D.

Conclusions

- Different planting types or practices drastically modified soil chemical and microbial properties. These changes consequently caused the landscaped soils to degrade these herbicides at different rates.
- Of all the landscape systems tested, herbicide persistence was consistently prolonged in the soil around trees that was low in both organic matter content and herbicide-degraders. Therefore, high runoff risks may be expected in such landscape systems.
- The knowledge of high or low-risk planting systems or practices may be used by city planners, developers, landscape architects, and professional landscapers for designing landscapes that are resistant to pesticide runoff.
- The same information may be also used for education of the general public (e.g., homeowners) that may lead to reduced or guided pesticide use in residential landscapes.

References:

1. Gilliom, R.J. *Hydrol. Proc.* **2001**, *15*, 3197-3201.
2. Bailey, H.C.; Deanovic, L.; Reyes, E.; Kimball, T.; Larson, K.; Cortright, K.; Connor, V.; Hinton, D.E. *Environ. Toxicol. Chem.* **2000**, 19, 82-87.
3. U.S. Environmental Protection Agency (EPA). *Total Maximum Daily Loads for Toxic Pollutants: Sand Diego Creek and Newport Bay, California,* http://www.epa.gov/ region09/water/tmdl/progress.html, 2002.
4. Alexander, M. In *Methods of Soil Analysis (II)*, Page, A.L. et al., Eds.; ASA: Madison, WI, 1982, pp. 815-820.

Seedling IPM in the Imperial Valley

Stephen Kaffka and Tom Babb [1]

Summary: Imidicloprid applied as a seed treatment increased the survival of sugarbeet seedlings as effectively as the current preferred treatment, chlorpyrifos, in three years of trials in the Imperial Valley. The use of imidicloprid as a low rate seed treatment should be economically competitive and help growers meet more strict water quality regulations in the future. Nevertheless, growers have been slow to adopt the use of seed treatments compared to insecticides applied to soil. Obstacles to the adoption of alternative pest management practices are discussed. Trials were supported by the California Department of Pesticide Regulation's Pest Management Alliance Program.

Introduction

Sugarbeet planting in the Imperial Valley takes place during September and early October when the populations of flea beetles and armyworms (*Spodoptera* sp.) can be large. These insects prey on sugarbeet seedlings. Growers and pest control advisors believe that insect control is necessary at planting and should continue until late fall when insect activity declines. Otherwise, the risk of stand failure and the need to replant is considered great or even certain. Management based on this assumption has been successful for many years, but it has been largely based on grower experience and tradition. There have been no quantitative estimates for the loss of sugarbeet seeds and seedlings following planting, and no assessment of when or how those losses occurred. The most commonly used materials for control (methomyl (Lannate®), chlorpyrifos (Lorsban®), and diazinon) are carbamate or organophosphate insecticides. Growers may become responsible for movement of these compounds from their farms to nearby surface water bodies in the future. Currently, there are no recommended alternatives to the use of these materials for sugarbeet seedling protection.

Pesticides found in surface waters are considered to be a non-point source pollution problem, but farmers have been exempt from the requirement for a waste discharge permit required for most point sources by the federal Clean Water Act. Beginning in January 2003, the waiver for this permit expires and farmers must begin to control the runoff leaving their farms. Eventually they will be responsible for the quality of farm runoff water. Starting in 1999, the California Beet Growers Association in cooperation with scientists from the University of California received a grant from the California Department of Pesticide Regulation to investigate the effects of alternative, less toxic methods of protecting emerging sugarbeet seedlings and mature sugarbeet crops from the effects of beet armyworms and other insects.

Evaluating seedling emergence

To evaluate alternative seedling protection strategies and document loss to insects and other causes, three trials were conducted in the Imperial Valley near Brawley in the fall of 1999 through spring 2002. Planting dates and seeding rates are provided in Table 1. After planting,

---

[1]Department of Agronomy and Range Science, University of California, Davis (srkaffka@ucdavis.edu) and California Department of Pesticide Regulation (formerly Agronomist, Spreckels Sugar Company)

the amount of seed remaining was weighed to get an exact weight for the seed planted. This amount was divided by the known field area to get the seed population per acre and per foot of row. We assumed that planting occurred uniformly. Different pre- and/or post emergence treatments were compared (Table 2). Each treatment was replicated three times in plots that were 20 rows wide running the length of the field. Three of the five treatments were used in all three years. Emerging seedlings were counted in four twenty-foot long rows in the middle rows of the plot four or five times after irrigation. At the last date, the aboveground portions of 30 seedlings were collected from the center row of each subplot, dried and weighed for comparison. Differences in dry weights at approximately the six to eight leaf stage indicate the amount of damage that occurred to seedlings after emergence in the different treatments. Yields were measured early in April approximately six and a half months following planting, at the beginning of the sugarbeet harvest in the Imperial Valley.

Results

1. Pre-emergence insecticide applications resulted in significantly larger numbers of established seedlings than treatments without insecticides. Seedlings were considered to be established when they had 6 to 8 true leaves. Pre-emergence losses were the most important cause of mortality. This was true despite differences in locations, irrigation practices and planters among the trials (Table 2). Post emergence mortality was less than expected in all three trials, suggesting that once seedlings emerge, most will survive. Imidicloprid applied to seeds protected seeds and seedlings as well as soil applied chlorpyrifos in the fall of 1999 and 2001, and satisfactorily in 2000. Flea beetles were the principal cause of damage at emergence and are well controlled by imidicloprid.
2. In both 2000 and fall 2001, the lower, less expensive rate of imidicloprid resulted in equivalent numbers of emerging seedlings. In 2001, seedling dry weight at the six-leaf stage was lower for the 20 gram imidicloprid rate compared to the 45 gram rate (not shown). Flea beetles were abundant in Fall 2001 during the trial but not in fall 2000.
3. Some post-emergence insect protection remains important in the Imperial Valley when fields are irrigated early in the fall, but the amount may be reduced by using a seed treatment insecticide like imidicloprid. Approximately 7 to 10 days after emergence, armyworm control can become important. After this point, an effective post-emergence insect control measure may be required in imidicloprid-treated plots in years or locations with large numbers of armyworms. Sugarbeet seedlings tolerate moderate amounts of damage, but there is no quantitative relationship between seedling damage and yield, so growers must use best judgment in deciding when to protect seedlings from additional damage. This will vary with the year and location, and time of year as well. As the planting season progresses, less post-emergence control should be necessary. So delayed planting is in itself an IPM practice.
4. High emergence rates are the key to successful stand establishment. Establishing a large percentage of seeds as seedlings saves growers money on seed costs and may make thinning unnecessary. Reducing the amount of pesticides applied has imputed environmental benefits and saves growers money (Table 3).

Alternative practices appear promising

In the Imperial Valley, where pre-emergence losses are high, an insecticide applied with or to the seed appears necessary. The larger number of seedlings emerging and becoming established in treatments including a pre-emergence insecticide leads to the inference that insect damage is occurring to seeds and emerging seedlings before they appear above ground. Such damage has been reported in England and elsewhere in Europe, where springtails (*Collembola* sp.) are sometimes implicated in losses (Durrant, et al., 1988). Growers know about the potential for such losses but the amount of loss has not been quantified before in California to our knowledge. Early post-emergence seedling damage appeared to be due almost entirely to flea beetles. Armyworm moths must first locate seedlings and then lay eggs. Eggs take several days to develop and may be subject to predation or disease themselves. In contrast, flea beetles were present in the field at planting. Imidicloprid is very effective against flea beetles even at low rates and substituted well for soil applied chlorpyrifos and as many as three aerial applications of chlorpyrifos/diazinon mixtures. The amount of insecticide used as a seed treatment is only approximately 15 to 35 grams a.i. per acre. This is a significant reduction in pesticide use compared to current practices.

In addition to having adequate numbers of seedlings, growers need healthy, vigorous plants. In 1999, treatments not receiving a pre-emergence insecticide resulted in severely damaged seedlings by the last counting date. Those seedlings surviving were reduced in size, often having damage to the apical meristem region. Even the imidicloprid treated seedlings were smaller and were beginning to suffer armyworm damage at the last counting date, suggested by lower seedling weights (Table 4). These results imply that some post-emergence worm control is necessary in the fall establishment period when armyworm or flea beetle pressure is significant. Compared to the standard grower's treatment, however, the amount of pesticide and the number of treatments needed could be reduced. This could spare growers a significant amount of cost, as well as reduce pesticide loss to the environment in surface water runoff.

Generally, when approximately 65 % to 70 % of the seed planted results in viable plants, sugarbeets can be planted to a final stand, and hand thinning is no longer needed. High emergence rates combined with lower seeding rates avoid the combination of large, unproductive gaps and too- narrow spacing between plants in the rows that occurs if more seed is used but fewer plants are established. Hand thinning costs in the Imperial Valley vary between $50 and $100 per acre. This expense can be saved by planting to a stand. In addition, lower seed rates also save money, provided high enough emergence and establishment rates are achieved reliably. If seed treatments are used, lower seed rates also save money on insecticides. Another way to save money is to use a lower rate of imidicloprid as a seed treatment. The label specifies 45 grams a.i. per 100,000 seeds currently, but rates as low as 20.0 grams a.i. per unit have been shown to be effective.

The limitations of these trials

1. The effects of drift and the possibility of reduced insect pressure within plots cannot be excluded. Plots were large in size. Twenty rows equal approximately 50 feet and there were 4 unsprayed plots in every set of five. This difficulty is unavoidable in all experiments of this kind. If experimental plots were partially protected from damage, then post-emergence losses observed in these trials are underestimates of the amount of loss possible and may underestimate the need for post-emergence insect control. But plot size had no influence on pre-emergence losses because there was no drift to consider at planting.
2. The years during which these trials were conducted and the locations may not have been representative of the severity of insect pressure possible in the Imperial Valley. But in response to this concern, differences in insect pressure were observed in all three years, though not quantified. Three different fields resulted in similar patterns of results in all three trials, even though yearly influences and irrigation practices varied in important ways. The lower rate of

imidicloprid, 20 grams a.i. per 100,000 seeds, was evaluated only the last two years, but relative seedling emergence results were similar in both years.
3. Quantitative economic thresholds have not been established for tolerance to damage from armyworms and flea beetles. Growers must still use judgment in deciding if or when to control insects in the post-emergence period. Nonetheless, the survival of large numbers of seedlings in unsprayed plots and the uniformity of yields demonstrates that sugarbeet seedlings are capable of sustaining some grazing damage early in development (prior to 4 to 6 true leaves), yet survive and produce an economic crop.

Obstacles to the adoption of reduced risk insect management practices

Successful farming practices have evolved over time. Despite potential benefits, alternatives face obstacles to their adoption that are not always apparent.

1. *The current practices work well*. Current stand establishment practices work well and growers are familiar with their use. Chlorpyrifos and diazinon are effective at controlling the insects that damage sugarbeet seedlings in the Imperial Valley.
2. *Skepticism about new practices*. The alternatives proposed have not been widely evaluated in the Imperial Valley. Three trials provide good evidence for effectiveness, but few farmers have direct experience with the new practices. Since growers typically invest about $1200 per acre in a sugarbeet crop, prudent concern about newly proposed practices is appropriate. A new set of trials in more locations is underway as a means to further evaluate and extend these practices.
3. *Costs.* The labeled rate for imidicloprid is 45 grams a.i. per 100,000 seeds (per unit). It may be applied as low as 28.5 grams per unit, but lower amounts are below what is listed on the label. Neither the company providing the insecticide nor the seed company applying the insecticide to seeds are willing to apply it at a lower rate, even though a lower rate appears to be sufficiently effective. It is not clear why a minimum rate of 28.5 grams was established. The most cost effective treatment is the lower rate. At the lower rate, imidicloprid is economically competitive with chlorpyrifos and diazinon, and with the use of imidicloprid as a soil treatment (Admire®). The lower the amount of active ingredient used, the better for the environment. Using lower rates may also help preserve the effectiveness of the insecticide.
4. *The need for new arrangements between growers and seed companies when ordering seed*. Seed must be treated with imidicloprid by the seed company before shipment. Growers cannot apply their own treatment. This requires both growers and seed companies to organize their plans earlier in the year than might be the case otherwise. Seed companies will not take back seed that is treated with imidicloprid. Imidicloprid is also phytotoxic. The higher the rate applied, the more phytotoxic it becomes. At the high rates used in Europe (90 grams a.i. per unit of seed) it can be applied only with a pellet coating. Pelleting increases seed costs. When applied with the normal polymer film coatings used with sugarbeet seed in the U.S., seed mortality can occur after a few months, especially if seed is poorly stored. So seed treated with imidicloprid must be planted within a few months of treatment. Furthermore, the planting season in the Imperial Valley occurs at about the time that sugarbeet seed is harvested in Oregon, where it is produced. Treating seed with insecticides requires more time than current treatments and may delay seed deliveries.
5. *Competing alternative practices*. Imidicloprid can be applied as a soil treatment called Admire®. This requires no special planning on the part of the grower or seed company. Its use is untested but trials similar to the ones discussed here are underway currently in the Imperial Valley. Applying insecticides to the soil is similar to current practices and uses the same

equipment and methods as current practices. A larger amount of insecticide is used in this way, however, and its use is less discriminating. The development of resistance may be more likely with higher rates of use. The chance of phytotoxic effects due to higher rates and application difficulties could increase.

Conclusions

Imidicloprid used as a seed treatment appears to protect sugarbeet seedlings from pre-emergence losses in the Imperial Valley. Pre-emergence losses are the most important factor in seed and seedling mortality. Using seed treatments is arguably the most environmentally sensitive way to apply insecticides, and reduces worker exposure as well. Despite these advantages, there are a number of practical and financial obstacles to the adoption of seed treatments that have not yet been overcome.

References

Durrant, M.J., Dunning, R.A., Jaggard, K.W., Bugg, R.B., and Scott, R.K. (1988). A census of seedling establishment in sugar-beet crops. Ann. Appl. Biol. 113:327-345.

Kaffka, S.R. (2003). New Best Management Practices for Sugarbeet Stand Establishment in the Imperial Valley. *The California Sugar Beet*. California Beet Growers Association. Two West Swain Street. Stockton, California.

Acknowledgments

Supported in part by a grant from the California Department of Pesticide Regulation (98-0330), Betaseed, Inc, Spreckels Sugar, Inc., Gustafson, Inc., and the California Sugarbeet Industry Research Committee. Acknowledgments are extended to Tom and Curt Rutherford, Larry Godfrey, Tom Terini, Larry Gibbs, Herman Meister, Elias Bassil, Gary Peterson, and Jorge Cisneros for their cooperation and help at various times with the field experiment.

Table 1. **Cultural comparisons between years**.

Year	Irrigation date	Planter type	Planting rate (seeds/ac)	Pre-irrigation	Days observed (since irrig.)**
1999-2000	Sept. 19	Monosem*	144,600	yes	10/16/19/25
2000-2001	Sept. 15	Milton	90,000	no	10/19/26/46
2001-2002	Sept. 16	Milton	70,000	yes	10/17/22/28

*vacuum type. Sugarbeet cultivar Beta 4776 was planted in all three years. **Days observed (seedlings counted) since irrigation began

Table 2. **Seedling emergence and establishment at thinning**.

Treatment	Cumulative emergence (% of seed)	Cumulative post-emergence mortality (% of seed)	Cumulative post-emergence mortality (% of seedlings)	Established (% of seed)	Pre-emergence mortality (% of seed)
			1999-2000		
Grower's	**82.2**	**2.7**	**3.5**	**79.3**	**17.8a**
Imid.@45g	**79.4**	**5.1**	**6.9**	**74.1**	**20.6a**
Control	**56.3**	**8.1**	**15.6**	**47.5**	**43.7b**
			2000-2001		
Grower's	**49.2**	**6.6**	**13.4**	**42.6**	**50.8a**
Imid.@45g	**38.7**	**—***	**—***	**29.0**	**61.3b**
Imid.@20g	**38.9**	**5.6**	**14.6**	**33.2**	**61.1b**
Control	**32.9**	**9.4**	**28.6**	**23.5**	**67.1c**
Imid.@45g + (1x)	**38.3**	**7.4**	**19.2**	**31.5**	**61.7b**
2001-2002					
Grower's	**68.3**	**1.3**	**1.9**	**67.0**	**31.7a**
Imid.@45g	**64.4**	**1.9**	**3.0**	**62.5**	**35.6a**
Imid.@20g	**68.8**	**2.5**	**3.6**	**66.4**	**32.1a**
Control	**51.7**	**0.7**	**1.4**	**51**	**48.3b**
Imid.@45g + (1x)	**66.8**	**0.8**	**1.2**	**66.1**	**31.2a**

***Some plots damaged by cultivation before counting. Pre-emergence mortality includes approximately 5% non-viable seed.**

Table 3. Comparative direct costs, not including field preparation, seed, or thinning ($/ac)

Treatment	1999-2000	2000-2001	2001-2002
Growers[a]	**73.50**	**64.20**	**52.70**
Imidicloprid@45[b]	**72.45**	**43.40**	**31.50**
Imidicloprid@45 +1x[b,c]	**---**	**60.55**	**49.00**
Imidicloprid@20[b]	**---**	**19.30**	**14.00**
Control	**0**	**0**	**0**

(a.) The Growers treatment involved chlorpyrifos at planting and up to 4 post emergence applications of chlorpyrifos/diazinon. The greater the cost, the more post-emergence applications applied. (b.) The cost of imidicloprid (Gaucho®) declined each year because the amount of seed used declined each year (see table 1). Imidicloprid@45 is imidicloprid applied at the rate of 45 grams a.i. per 100,000 seeds. Similarly, imidicloprid@20 is 20 grams per 100,000 seeds. Controls received no insecticides. All treatments included fungicides. (Imidicloprid+1x) means that one post-emergence aerial application of chlorpyrifos/diazinon at approximately 14 to 16 days after irrigation. The cost of imidicloprid seed treatment was estimated at $1.00 per gram applied to each unit. This may underestimate the actual current price. (c.) Included one post-emergence aerial application of chlorpyrifos/diazinon at approximately 14 to 16 days after irrigation. No insecticides were used in the control treatments.

Assessing dormant season organophosphate use in almonds and prunes - Examples of using the Pesticide Use Report database

Minghua Zhang* and Larry Wilhoit
California Department of Pesticide Regulation
1001 I Street, Sacramento, CA 95814
*(916) 324-1256, mzhang@cdpr.ca.gov

Background

During the past decade, California growers used one to 1.5 million pounds of organophosphate insecticides (OPs) annually during the dormant period to control overwintering agricultural pests. California almond orchards accounted for 10 to 33% and prunes accounted for 5 to 8% of the state's total dormant OP use from 1992 to 2000. Insecticides are used during winter months primarily for control of peach twig borer (PTB), San Jose scale (SJS), and European red mite, brown mite, and oriental fruit moth. In the early 1980s, dormant OPs were recommended as an effective and environmental friendly control for overwintering insects in almond orchards (Rice et al., 1972; UC IPM, 1985). Although OPs are still effective in controlling these overwintering pests, their use has raised concerns in California due to their appearance in surface water. Concentrations of diazinon and chlorpyrifos in the Sacramento and San Joaquin River watersheds were at levels high enough to be toxic to some aquatic organisms (Grieshop and Raj, 1992; Spurlock, 2002; Werner et al., 2002) and, therefore, a TMDL (Total Maximum Daily Load) assessment has been prepared by the Central Valley Regional Water Quality Control Board for these two chemicals. Recent studies have shown that the major source of OP runoff has been attributed to applications during the winter rainy season in California, typically November-March (Domagalski, 1997; Spurlock, 2002; Guo, 2002).

Consequently, the California Department of Pesticide Regulation (DPR) and other organizations have been encouraging the use of alternatives to OPs. Many organizations and government agencies have provided funding to find ways to reduce OP use during dormant season on orchards. So, has OP use declined? The pesticide use report (PUR) can help answer the question. This report assesses OP use in almonds and prunes during the dormant season using the PUR and simple statistics.

Pesticide Use Report

The PUR is the largest and most complete database on pesticide use in the nation. Limited use reporting requirements for pesticides have been in force in California since at least 1950 (CDPR, 2000). During the late 1980s, concerns of worker health and safety and the environmental impacts of pesticides demanded more realistic and comprehensive pesticide use data to accurately estimate exposure risks. DPR began a full use reporting program in 1990 in response to these concerns, and the Food Safety Act of 1989 (Chapter 1200, AB 2161; CDPR, 2000) gave the Department authority to require full reporting. Except for home and garden use, and most industrial and institutional uses, all other uses of pesticides must be reported within a month of application (AB2161).

The PUR database currently contains 32 data fields including the amount of products/active ingredients used, commodity/crops received the application, application date and methods, geographic locations of the application, and the operator identifications (CDPR, 2000). The data are reported to county agricultural commissioner's offices by the pesticide applicators and/or growers, and then each county submits the data to the DPR for compilation. The compiled data are then iteratively reviewed and error checked by the county biologists, the state DPR scientists, and an automated program before its distribution to the public.

The rich information contained in the PUR has made the database widely used by state regulators, university researchers, industry scientists, commodity groups, and non-profit organizations for risk assessment, public health investigations, endangered species mapping, water quality, air quality, and economic impact assessment as well as pest management studies. A recent comprehensive review by Epstein and Bassein (2002) used the PUR as the primary source to discuss the patterns of pesticide use and the implications for pesticide reduction strategies in California.

OP use in almonds

The objectives of the almond OP study were to determine the trends in dormant OP use in California almonds from 1992 to 2000, to characterize the spatial patterns of pesticide use in almonds, and to investigate possible explanations for the changes found.

Thirteen counties comprising 98% of California's almond-growing acreage were selected for the study: Butte, Colusa, Glenn, Sutter, Tehama, Yolo (Northern California); Merced, San Joaquin, Stanislaus (Central California); and Fresno, Kern, Madera, Tulare (Southern California). The dormant season for pesticide use was defined as December 10 through March 20, while in-season was defined as March 21 through December 9. This dormant period was chosen to capture the most common dormant applications and bloom time *Bacillus thuringiensis* (Bt), applications. Bt is used to control PTB and is one alternative to dormant OPs. There are many ways to measure pesticide use. Measures of pesticide use include pounds of active ingredient (AI) applied, pounds of AI per acre planted, cumulative acres treated, cumulative acres treated per acres planted, percent acres treated, and number of growers using pesticides. Among these measurements, we used pounds of AI per acre planted in statistical analyses because this measure removes the effect of differences in acres planted seen annually. We also examined the percent acres treated and number of growers using different practices.

During the dormant season, OP use on almonds decreased statewide from 1992 to 2000 as measured by pounds of AI per almond acres planted, percent acres treated, and number of growers (Figure 1). This decrease, as measured by pounds of AI per acre planted, was statistically significant for the major almond growing region as a whole and for major growing counties except Sutter (Table 1). However, this decrease, as measured by acres treated, was statistically significant for all the counties in the region. It was observed that there was one reported application in 1996 in Sutter with an unusually high entry for pounds of AI that was likely an error in reporting. If this application were left out, Sutter would also show a statistically significant decrease in use as measured by pounds of AI per acre planted.

In contrast, the use of one main alternative to dormant OPs, no insecticide treatment, increased from 1992 to 2000 (Figure 1). The number of growers who used no dormant insecticides increased from 1300 in 1992 to 2100 in 2000, while the percent of acreage with no dormant insecticide use increased from 35% in 1992 to 57% in 2000 (Figure 1). The use of dormant pyrethroids, another alternative to dormant OPs, by all measures generally increased from 1992 to 2000, although year-to-year variation exists (Figure 1). This increase, as measured by pounds per acre planted, was statistically significant for the almond growing region as a whole, while only significant for 4 out of 13 counties (Table 1). In Yolo County, the use of pyrethroid declined significantly (Table 1). Interestingly, the use of dormant oil without any other insecticide increased when measured by percent acres treated and number of growers, but fluctuated from year to year in pounds per acre planted (Figure 1). Kern County had a statistically significant increase while Madera County had a statistically significant decrease in dormant oil use (Table 1). The results did not show any discernable overall trend in the use of Bt, another OP alternative, by any measure during the entire period 1992-2000 (Figure 1). The use of Bt increased from 1992 to 1995, but generally decreased after that. Figure 2 shows the spatial distribution of the declining dormant OP use. The largest decrease was found in the San Joaquin Valley.

During the growing season, OP use decreased statewide from 1992 to 2000 as measured by pounds of active ingredients per almond planted acres, percent acres treated, and number of growers. Most of the decrease occurred between 1997 and 2000. This decrease, as measured by pounds per acre planted, was statistically significant for the major almond growing region and significant for 6 of the 13 almond growing counties (Table 2). These counties were Colusa, Fresno, Madera, Merced, San Joaquin, and Stanislaus. The rest of counties had no statistically significant changes in the last ten years for in-season OP use.

There were no statistically significant trends for in-season use of pyrethroids, Bt, and oil alone in the almond growing region as a whole from 1992 to 2000 (Table 2). Similarly, the percent acres treated and number of growers using no in-season insecticides fluctuated from year to year with no significant trend. The use of pyrethroid and Bt increased from 1992 to 1997 and 1998, respectively, then gradually decreased. The use of oil alone increased quite dramatically from 1995 to 1999. Although pyrethroid use increased in four counties (Table 2), there was no clear spatial pattern in pyrethroid use trends among almond growing counties.

The significant declining trend of OP use, whether it was measured by pounds per acres planted or by the percent acres treated, reflects the profound changes in pest management strategies in the California almond farm community (CDPR, 2001; Epstein et al, 2001, 2002; Swezey and Broome, 2001; Thrupp, 2001). The decrease of OP use may be attributed to many factors, such as pest levels, cost of pesticides, price of almonds, weather, and availability of alternatives, that interact in a complex manner (Giseshop and Raj, 1992; Hendricks, 1995; Flint, 1998; Epstein et al, 2001; Thrupp, 2001). Almond production has been rather stable (CDFA, 2001) and the almond damage rate measured by nut rejects did not change in the last decade (Almond Board, 2001). The stable almond production, declining use of OPs, and state-wide increasing use of pyrethroids in the last ten years suggest that either the chemical alternatives to OP use were successful and/or almond growers focused on other practice strategies that are less reliant on pesticide use (Hendricks, 1995; Thrupp, 2001).

OP use in prunes

More than fifteen counties grow prunes in California. The prune industry has traditionally relied on OP and carbamate insecticides to control the majority of the arthropod pests. Due to environmental and human health concerns, industry representatives and growers have been trying to find alternatives to OPs. The major pests in prunes are San Jose Scale, Peach Twig Borer and Oriental Fruit Moth (California Tree Fruit Agreement, 2000). Some of the same alternatives used in almonds are also being tested in prunes.

In this part of the study, we focused on Sutter County and four types of insecticides: oils, OP, pyrethroids, and Bt. Using information from the prune board, the dormant season for prunes was defined as the period from December 1 to February 28 and in-season was defined as March 1 to September 30. Pesticide use on individual fields was categorized relative to the county average rate of use (pounds of active ingredient per acre planted) for each insecticide type applied. Four pesticide use categories were created as: very-low use (0-25% of the county average rate); low use (25-50% of the county average); moderate use (50-100% of the county average); and above average use (over 100% of the county average). The pesticide use categories provided a quick reference point for comparing pesticide use intensity on prunes in Sutter County.

In California, OP use on prunes also declined dramatically in the last decade whether it was measured by total pounds of AI or by the pounds of AI per acre planted (Figure 3). In Sutter County dormant OP use in prunes increased from about 5,000 pounds in 1993 to 21,000 pounds in 1994 and then decreased to 10,000 pounds in 2000 (Figure 4), while in-season OP use fluctuated around 5,000 pounds. The use of dormant pyrethroids increased from 17 lbs. in 1993 to 370 lbs in 2000 (Figure 5). The use of in-season pyrethroids and Bt increased from 1993 to 1997and then decreased (Figure 5).

Table 3 shows the number of prune fields that used different insecticide use categories in Sutter County in 2000. For example, “22”, the first value in Table 3, means that 22 fields used oils at rates that were 0-25% of the county average. In Sutter County, 73% of all prune fields used dormant oils, 44% of the fields used dormant pyrethroids, while only 31% of the fields used dormant OPs. The percent of fields using in-season oils, pyrethroids, and OPs was less than their use during the dormant season (Table 3). It is possible that dormant season applications better control overwintering pests and minimize in-season natural enemy disruptions. However, dormant season OP and pyrethroid applications may produce pesticide runoff to surface water. Therefore, use of low risk pesticides, such as oils and Bt, or no insecticides may be better solutions for reducing water quality impacts while minimizing disruptions to natural enemies.

Potentials and Drawbacks of the PUR

As demonstrated in the previous sections assessing OP use in almonds and prunes, the PUR can be valuable to various areas including pest management. However, the PUR data are census data that were not collected by scientifically designed procedures. Many people have experienced errors and outliers in the PUR data. Although the PUR is widely used among communities, complaints on the data quality can be heard. As CDPR (2000) pointed out, 100 percent accuracy will never be achieved given the complexity of the data structure and the large volume of the data being processed. However, the error rates for some kinds of errors decreased from around 4% in 1990 to less than 0.005% in 1997; most other kinds of errors (except for inconsistencies in location and acres planted) were less than 5% (Wilhoit et al, 2001).

The low error rates for most of the PUR data fields reflect an acceptable level of accuracy for the PUR. In addition, DPR continues to improve the data quality. The PUR has the potential to be useful for many purposes to various groups including regulators, researchers, educators, the public and growers. Examples can be found in using the PUR to address issues relating to evaluating and promoting integrated pest management, identifying successful alternative pest management systems, promoting reduced-risk pesticides, protecting endangered species, establishing use limits for pesticides of concern in air and water quality, as well as protecting human health (http://www.cdpr.ca.gov/docs/; Guo, 2002; Zhang et al., 2002).

From the regulatory viewpoint, the PUR is often used for establishing the relationship between use and pesticide concentrations, to predict pesticide residues in the environment, and to establish the upper use limit for any pesticide of concern (http://www.cdpr.ca.gov/docs). It is also common that DPR uses the PUR to select monitoring locations and sampling intervals, and also to estimate exposure risk assessment. In all, the PUR has been widely used for agriculture and environmental assessment. The PUR is a valuable and powerful resource for sustainable agriculture and a healthier environment.

Acknowledgement

We would like to acknowledge the people in the Agricultural GIS laboratory at the University of California Davis for providing some of the data, and thank Dr. Lisa Ross in the California Department of Pesticide for valuable comments. We also appreciate partial financial support from the Department of Pesticide Regulation and from the PESP program in the US EPA Region 9.

References

1. Almond Board, 2001. Almond Industry Position Report. http://www.almondboard.com.
2. California Department of Food and Agriculture, 2001. Agricultural Resource Directory, CDFA, Sacramento, CA.
3. California Department of Pesticide Regulation (DPR), 2000. Pesticide Use Reporting: An Overview of California's Unique Full Reporting System. Sacramento, CA.
4. California Tree Fruit Agreement, 2000. California peaches, plums and nectarines. 2000 Research Report.
5. Domagalski, J.L., Dubrovsky, N.M., Kratzer, C.R., 1997. Pesticides in the San Joaquin River, California – inputs from dormant sprayed orchards. Journal of Environmental Quality 26, 454-465.
6. Epstein, L., Bassein, S., Zalom, F. G., Wilhoit, L.R., 2001. Changes in pest management practice in almond orchards during the rainy season in California, USA. Agriculture, Ecosystems and Environment. 83, 111-120.
7. Epstein, L. Bassein, S. 2002. Patterns of pesticide use in California and the implications for strategies for reduction of pesticides. Annual Review. (in preparation).
8. Flint, M.L, Cullen, E., Zilbert, E., Zalom, F.G., Miyao, G., Coviello, R., 1998. Pest management record-keeping duties shift with computerization. California Agriculture 52, 27-31.
9. Grieshop, J. I., Raj, A.K., 1992. Are California's farmers headed toward sustainable agriculture? California Agriculture 46, 4-7.
10. Guo, L. 2002. Correlation analysis of surface water pesticide load with precipitation and pesticide use in Sacramento and San Joaquin Valleys in California. Environmental Monitoring, California Department of Pesticide Regulation, Sacramento, CA. (in preparation).
11. Hendricks, L.C., 1995. Almond growers reduce pesticide use in Merced County field trials. California Agriculture 49, 5-10.
12. Rice, R.E., Jones, R.A., Black, J.H. 1972. Dormant sprays with experimental insecticides for control of peach twig borer. California Agriculture 26: 14.
13. Spurlock, F., 2002. Analysis of Diazinon and chlorpyrifos surface water monitoring and acute toxicity bioassay data, 1991-2001. Environmental Hazards Assessment Program, Environmental Monitoring Branch, California Department of Pesticide Regulation, Sacramento, CA. EH01-01.
14. Swezey, S.L., Broome, J., 2001. Growth predicted in biologically integrated and organic farming. California Agriculture. 54, 26-35.
15. Thrupp, L.A. 2001. Principles for implementing sustainable agriculture: lessons from successful partnerships in integrated pest/crop management initiatives. Sustainability of Agricultural Systems in Transition. ASA Special Publication no. 64. 155-165.
16. University of California Statewide Integrated Pest Management (UC IPM), 1985. Integrated Pest Management for Almonds. UC Publication 3308.
17. Werner, I., Deanovic, L.A., Hinton, D.E. et al. 2002. Toxicity of stormwater runoff after dormant spray application of diazinon and esfenvalerate (Asana) in a French prune orchard, Glenn County, California, USA. Bull. Environ. Contam. Toxicol. 68, 29-36.

18. Wilhoit, L, Zhang, M., Ross, L, 2001. Data quality of California's pesticide use report. PM01-02. California Department of Pesticide Regulation, Sacramento, CA.
19. Zhang, M., Wilhoit, L., Ross, L., Geiger, C., Gorder, N. 2002. Dormant season OP use in California almonds. Pest Management and Licensing, California Department of Pesticide Regulation. Sacramento, CA. (in final review).

Table 1. Standardized regression slopes of pesticide use trends for OPs, pyrethroids, and oils alone in dormant season almonds using pounds per acre planted as a measure. Significance: ** p < 0.01, * p < 0.05.

	Lbs OP/ Acre Planted		*Lbs Pyrethroids/ Acre Planted*		*Lbs Oil Alone/ Acre Planted*	
County	*Slop*	*Sig.Le*	*S*	*Sig.Leve*	*S*	*Sig.Leve*
BUTTE	-0.7	*				
COLUSA	-0.8	**				
FRESNO	-0.9	**	(	**		
GLENN	-0.7	*				
KERN	-0.9	**	(	**	(	*
MADERA	-0.8	**	(	*	-	**
MERCED	-0.8	**				
SAN JOAQUIN	-0.9	**				
STANISLAUS	-0.9	**				
SUTTER						
TEHAMA	-0.7	*				
TULARE	-0.6	*	(	*		
YOLO	-0.8	*	-	*		
ALMOND REGION	-0.9	**	(	*		

Table 2. Standardized regression slopes of the pesticide use trends for OPs, pyrethroids, and oils alone in the growing season almonds using pounds per acre planted as a measure. Significance: ** p < 0.01, * p < 0.05.

	Lbs OP/ Acre Planted		*Lbs Pyrethroids/ Acre Planted*		*Lbs Oil Alone/ Acre Planted*	
County	*Slop*	*Sig.Le*	*S*	*Sig.Leve*	*Slope*	*Sig*
BUTTE						
COLUSA	-0.8	**				
FRESNO	-0.7	*			0.78	
GLENN						
KERN			(	**		
MADERA	-0.8	**	(	*		
MERCED	-0.9	**	(	*		
SAN JOAQUIN	-0.8	**				
STANISLAUS	-0.7	*			0.89	
SUTTER						
TEHAMA						
TULARE						
YOLO			(	**		
ALMOND REGION	-0.7	*				

Table 3. Number of Sutter County prune fields in 2000 that were treated with different rates of dormant and in-season oils, *Bacillus thuringiensis* (Bt), OPs, and pyrethroids. Rates were measured by pounds of pesticide active ingredient (AI) per acre planted. Very-low rates were 0 – 25% of the county average (given in the last row), low rates were 25 – 50% of the county average, moderate rates were 50 – 100% of the county average, and above average rates were greater than the county average. There were a total of 472 Sutter County prune fields in 2000.

Pesticide Use Category	**Dormant Insecticides (Dec. 1 Feb. 28)**				**In-Season Insecticides (March Sep. 30)**			
	Oils	BT	OP	Pyre-thr	Oils	BT	OP	Pyre-thr
Very-low								
Low								
Moderate								
Above average								
No. fields treated each AI type								
% of fields treated each type								
No. fields not trea each type								
Ave Lb/Acre Plar								

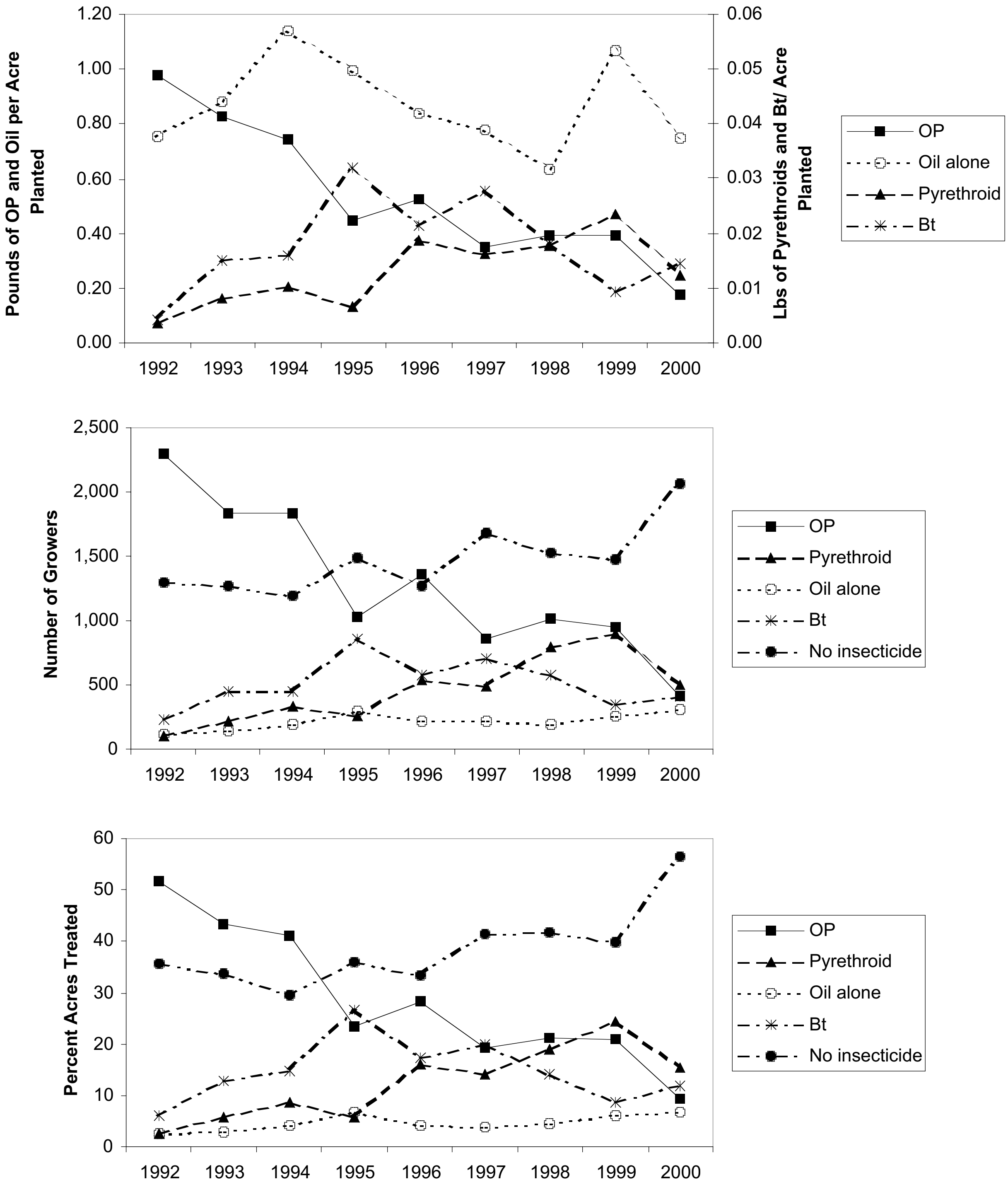


Figure 1. Pounds of AI per almond acre planted, percent of almond acres treated and number of almond growers using various dormant season insecticide practices.

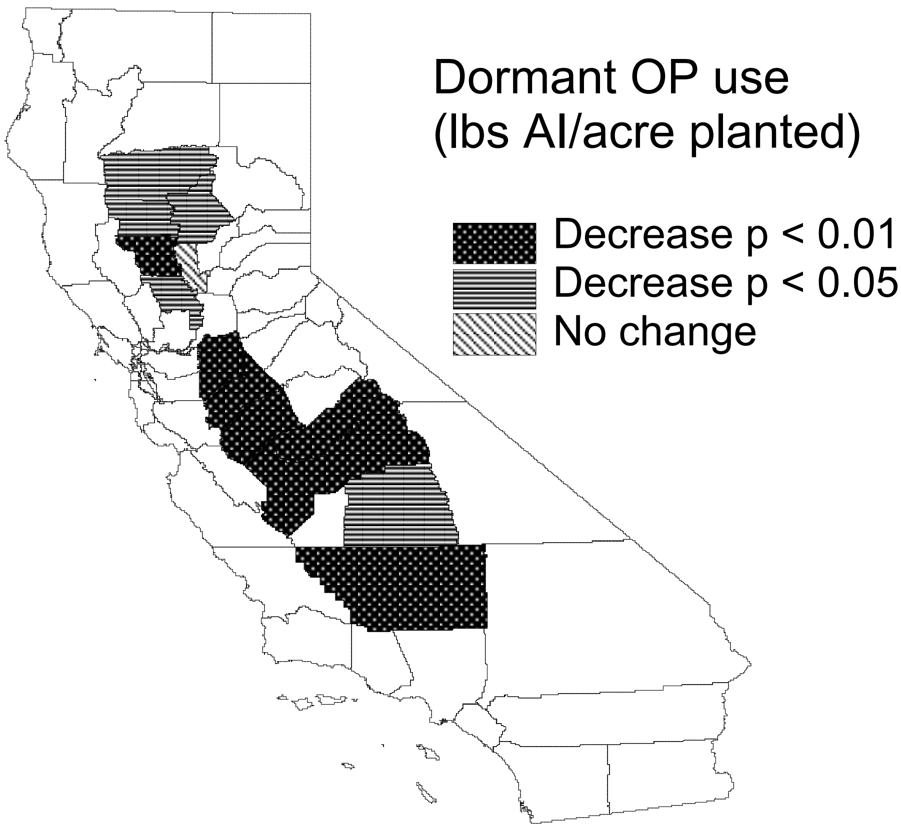


Figure 2. Trend of OP use during the dormant season by California counties from 1992 to 2000. The different shadings represent different levels of statistical significance. No shading indicates no almond or little almond growing in the counties.

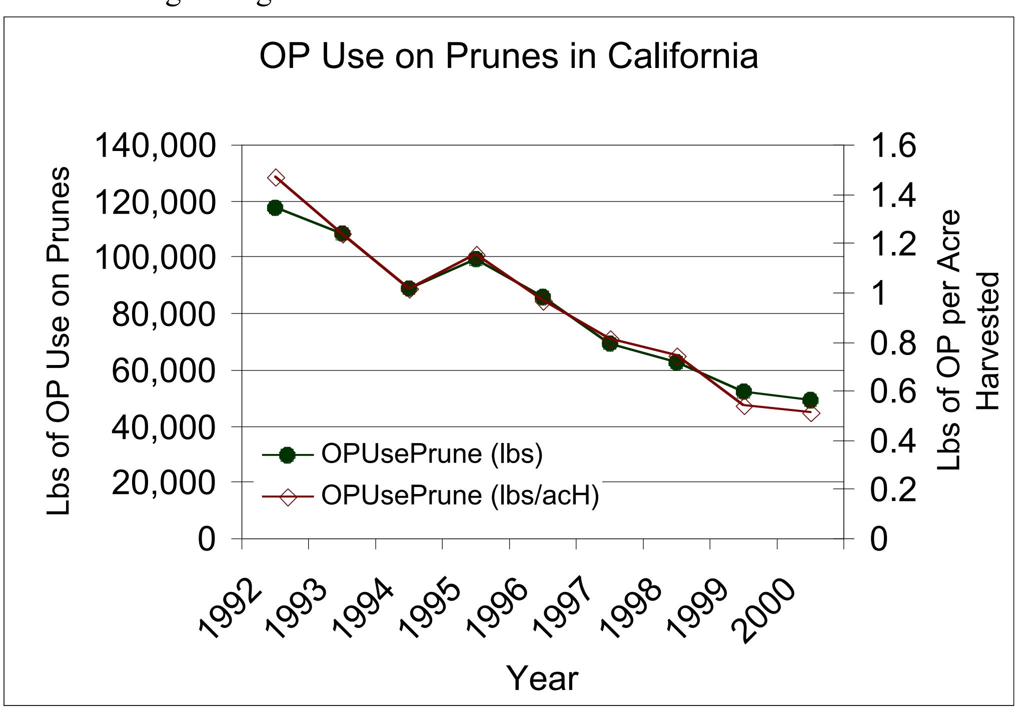


Figure 3. OP use on prunes in California from 1992 to 2000.

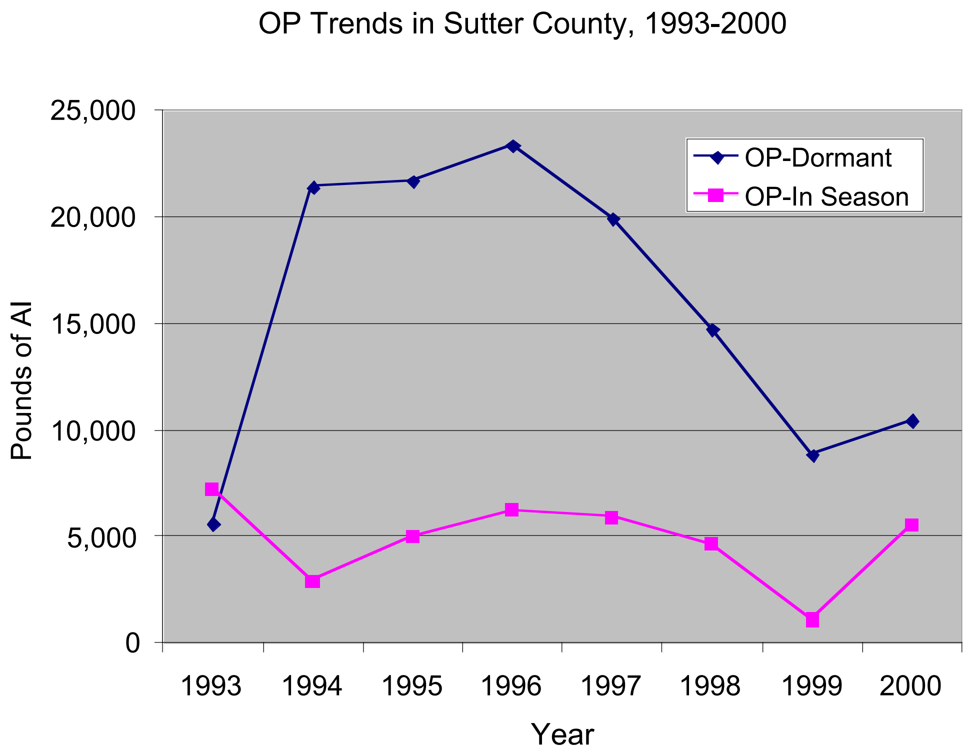


Figure 4. OP use in dormant and in-season in Sutter County from 1993 to 2000.

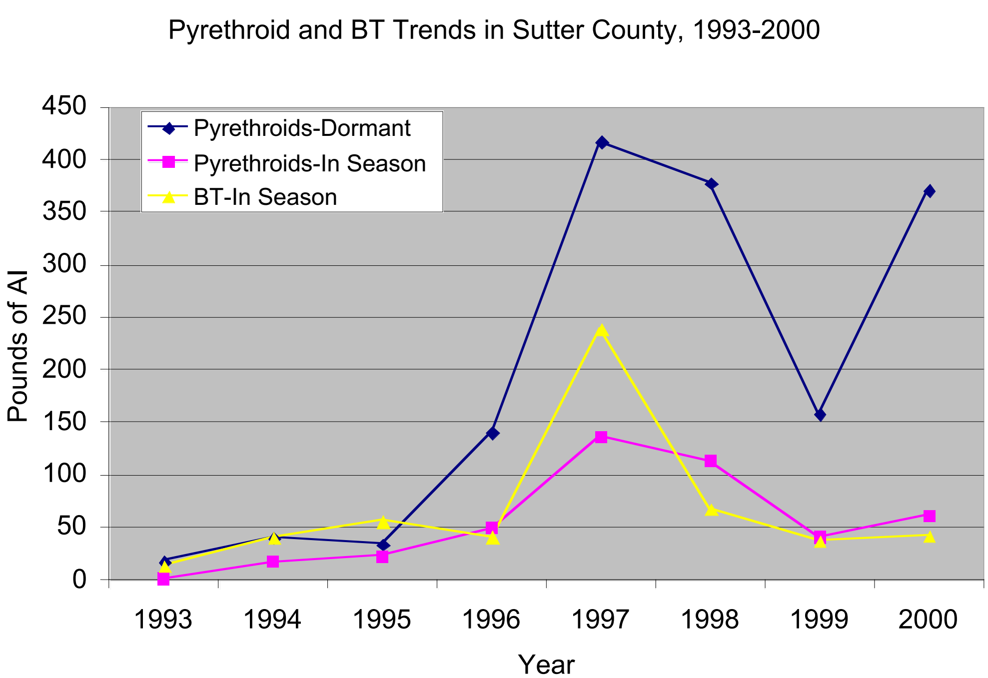


Figure 5. Pyrethroid and Bt use in dormant and in-season in Sutter County from 1993 to 2000.

Sean L. Swezey
Director
University of California
Sustainable Agriculture Research and Education Program

The California organic agricultural industry is growing in size and consumer acceptance. In 2001, over 2,000 registered farms produced a declared value of $220 million on over 190,000 acres, according to the California Department of Food and Agriculture's Organic Program. Based on the approximate 10% expansion of acreage and value per year during the last decade, we predict that organic production will include 10-20 percent of California production value and cropland in the next twenty-five years. Recent data indicate that organic farm gate production value in California is concentrating in a small percentage of larger enterprises, while also including numerous small production units. Recent innovations in the production of relatively labor-intensive and high fresh-market value organic crops, apples and strawberries, are discussed as illustrative of organic production trends in California. Organic production techniques for these commodities in California have provided benchmarks against which other management options are measured. Organic apple and strawberry growers manage pests principally through crop rotation, pest disruption, and physical and biological controls, while managing soil fertility and health with cover crops and additions of composted organic matter, rather than relying on synthetic inputs.

Organic Education: Concepts and Examples

Mark Van Horn, Director
Plant Science Teaching Center and Student Farm
University of California
One Shields Avenune
Davis, CA 95616
530/752-7645; mxvanhorn@ucdavis.edu

The USDA implemented the National Organic Program (NOP) on October 21, 2002, signaling a recognition that organic farming had reached a point, both nationally and internationally, that federal regulatory involvement in organic agriculture could no longer be considered optional. However, organic farming has been a growing sector of California and US agriculture for over thirty years, and more than twenty years ago it was the topic of a well publicized USDA report (USDA, 1980) and an American Society of Agronomy (ASA) symposium and subsequent publication (ASA, 1984). In fact, California's first law defining and regulating organic farming was passed in 1979, six years after the 1973 founding of California Certified Organic Farmers, which was then a self-regulating grass-roots organization (CCOF, 1988). Since that time, organic production has grown steadily with overall annual growth rates of approximately 15 to 20% statewide and nationally throughout the last decade (Dimitri and Greene, 2002; Klonsky et al, 2002; Swezey and Broome, 2000). In addition, organic farming is no longer solely a small scale proposition; large scale organic production (and processing) of many commodities is occurring throughout the state and nation and organic products are currently sold in over 73% of conventional grocery stores nationally (Dimitri and Greene, 2002).

Parallel to the evolution of organic farming, there has been an evolution of educational programs dealing with organic farming and related topics at colleges and universities over the last three decades. Mirroring the development of the organic industry itself, such programs first became noticeable in California approximately thirty years ago and in recent years have shown significant growth and a movement from the fringe toward the center. As more faculty look at organic agriculture as a legitimate area of education (and research) and student demand for instruction in this area increases, many institutions have begun to offer courses and curricula related to organic farming. However, the content and methods of such educational efforts vary significantly and we may be able to more effectively design and develop educational programs in organic agriculture if we first examine the nature of organic farming.

The USDA NOP Program Standards define organic production as a, "production system that is managed … to respond to site-specific conditions by integrating cultural, biological and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity" (Federal Register, 2000). This definition, which by law applies to all organic farms in the US, clearly states that organic farming includes environmental and ecological goals as well as production goals. Organic farming can thereby be seen as a form of productive ecosystem management that must be approached from a holistic perspective to achieve its diverse goals. Therefore, organic farming education obviously must include strong ecological and environmental science components. However, the implications of the NOP definition extend even further. By the inclusion of environmental goals, the NOP definition acknowledges that organic farming is an example of *agriculture responding positively to changes within society* that result in additional expectations being placed upon agriculture. From a marketing or economic perspective, the success and growth of organic farming is a direct result of organic farmers' positive response to social changes that put special value on agricultural products that are produced in environmentally sound ways.

Although organic farming is not synonymous with sustainable agriculture, organic farming clearly has been part of a movement toward a more sustainable agriculture (NRC, 1989). While organic farming focuses on production (economic) and environmental goals, sustainable agriculture adds social goals to this list as well. Thus, both organic agriculture and sustainable agriculture have broad goals that address societal issues beyond agricultural production. Accordingly, many educational programs typically link the two, along with the related academic discipline of agroecology, and it is appropriate that we link them in this discussion. Agroecology is commonly defined more broadly than some might expect. It includes social, economic, and policy aspects, as well as ecological, environmental and productive (e.g., agronomic) ones and "is concerned… with the optimization of the agroecosystem as a whole" (Altieri, 1983). Thus, agroecology explicitly recognizes that multiple factors impact producers' options and choices, as well as the consequences of those choices on all of the aspects of the system. If organic and sustainable agriculture are, indeed, about trying to respond in positive ways to society's growing desire for a more environmentally and socially sound and productive agriculture and adapting to changing environmental, economic, political, etc. conditions, then organic educational programs must provide students with an appropriately broad range of skills and knowledge. Graduates of these programs must not only understand the biophysical world and how it can be productively and sustainably managed, but also the social, economic and political processes that impact, and are impacted by, agriculture. Indeed, understanding social ("soft") systems is critical if we are concerned with change and adaptation in agriculture, because it is *people* and their behavior that must change for agriculture to change.

Developing a curriculum that provides such an education may require developing new (and reviving old) educational methods. Educators in Europe (Lieblein et al, 2000) and Australia (Bawden, 1992) have explored these concepts in some depth. Francis et al (2001) drew upon the lessons of some of these experiences and suggests that "ecological agriculture education" may differ from conventional agricultural education in three fundamental ways: 1. by focusing on understanding *systems* to complement disciplinary knowledge, 2. by introducing concepts, methods and learning objectives from the social sciences and integrating them with those from the natural sciences, and 3. by encouraging "action research and education" which includes concepts of problem solving, experiential field-based learning, and expanding our notions of teacher and student. Fully embracing all of these notions instantaneously is not suggested; however, exploring these concepts and how they might be used to modify curricula has the potential to help us develop more effective educational programs in organic and sustainable agriculture.

Both UC Davis and Cal Poly San Luis Obispo are working to develop such programs (e.g., Francis, 2002) and there are several parallels between the efforts at these two institutions. Both currently offer an undergraduate course in organic farming and other courses related to sustainable agriculture and are expanding efforts in these areas. As with many colleges and universities around the country, sustained student interest and activism, along with the efforts of some key faculty supporters, were critical in initiating and maintaining activities, courses and programs focusing on organic farming, sustainable agriculture and related topics at both schools for several years. Student-initiated programs/facilities (both named "the Student Experimental Farm" and established in 1977 and 1989 in Davis and San Luis Obispo, respectively) have been important focal points for developing, maintaining and expressing student and faculty interest in organic and sustainable agriculture at these institutions (e.g., http://studentfarm.ucdavis.edu/). Both Farms are important sites for a wide range of experiential learning activities such as student internships and research projects and course activities; both farms are certified organic and feature ongoing educational projects, including ones which produce and sell organic products to subscribing customers (i.e., through a community supported agriculture, or CSA, program) and through other venues. Such programs *emphasize students and their learning*; while faculty and staff move increasingly toward the roles of facilitators and partners in the educational process. In the future, these Farms will remain vital to their institutions' expanding organic and sustainable agriculture educational programs, by providing unique opportunities for experiential learning, problem solving and integrated learning opportunities.

Developing organic educational programs raises numerous issues, challenges and opportunities, as implied by the discussion above. Additional issues, that may or may not be directly related to organic farming, may also arise. For example, what are the backgrounds, broader interests and goals of students interested in organic farming? Such issues, as well as the concepts and examples discussed above, will be addressed.

Citations:

Altieri, M.A. 1983. Agroecology: the scientific basis of alternative agriculture. Division of Biological Control, Berkeley, CA

ASA 1984. Organic farming: current technology and its role in a sustainable agriculture: proceedings of a symposium. ASA special publication no. 46. Madison, WI

CCOF. 1988. Certification Handbook. CCOF, Santa Cruz, CA

Bawden. R.J. 1991. Systems thinking and practice in agriculture. J. Dairy Sci. 74:2362-2373.

Dimitri, C. and C. Greene. 2002. Recent growth patterns in the U.S. organic foods market. ERS Ag Info Bull No. AIB777. USDA, Washington DC

Federal Register. 2000. 7CFR Part 205 National Organic Program; Final Rule. USDA, Agricultural Marketing Service , Washington DC

Francis, C.A., Leiblein, G. Helenius, J. Salomonsson, L. Olsen, H. and J. Porter. 2001. Challenges in designing ecological agriculture education: A Nordic perspective on change. Am. J. Alt. Ag. 16: 89-95.

Francis, H. 2002. Organic agriculture taking root at Cal Poly, SLO. Newsletter of CCOF 19(3): 16.

Klonsky, K. Tourte, L. Kozloff, R. and B. Shouse. 2002. A statistical picture of Calfornia's organic agriculture, 1995-1998. Univ Calif Ag Issues Cntr, Davis, CA

Lieblein, G. Francis, C. Barth-Eide, W. Torjusen, H. Soberg, S. Salomonsson, L. Lund, V. Ekblad, G. Persson, P. Helenius, J. Loiva, M. Seppanen, L. Kahiluoto, H, Porter, J. Olsen, H. Sriskandarajah, N. Mikk, M. and C. Flora. 2000. Future education in ecological agriculture and food systems: A student-faculty evaluation and planning process. J. Sust. Ag. 16(4):49-69.

National Research Council (U.S.). Committee on the role of alternative farming methods in modern production agriculture. 1989. Alternative agriculture. National Academy Press, Washington, DC.

Swezey, S.L. and J.C. Broome. 2000. Growth predicted in biologically integrated and organic farming. Cal. Ag. 54(3): 26-35.

USDA. USDA study team on organic farming. 1980. Report and recommendations on organic farming. USDA, Washington, DC

Cover crop cultivar and planting density impacts on cover crop productivity, and weed biomass and seed production in an organic system in the Central Coast of California

Eric B. Brennan
Research Horticulturist
USDA-ARS
1636 East Alisal Street, Salinas, CA 93905
Phone: (831)-755-2822, Fax: (831)-755-2814, ebbrennan@ucdavis.edu

Richard Smith
Vegetable Crop and Weed Science Farm Adviser
University of California Cooperative Extension
1432 Abbott Street, Salinas, CA 93901
Phone: (831)-759-7350, Fax: (831)-758-3018, rifsmith@ucdavis.edu

Abstract

Cover crops are important components of crop rotations on organic farms and affect soil quality, nutrient cycling, and pest and disease management. This study compared cover crop light interception, cover crop biomass production, weed biomass production and weed seed production in several winter cover crops including two cereals (rye and oats), a mustard mixture, and two legume/oat mixtures. The cereals were planted at two densities and the other cover crops were each planted at a single density. Light interception differed markedly between the different cover crop treatments especially early in the season and increased with cover crop density. There were significant differences in cover crop biomass production that changed over the season. By the last harvest date, the legume/oat mixtures and rye at the high seeding rate had produced significantly more biomass than oats at the low seeding rate and mustard. Weed biomass production was highest under the legume/oat mixtures, and significantly more chickweed seed production occurred under these mixtures than under all of the other cover crops. The data suggest that increasing the seeding rate of the cereals and adding more oats to the legume/oats mixture reduced chickweed seed production. The relevance of these results to organic production systems are discussed.

Introduction

Cover crops are essential components of sustainable farming systems and affect crop yield, soil quality, nutrient cycling, and pest and disease management (Ingles et al., 1994; Lal et al., 1991; Teasdale, 1996). Cover crops also mitigate the negative environmental affects of intensive agricultural production such as nitrate leaching, soil erosion, and pollution of fragile marine resources (Meisinger et al., 1991). Organic farmers identified cover cropping and weed management as top research priorities (Walz, 1999). Previous cover crop research in the Central Coast occurred in conventional systems with non-legume cover crops (Jackson et al., 1993; Wyland et al., 1996). However, because cover crops are more critical to the success of and common on organic farms, future cover crop research in this area should occur on organic systems and include legume/cereal mixtures that are prevalent in organic systems. To optimize cover crop benefits, organic farmers need more information on how cover crop planting density and variety affect cover crop biomass production and weed management. To begin to address this need we compared the performance of several winter cover crops including two cereals (rye and oats), a mustard mixture, and two legume/oat mixtures.

Materials and Methods

Site and Experimental Design: The field experiment was conducted at the USDA-ARS certified organic research plot along Spence Road in Salinas, California from October, 2001 to March, 2002. The soil at the site is a Chualar series loamy sand (fine-loamy, mixed, thermic Typic Argixerol). The research plot had been fallow for several months prior to the experiment and before that a crop of frisee had been grown. The cover crops were planted on October 22 and 23, 2001 with a Case International 5100 grain drill with 17.7cm (7") between 18 seed lines. Pelletized chicken manure was broadcast and harrowed into to the plot at approximately 23kg (50lb) of nitrogen per acre prior to planting the cover crops. The experimental design was a randomized block design with 4 replicates and 7 treatments. The cover crop descriptions and seeding rates listed in table 1 were expected rates based on the seedling charts on the grain drill. Each cover crop treatment was planted as a 3m (118") wide by 90m (295') long strip. The legumes in the legume/oats mixes were innoculated with Rhizobium prior to planting. The plots were sprinkle irrigated following planting and thereafter as needed to supplement the winter rainfall.

Table 1. Cover Crop Treatments

Treatment Abbreviation	Cover Crop Variety	Seeding Rate (kg/ha) [lb/acre]
Oats 1x	*Avena sativa* cv 'Cayuse'	(89) [100]
Oats 2x	*Avena sativa* cv 'Cayuse'	(178) [200]
Rye 1x	Secale cereale cv 'Merced'	(71) [80]
Rye 2x	Secale cereale cv 'Merced'	(142) [160]
Mustard	Mustard Mix†	(25) [28]
90/10 LegOat	90% Legume: 10% Oats Mix ‡	(89) [100]
58/42 LegOat	58% Legume: 42% Oats Mix §	(89) [100]

† The mustard mix is known as 'Caliente 105' (High Performance Seed Company, Moses Lake, WA) and included 50% *Brassica hirta* and 50% *B. juncea*). Percentages of the mixes are by weight.
‡ 35% Bell Beans (*Vicia faba*), 25% 'Magnus' peas (*Pisum sativum*), 15% common vetch (*Vicia sativa*), 15% 'Lana' vetch (*Vicia villosa* ssp. *dasycarpa*), 10% 'Cayuse' oats.
§ 22% Bell Beans (*Vicia faba*), 16% 'Magnus' peas (*Pisum sativum*), 10% common vetch (*Vicia sativa*), 10% 'Lana' vetch (*Vicia villosa* ssp. *dasycarpa*), 42% 'Cayuse' oats.

Cover Crop Emergence: One month after planting, cover crop emergence was determined by counting the number of emerged cover crop plants in 1m (38") of 2 seedlines on each side of each treatment strip in 3 replicates.

Cover Crop Light Interception: A Li-Cor line quantum sensor (LI-191-SA, Lincoln Nebraska) was used to measure photosynthetically active radiation (PAR) at the soil surface in the inter-row area on several dates throughout the growing season starting on November 30, and approximately every week for the next month, and every 2-3 weeks thereafter. At each measurement date, PAR was recorded from the same location of 3 inter-row areas between and parallel to 4 cover crop rows on each date for each plot. Light measurements were taken on clear days during a period 1.5 hours before or after solar noon. Above canopy PAR was determined prior to measuring below canopy PAR for each replicate. Light interception by the cover crop canopy was determined by calculating from the ratio of the above and below canopy measurements for each plot. Light measurements were taken in all 4 replicates.

Cover Crop and Weed Biomass Production: Cover crop biomass and weed biomass were determined by harvesting the above ground biomass from a 1 x 1m (39"x 39") quadrant of each plot in December 6, 2001, January 17, 2002 and February 22-25, 2002. The harvested samples were oven-dried at 55-65°C (131-149 °F) and weighed. Biomass measurements were taken in 3 replicates.

Weed Seed Production: Weed seed production under the cover crops was determined by gently vacuuming the soil surface from two 50 cm x 100 cm (20"x 39") quadants at the final harvest (February 22-25). The vacuumed material contained weed seeds, gravel, soil and miscellaneous organic material. The weed seeds were separated from the vacuumed material by passing each sample through a series of screens, and then by using water to carefully elutriate the weed seeds from the remaining soil and gravel. Common chickweed (*Stellaria media*) seed dominated the weed seed samples and thus all analyses of weed seed production were conducted with this species. For each plot, the dried weight of chickweed seed production was determined and the number of chickweed seeds was calculated based on the average weight of 100 seeds from each of the treatments in one of the replicates. Weed seed production was determined in 3 replicates.

Data Analysis: The cover crop and weed biomass data were analyzed with the PROC MIXED procedure in SAS (Cary, NC). The biomass data were log transformed to stabilize the variances prior to analysis. Treatment means were compared using Bonferroni t-tests, and to control the experiment-wise error rate at the $P \leq 0.05$ level. The chickweed seed production data were square-root transformed to stabilize variances and analyzed with the PROC GLM procedure in SAS. A single degree of freedom contrast was used to compare chickweed seed production under the legume/oat mixtures to that under the all of the other cover crops combined.

Results

Cover crop emergence was relatively uniform within each treatment for all of the replicates. The planting densities of the Oats 2x and Rye 2x treatments were approximately twice that of the 1x rate for each (Table 2). The emerged density of the rye treatments was approximately 50% less than expected due to either poor germination or high seedling mortality. Of the seven cover crop treatments, emerged density was lowest in the 90/10 LegOat mix and highest in the Oats 2x treatment.

Table 2. Cover crop density one month after planting.

	---Cover Crop Emergence (mean ± standard error)---	
Treatment	**Plants/m^2**	**Plants/ft^2**
Oats 1x	363.3 ± 23.0	33.8 ± 2.1
Oats 2x	756.3 ± 55.7	70.3 ± 5.2
Rye 1x	225.8 ± 26.8	21.0 ± 2.5
Rye 2x	426.3 ± 3.8	39.6 ± 0.4
Mustard	522.5 ± 90.3	48.6 ± 8.4
90/10 LegOat	107.0 ± 16.0	9.9 ± 1.5
58/42 LegOat	158.8 ± 18.0	14.8 ± 1.7

Canopy light interception differed markedly between the different cover crops varieties and rates within a variety (Figure 1). The legume/oat mixtures intercepted the least amount of light for the first half of the season, however, by the latter part of the season (i.e. 84 days after planting) these mixtures intercepted more light than the other cover crops. Doubling the planting density increased light interception by approximately 42% for oats and 84% for rye early in the season (38 days after planting) and light interception remained higher at the higher density throughout the season. Light interception by the mustard and cereal cover crops had leveled off

72 days after planting and slightly declined after 84 days after planting. In contrast, light interception continued to increase for the legume mixtures up to the last harvest. Across all cover crop treatments, early season light interception was positively correlated with cover crop density. However, by 72 days after planting, light interception was not linked to stand density (Figure 2).

There were clear differences in cover crop biomass production between the different cover crops (Figure 3). A highly significant ($P<0.001$) treatment x date interaction for cover crop biomass production indicated a change in the relative ranking of the treatments over time. For example, the average biomass production by mustard was the highest in December but the lowest in February. Furthermore, in December the legume/oat mixtures had less biomass than the other cover crops, but by February these mixtures had produced the same amount of biomass as the Rye 2x and Oats 2x treatments. The higher seeding rates of rye and oats resulted in more biomass production, this was not significant. In addition, biomass production by the mustard and cereal cover crops appears to have peaked by January while that of the legume/oat mixtures continued to increase.

Above ground weed biomass production in the cover crop treatments throughout the season are shown in figure 4. Weed biomass production increased from December to January and then declined by the February harvests for all cover crop treatments. Averaged across the season, weed biomass production was significantly higher under the legume/oat mixtures than the other cover crops. Increasing the percentage of oats in the legume/oats mixture did not significantly reduce weed biomass.

Large amounts of weed seed production occurred under all cover crops as illustrated for common chickweed (Figure 5). Although analysis indicated that cover crop did not significantly affect seed production ($P = 0.07$), a single degree of freedom comparison of chickweed seed production under the legume/oat cover crops versus the mustard and cereals showed that significantly more chickweed seed production occurred under the legume/oat mixtures ($P =0.02$). Although not statistically significant, the data suggest that increasing the seeding rate of the cereals and adding more oats to the legume/oats mixtures reduced chickweed seed production.

Discussion

Our results showed that cover crop variety and planting density affected cover crop performance in several significant ways. Light interception by the mustard and cereal cover crops was greater than that of the legume/oat mixtures early in the season, and this effect appears to be due to cover crop density. These early season differences in canopy development had a major impact on weed biomass and more importantly weed seed production under the cover crop. These results are particularly relevant to organic farming systems where weed management is expensive and weed management tools are more limited (Gaskell et al., 2000). We speculate that using cover crops with poor early-season competitive ability may significantly increase the weed seed bank and increase future weed management costs. Weed growth and seed production during a cropping period are controlled by crop competitive ability that is mainly determined by seeding rate, planting arrangement, planting date, and cultivar (Mohler, 2000). Although the higher seeding rate of the cereals did not significantly reduce weed biomass production we believe that this was due to the small number of replicates in the experiment. It is likely that increasing the seeding rate and planting the legume/oat mixtures earlier in the fall would likely improve their competitive ability. We have begun studies on organic farms in the Central Coast to determine seeding rates that optimize cover crop biomass production and weed competitive ability, and to develop cover crop mixtures with increased weed suppressive ability.

Research on the impacts of cover crops on weed management often focuses on the physical and allelochemical effects of cover crop mulch or residue on weed control in cash crops that follow the cover crop (Creamer et al., 1997; Creamer et al., 1996; Masiunas et al., 1995; Teasdale, 1996; Teasdale and Abdul-Baki, 1998). However, the potential benefits of cover crops in weed control in subsequent cash crops may be negated if weeds growing under the cover crop canopy produce large amounts of seeds as occurred under the legume/oat mixtures in our study. Other studies have evaluated the ability of cover crops to suppress weed emergence and biomass production during the cover cropping period (Akemo et al., 2000; Creamer and Baldwin, 2000) however, our study is one of the first to quantify weed seed production during the cover crop. The results of the present study and another study with the burning nettle weed (*Urtica urens*) indicate that the cover cropping period is one of the weakest links in the weed management programs on organic farms because large amounts of weed seed production (i.e. > 2000/m^2) occur can occur while cover cropping. It would be useful for farmers to have information on the timing of weed seed production under cover crops so that they could minimize this by mowing the cover crop or incorporating it prior to this date. Although we did not monitor weed seed production throughout the growing season, the weed biomass data show a marked decline in weed biomass from January to February. We speculate that this decline was due to leaf senescence by the weeds and increased allocation of resources from vegetative growth to seed production.

Interestingly, despite their lower early-season growth, the legume/oat mixtures were among the top producers of biomass. Furthermore, the data suggest that biomass production by these mixtures continued to increase near the end of the experiment while that of the other cover crops had peaked in January. The poor soil fertility at our study site may explain why the legume/oat mixtures yielded more biomass than the mustard by the end of the season. The chlorotic appearance of the mustard and cereal cover crops suggests that they were nitrogen deficient. Biomass production by the cover crops in this study was approximately 60% lower than yields at a higher fertility site nearby (Brennan and Smith, unpublished data).

Cover crops can play an important role in nutrient cycling by minimizing nitrate leaching (Jackson, 2000; Wyland et al., 1996) and with legumes by fixing nitrogen (Drinkwater et al., 1998). However the potential nitrogen fixation benefits of legume cover crops on nitrogen cycling may be negated if they fail to trap residual soil nitrogen due to poor growth early in the winter. Nitrogen uptake by cover crop is related to dry matter production and evapotranspiration, and cover crops with poor fall growth are not likely to effectively reduce nitrate leaching (Meisinger et al., 1991).

Aknowledgements

We greatly appreciate the assistance of Esther Meela, Heather Sowersby, Pat Headley, and Dave Miltz who helped with the field for this project.

Literature Cited

Akemo, M.C., E.E. Regnier, and M.A. Bennett. 2000. Weed suppression in spring-sown rye (*Secale cereale*)-pea (*Pisum sativum*) cover crop mixes. Weed Technology 14:545-549.

Creamer, N.G., and K.R. Baldwin. 2000. An evaluation of summer cover crops for use in vegetable production systems in North Carolina. Hortscience 35:600-603.

Creamer, N.G., M.A. Bennett, and B.R. Stinner. 1997. Evaluation of cover crop mixtures for use in vegetable production systems. Hortscience 32:866-870.

Creamer, N.G., M.A. Bennett, B.R. Stinner, J. Cardina, and E.E. Regnier. 1996. Mechanisms of

weed suppression in cover crop-based production systems. Hortscience 31:410-413.
Drinkwater, L.E., P. Wagoner, and M. Sarrantinio. 1998. Legume-based cropping system have reduced carbon and nitrogen losses. Nature 396:262-265.
Gaskell, M., B. Fouche, S. Koike, T. Lanini, J. Mitchell, and R. Smith. 2000. Organic vegetable production in California - Science and practice. HortTechnology 10:699-713.
Ingles, C., M. Van Horn, R.L. Bugg, and P.R. Miller. 1994. Selecting the right cover crop gives multiple benefits. California Agriculture 48:43-48.
Jackson, L.E. 2000. Fates and losses of nitrogen from a nitrogen-15-labeled cover crop in an intensively managed vegetable system. Soil Science Society of America Journal 64:1404-1412.
Jackson, L.E., L.J. Wyland, and L.J. Stivers. 1993. Winter Cover Crops to Minimize Nitrate Losses in Intensive Lettuce Production. Journal of Agricultural Science 121:55-62.
Lal, R., E. Regnier, D.J. Eckert, W.M. Edwards, and R. Hammond. 1991. Expectations of cover crops for sustainable agriculture, p. 1-11, *In* W. L. Hargrove, ed. Cover Crops for Clean Water. Soil and Water Conservation Society, Jackson, Tennessee.
Masiunas, J.B., L.A. Weston, and S.C. Weller. 1995. The Impact of Rye Cover Crops on Weed Populations in a Tomato Cropping System. Weed Science 43:318-323.
Meisinger, J.J., W.L. Hargrove, R.L. Mikkelson, and V.W. Benson. 1991. Effects of cover crops on groundwater quality, p. 57-68, *In* W. L. Hargrove, ed. Cover Crops for Clean Water. Soil and Water Conservation Society, Jackson, Tennessee.
Mohler, C.L. 2000. Enhancing the competitive ability of crops, p. 269-321, *In* M. Leibman, et al., eds. Ecological Management of Agricultural Weeds. Cambridge University, Cambridge.
Teasdale, J.R. 1996. Contribution of cover crops to weed management in sustainable agricultural systems. Journal of Production Agriculture 9:475-479.
Teasdale, J.R., and A.A. Abdul-Baki. 1998. Comparison of mixtures vs. monocultures of cover crops for fresh-market tomato production with and without herbicides. HortScience 33:1163-1166.
Walz, E. 1999. Third Biennial National Organic Farmers' Survey Organic Farming Research Foundation, Santa Cruz, California.
Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S. Koike, and B. Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, and pests and management costs. Agriculture, Ecosystems and Environment 59:1-17.

Figure 1. Percentage of the photosynthetic photon flux density intercepted by the cover crop canopy following planting.

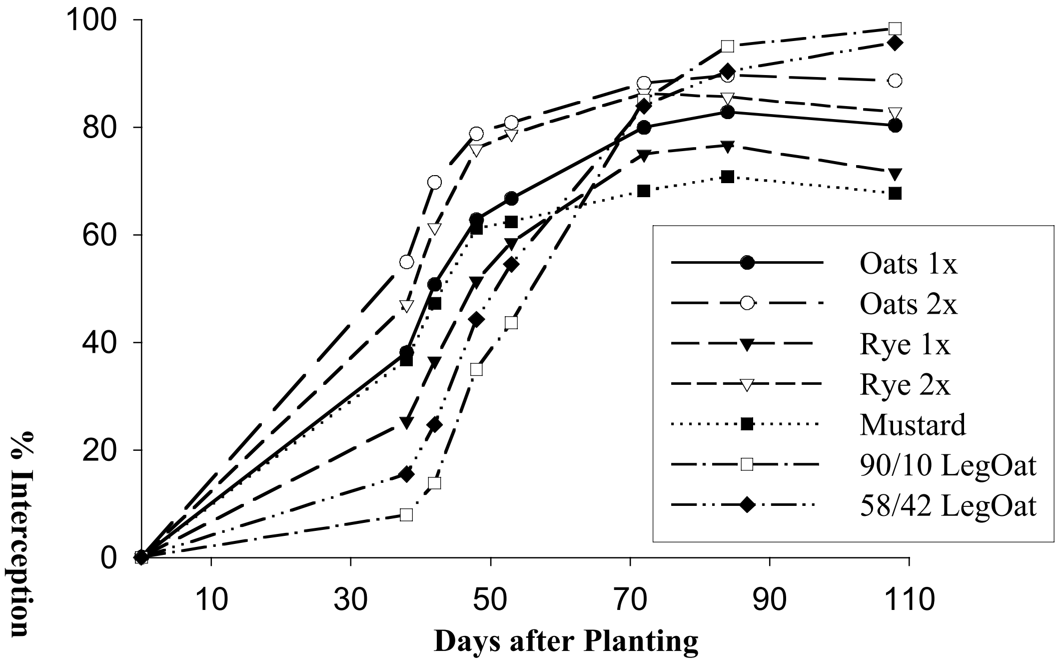


Figure 2. Percentage of photon flux density intercepted as a function of cover crop density on two dates after planting. The linear regression lines for the two dates shown, and the label between the data points for the two dates indicate the cover crop treatment for the various densities.

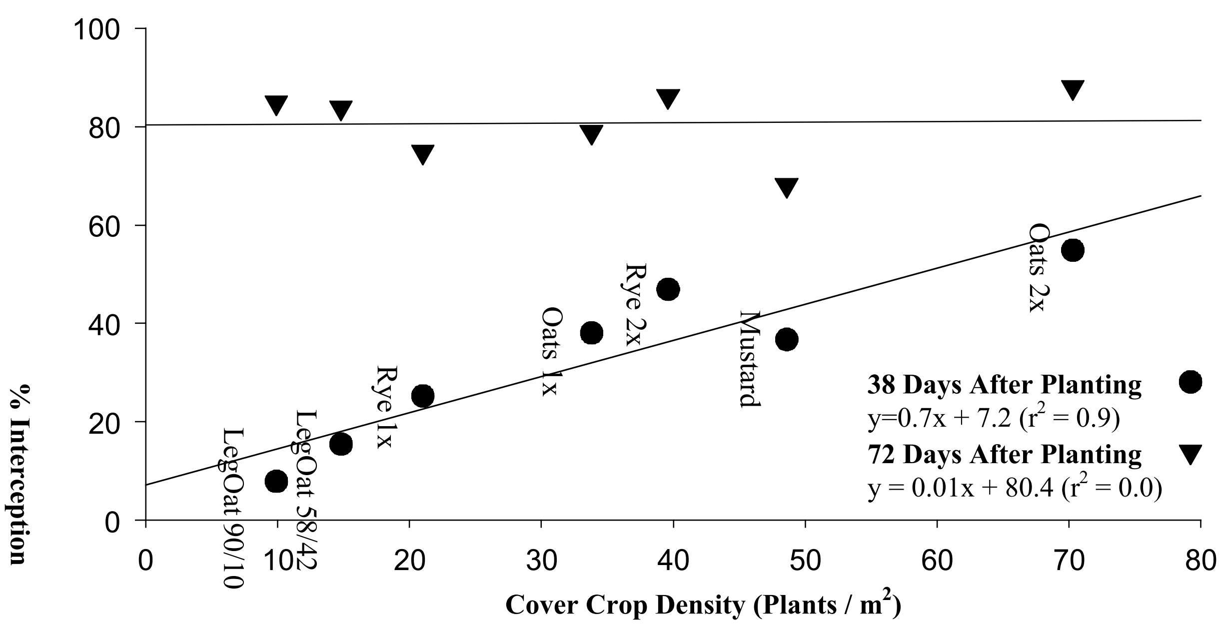


Figure 3. Above-ground cover crop biomass production on three harvest dates. Bars are mean ± 1 standard error. On the February harvest date, bars with the sample letter are not significantly different based on an experiment-wise error rate of P ≤ 0.05.

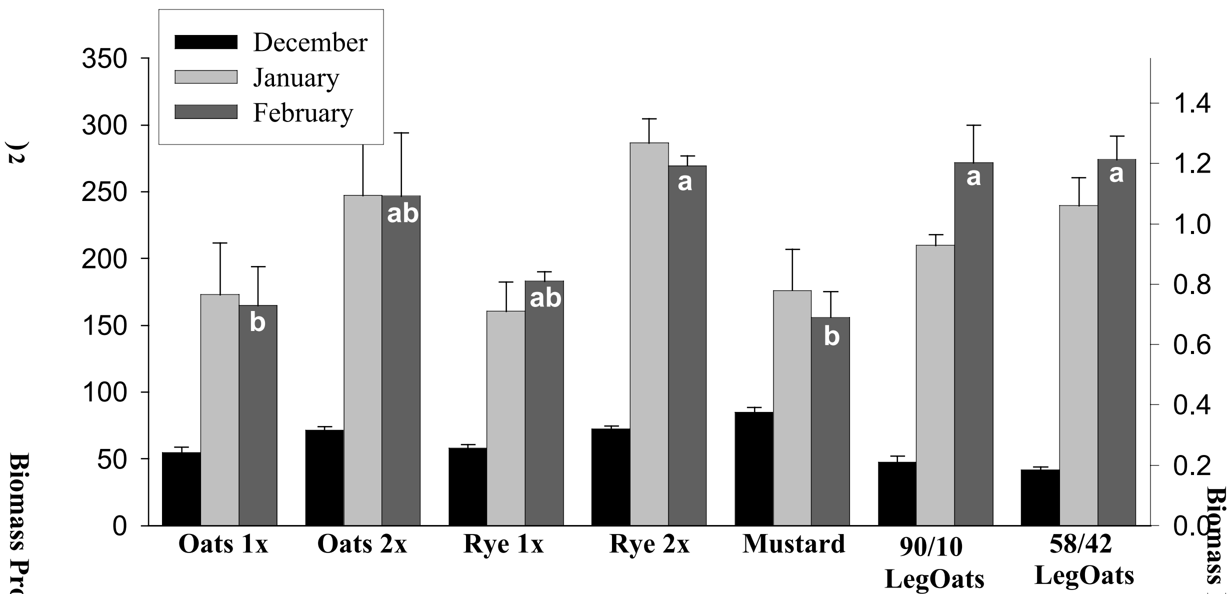


Figure 4. Above-ground weed biomass production under cover crops on three dates. Bars are mean ± 1 standard error. Across all dates, weed biomass production is significantly different at the P ≤ 0.05 experiment-wise error rate if the letter in the center bar differs between treatments.

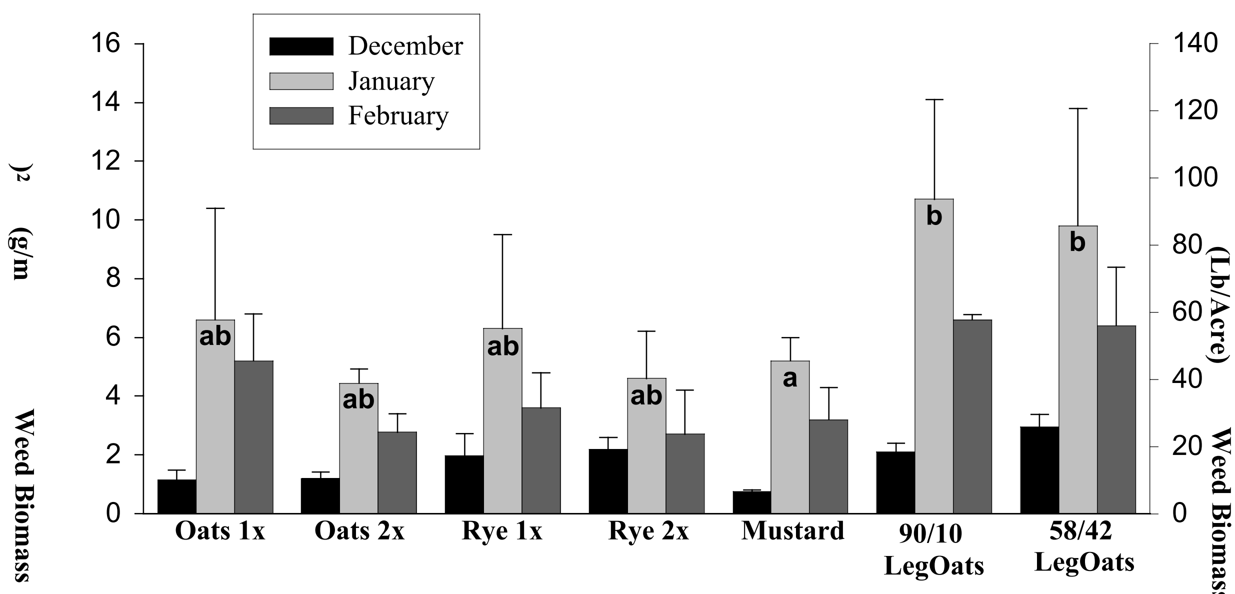
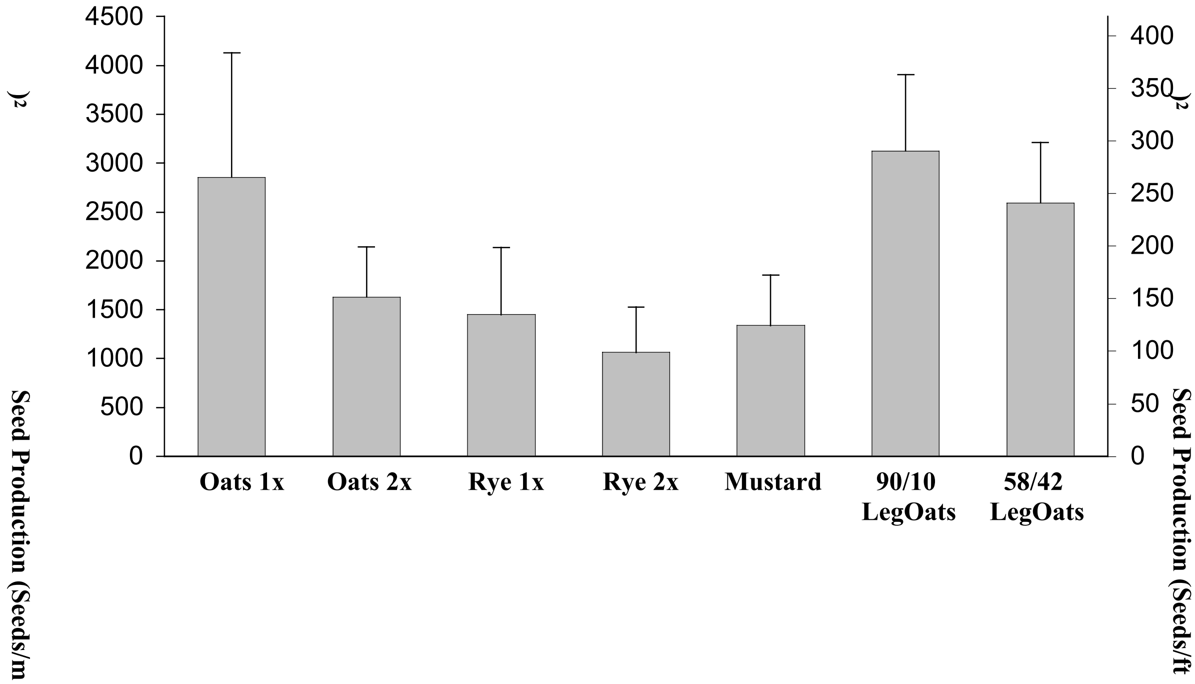


Figure 5. Chickweed seed production under cover crops by the February harvest (130 days after planting cover crops).



Implementing a Total Maximum Daily Load For Salt and Boron in The Lower San Joaquin River

Eric Oppenheimer, Environmental Scientist
Central Valley Regional Water Quality Control Board
3443 Routier Rd., Sacramento, CA 95827
tel.: 916-255-3234; e-mail: oppenhe@rb5s.swrcb.ca.gov

Introduction

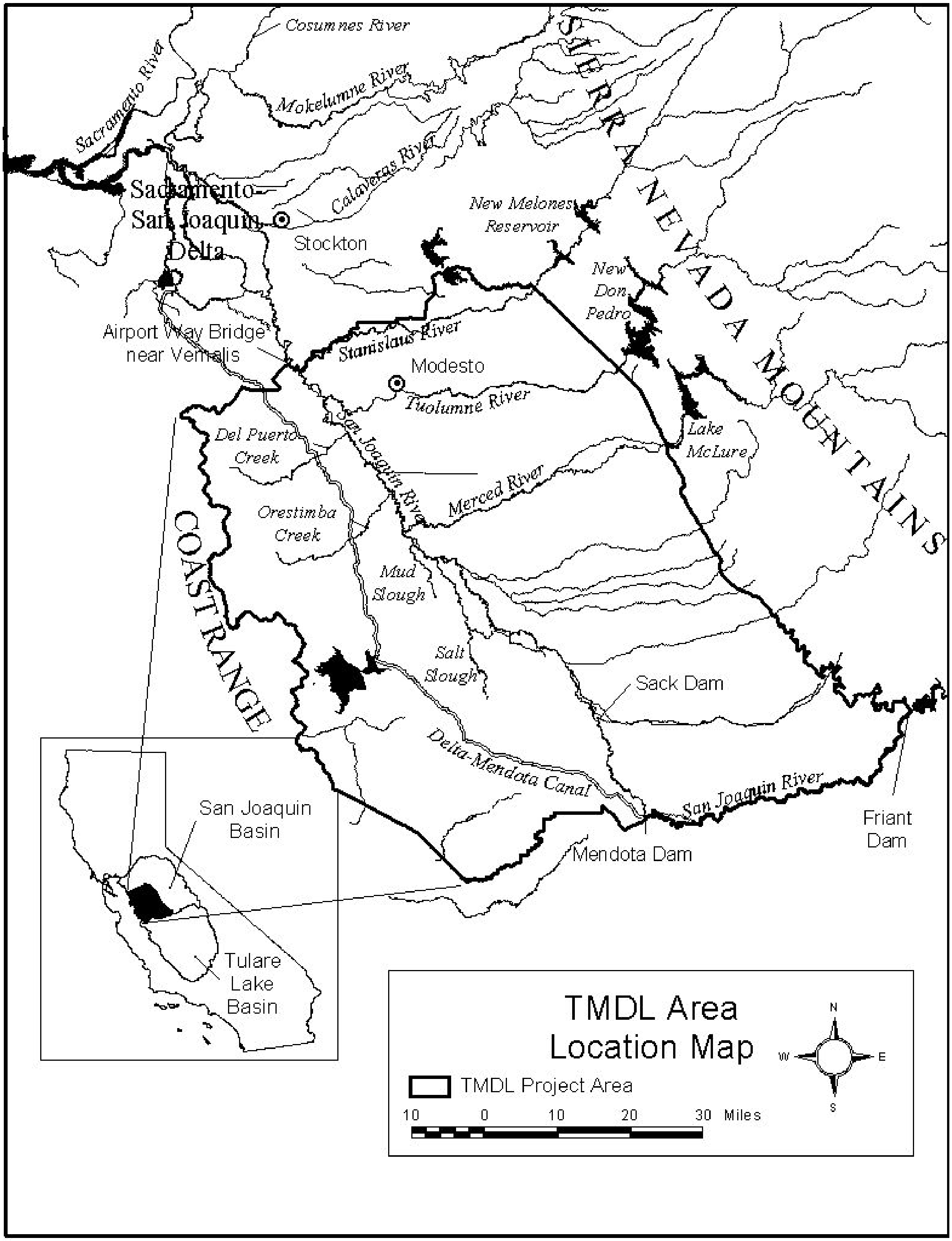
Extensive water quality data collected by the Central Valley Regional Water Quality Control Board (Regional Board) staff and others indicate that the lower San Joaquin River (SJR) frequently exceeds water quality objectives during the irrigation season. Therefore the river is listed on California's 303(d) list of impaired waters for salt and boron, necessitating development of a Total Maximum Daily Load (TMDL). In January 2002 a technical TMDL report for salt and boron in the lower SJR was developed to address the 303(d) listing. The technical TMDL report contains all of the required elements of a TMDL, including; (1) a problem statement that describes the waterbody being addressed and reasons for impairment; (2) numeric targets that set quantifiable end-points that the TMDL seeks to achieve; (3) a source analysis that identifies and describes the significant sources of pollutant loading to the SJR; and (4) assignment of load allocations (limits) to responsible parties (Oppenheimer and Grober, 2002). The technical TMDL report is a Regional Board staff work product and does not have any regulatory authority or effect until portions of the TMDL are incorporated into the Water Quality Control Plan for the Sacramento and SJR Basins (basin plan) through a formal basin plan amendment. Although current federal regulation does not require TMDLs to include implementation plans, a program of implementation for the salt and boron TMDL must be developed as part of the basin plan amendment process.

Area of interest

The main stem of the SJR is about 300 miles long and drains approximately 13,500 square miles of California's Central Valley. The drainage area includes portions of the western Sierra Nevada, the eastern slope of the Coast Range and the Central Valley floor. The geographic scope of the salt and boron TMDL is limited to the SJR downstream of the Mendota Dam to the Airport Way Bridge near Vernalis (Figure 1). For TMDL planning and analysis purposes, the lower SJR watershed excludes areas upstream of dams on the major reservoirs on the east side of the basin: New Don Pedro, New Melones, Lake McClure, and similar east side reservoirs in the SJR system. The lower SJR watershed, as defined here, drains approximately 4,531 square miles (2.9 million acres). The TMDL project area includes approximately 1.4 million acres of agricultural lands, 134,000 acres of urban area, and 134,000 acres of managed wetlands[2].

---

[2] Agricultural and urban land use data calculated from California Department of Water Resources Land Use Survey Data; wetland land use data calculated from modified U.S. Fish and Wildlife Service National Wetlands Inventory System data.



Figur1. Lower San Joaquin River

Numeric targets

To develop a TMDL, it is necessary to have one or more quantitative measures that can be used to evaluate the relationship between pollutant sources and their impact on water quality (USEPA, 1999). Numeric water quality objectives (WQOs) have already been established for salinity in the form of electrical conductivity (EC) and boron in the SJR at the Airport Way Bridge near Vernalis. These numeric WQOs provide quantifiable and finite target values that can be directly used as numeric targets for the salt and boron TMDL. The salinity WQOs for the SJR near Vernalis are 1000 μS/cm between September 1 and March 31, and 700 μS/cm between April 1 and August 31 (based on a 30 day running average). The boron WQOs for the SJR at Vernalis are 1.0 mg/L between September 16 and March 14, and 0.8 mg/L between March 15 and September 15 (based on a monthly mean). These WQOs have been established to protect the most sensitive beneficial uses of water, which are principally irrigation supply and municipal supply. This first phase of the salt and boron TMDL has been designed to meet the existing water quality objectives at Vernalis only. The Regional Board is currently in the process of evaluating new salt and boron WQOs for the SJR upstream of Vernalis. The TMDL will, therefore, need to be revised to meet any new or modified WQOs.

Sources of salt

The lower SJR has been apportioned into seven component geographic sub-areas to help identify the areas that contribute the greatest salt and boron loads. A combination of historical data and modeling was used to calculate salt loading from each sub-area for water years 1977 through 1997 (Table 1).

Table 1: Total Sub-area Salt and Boron Loading (WY 1977-1997)

Sub-area	Discharge		Salt Load		Boron load	
	thousand acre-feet	percent	thousand tons	percent	tons	percent
SJR upstream of Salt Slough	862	23%	100	9%	66	7%
Grassland	212	6%	400	37%	490	50%
North West Side	230	6%	320	30%	340	35%
East Valley Floor	149	4%	57	5%	21	2%
Merced River	549	15%	48	4%	14	1%
Tuolumne River	994	27%	92	9%	25	3%
Stanislaus River	679	18%	60	6%	19	2%
Totals	3,675	100%	1,077	100%	975	100%

On average, approximately 1.1 million tons of salt and 975 tons of boron were discharged from the San Joaquin Basin each year as measured in the SJR near Vernalis between water years 1977 and 1997. The Grassland and Northwest Side Sub-areas are the largest source of both salt and boron to the SJR. These two sub-areas contribute approximately 67 percent of the SJR's total salt load and 85 percent of the boron load. The Stanislaus, Tuolumne, and Merced River Sub-areas collectively contribute about 19 percent of the rivers total salt load and about nine percent of the boron load. The East Valley Floor Sub-area provides approximately six percent of the SJR salt load and only one percent of the boron load.

The majority of the controllable salt and boron loading to the SJR is generated from non-point sources. The TMDL source analysis indicates that surface agricultural return flows (tailwater) and subsurface agricultural return flows (tile drainage) respectively contribute approximately 26 and 17 percent of the rivers total salt load at the Airport Way Bridge near Vernalis. Groundwater accretions account for approximately 30 percent of the SJR's total salt load with lesser amounts of salts coming from the major tributaries on the east side of the San Joaquin Valley and from managed wetlands. Only about 2 percent of the SJR's salt load comes from municipal and industrial sources (Oppenheimer and Grober, 2002).

In addition to the salts derived from within the SJR watershed, significant quantities of salts are imported to the watershed from the Delta via the Delta-Mendota Canal (DMC). The DMC is a major agricultural water supply conveyance that flows from the Tracy Pumping Plant in the South Delta to the Mendota Pool. San Joaquin Valley irrigators receive deliveries directly from turnouts along the DMC and from the Mendota Pool. The imported DMC salt load is delivered to water users in their supply water. These water users are widely distributed over the west side of SJR basin; imported DMC salt is discharged into the river in return flows from these west side water users. Salt contributions from the DMC were equivalent to approximately 47 percent of the total salt load discharged from the SJR at the Airport Way Bridge near Vernalis between water years 1977 and 1997 (Ibid.).

Implementation: Regulatory Context

The salt and boron TMDL will set load allocations (limits) necessary to meet existing WQOs for the SJR at the Airport Bridge near Vernalis. USEPA regulations do not require TMDLs to include implementation plans, however, the Regional Board must incorporate the TMDL into the basin plan, in part, because the TMDL *"supplements, interprets or refines an existing water quality objective"* (written com. Atwater, 1999). California Water Code Section 13242 requires the Regional Board to adopt a program of implementation for achieving WQOs as part of a basin plan amendment. The Salt and Boron TMDL Basin Plan Amendment will satisfy the requirements of both the Federal Clean Water Act and the California Water Code by incorporating elements of the Technical Salt and Boron TMDL into the basin plan and include a program of implementation to ensure that the TMDL results in achieving existing WQOs. The program of implementation will describe the actions and policies that the Regional Board will use to implement the TMDL, including prohibitions of discharge, waste discharge requirements (WDRs), and waivers of WDRs.

As mentioned above, point sources of salt and boron make up a relatively small portion of the total loading to the river. Accordingly, the program of implementation for this TMDL will focus on non-point sources of pollution while TMDL waste load allocations for point source discharges will likely be implemented through the Regional Board's existing National Pollutant Discharge Elimination System (NPDES) program. The Regional Board will seek compliance with the TMDL load allocations at the sub-area level by using regulatory and non-regulatory mechanisms to achieve load reductions. It is anticipated that the Regional Board's conditional waiver of waste discharge requirements for discharges from irrigated lands (waiver) will be integrated with the TMDL salinity control program. The waiver, which was adopted by the Regional Board in December 2002, establishes two categories of waivers of waste discharge requirements.

One category applies to dischargers who participate in a group effort on a watershed level to comply with the conditions of the waiver. The other category applies to individual dischargers who do not participate in a group watershed or sub-watershed effort.

Regardless of which category a discharger falls under, the following requirements must be met:

(3) Discharges shall not cause or contribute to conditions of pollution or nuisance as defined in Section 13050 of the California Water Code; and

(4) Discharges shall not cause or contribute to exceedances of any Regional, State, or Federal numeric or narrative water quality standard. (CRWQCB, 2002)

Dischargers are considered in compliance with the waiver if they meet specific conditions which include requirements for monitoring to assess the sources and impacts of waste discharges, prioritization of pollutant sources, and implementation of management practices to prevent the release of wastes to surface waters. The waiver also includes time schedules for completion of key milestones and submittal of deliverables.

Implementation: Physical Context

There is no single set of implementation practices that can be prescribed to ensure that the WQOs for salt and boron will be met. From a physical standpoint, salt and boron water quality improvement in the SJR can be achieved through one or more of the following methods:

1) <u>Increasing the assimilative capacity of the SJR by providing more dilution flow:</u>

Authority over water rights in California rests with the State Water Resources Control Board (SWRCB). The Regional Board does not have the authority to require increased flows in the SJR to address the salinity problem. The SWRCB's Water Rights decision 1641, however, requires the U.S. Bureau of Reclamation (USBR) to release water to the SJR for the purpose of meeting the Vernalis salinity objective. The Regional Board will continue to work with the SWRCB to ensure that future water rights decisions in the SJR watershed do not exacerbate the salt and boron problem. It may recommend, to the SWCRB, actions to mitigate for the USBR's responsibility for SJR salt loads.

2) <u>Reducing salt and boron loads being imported to the SJR watershed in supply water:</u>

The salt and boron TMDL provides incentives for reducing salt and boron loads imported to the SJR watershed in supply water by placing load allocations on water suppliers. The TMDL allows water suppliers to provide dilution flows or mitigation elsewhere in the basin to offset the impacts of salt imports since the degree to which water suppliers can reduce salt concentrations in supply water is questionable due to ambient conditions at the Delta pumps and the operational constraints of the state and federal water projects. For example, the USBR could receive load allocation credit for the additional assimilative capacity that is created from water that they release to meet the Vernalis WQO.

3) Reducing salt and boron loading from point and non-point sources:

It is anticipated that any required reductions in loading to the SJR will be achieved through water district or regional scale implementation of management practices. Salinity management practices must be site-specific because the salt generating capacity and drainage needs vary throughout the SJR watershed due to differences in soils, supply water quality, and drainage and irrigation technology. The Regional Board cannot specify the method of compliance for achieving effluent limits. Individual dischargers or groups of dischargers will therefore need to determine the implementation practices that are most suitable for their own needs. Technical groups for the San Joaquin Valley Drainage Program, CALFED and other efforts investigating the salinity problem have identified a number of practices that may be effective in reducing salt levels in the river (CRWQCB, 2000). These practices include:

- Water conservation
- Tailwater/tilewater recovery
- Sequential reuse and volume reduction
- Integrated on farm drainage management
- Evaporation ponds
- Water treatment
- Land retirement

4) Increasing the amount of salt exported from the SJR watershed, including re-operation of drainage (real-time management):

The salt and boron TMDL includes base load allocations that limit the mass of salt and boron that can be discharged to the SJR to ensure that the water quality objectives are met. To be conservative and to minimize the number of water quality exceedances, these design flows are based on the critical low flow that is expected to occur during a given month and water-year type. The base load allocation represents an expected worst-case, minimum load allocation for which dischargers must have the ability to comply. Most of the time, however, the actual flow in the river will be greater than the design flow because the design flow is based on critical conditions.

This TMDL recognizes the need to export salts out of the basin and maintain a salt balance by providing opportunities to use real-time load allocations in lieu of the fixed base load allocations. The concept of real-time management is straightforward: salts are retained by discharges during times when no loading capacity is available; salts are then discharged during higher flow periods when loading capacity is typically available. Previous studies indicate that water quality in the SJR could be significantly improved through re-operation of tile drainage (Grober, 1997). The real-time load allocations are based on real-time flow and water quality conditions and on a weekly or monthly forecast of assimilative capacity. The real-time load allocations would supercede the base allocations whenever the real-time load allocations are greater than the base load allocations.

Implementation of a real-time management program will require a coordinated effort among the dischargers in the watershed. Point and non-point source dischargers will need to develop and maintain the necessary operational and facilities infrastructure to provide accurate forecasts of assimilative capacity and to manage discharges in response to real-time conditions. Development of a proven real-time management framework is a prerequisite for use of the “additional real-time load”.

Summary

The Regional Board is in the process of developing a basin plan amendment to implement a TMDL for salt and boron in the lower SJR. Salt and boron impairment in the SJR is caused by a number of factors including reduced river flow, salt imports to the watershed, and discharges from point and non-point sources of pollution. Effective implementation must address each factor that contributes to water quality degradation. The Regional Board's authority does not extend into the area of water rights, which govern river flow, but the SWRCB has already taken a proactive approach in addressing a portion of the salinity problem through the water rights process. The Regional Board will need to continue to work with the SWRCB to ensure salinity issues are considered in future water rights decisions. The salt and boron TMDL has been designed to place responsibility for salt and boron loading to the river on both dischargers and water suppliers. Additionally, the TMDL has been designed to provide the maximum flexibility to dischargers and water suppliers through the incorporation of real-time load allocations.

References

Attwater, W.R., March 1999, State Water Resources Control Board Memorandum, written communication.

California Regional Water Quality Control Board, Central Valley Region (CRWQCB). 2000. *Basin Plan Amendment for Salt and Boron,* Central Valley Regional Water Quality Control Board Draft Staff Report. Central Valley Regional Water Quality Control Board main website (www.swrcb.ca.gov/rwqcb5), direct link (www.swrcb.ca.gov/rwqcb5/programs/salt_boron/documents.html): Accessed 12/16/2002.

California Regional Water Quality Control Board, Central Valley Region (CRWQCB). 2002. *Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands*. Resolution No. R5-2002-0201. Sacramento, CA.

Grober, L.F. 1997. *SJRIO Wetland Discharge and Tile Drainage Reoperation Studies*, October, 1997, California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA.

Oppenheimer, E. I, Grober, L.F. 2002. *Total Maximum Daily Load for Salinity and Boron in the Lower San Joaquin River*, January 2002, California Regional Water Quality Control Board, Central Valley Region. Sacramento, CA.

U.S. Environmental Protection Agency (U.S. EPA). 1999. *Protocol for Developing Nutrient TMDLs*. EPA 841-B-99-007. Office of Water (4503F), United States Environmental Protection Agency, Washington D.C.

The San Joaquin River Dissolved Oxygen TMDL – Source analysis & IMPLEMentation plan development

Mark Gowdy, Water Resources Control Engineer
Central Valley Regional Water Quality Control Board
3443 Routier Rd., Sacramento, CA 95827
tel.: 916-255-6317; e-mail: gowdym@rb5s.swrcb.ca.gov

Introduction
The San Joaquin River experiences regular violations of the Central Valley Regional Water Quality Control Board (Regional Board) water quality objective for dissolved oxygen in the Stockton Deep Water Ship Channel (DWSC) just west of downtown Stockton, CA. The impairment is caused by a number of key factors, including loadings of oxygen demanding substances from upstream, altered channel geometry of the DWSC and upstream exports and diversions that reduce flow through the DWSC. An overview of our understanding of the causes of this low dissolved oxygen impairment is followed by a discussion of the need for further study in the watershed upstream of the DWSC. Further study is required before a comprehensive implementation plan to correct the impairment can be developed.

DWSC Dissolved Oxygen Impairment
The San Joaquin River has been dredged by the U.S. Army Corps of Engineers to a depth of 35 ft. to allow for the navigation of ocean going cargo vessels between San Francisco Bay and the Port of Stockton in Stockton, CA. The San Joaquin River, just upstream of where it enters the DWSC at Channel Point near Stockton, CA (see Figure 1), is naturally about 10 ft. deep. The entire length of the DWSC is within the tidal prism and experiences regular flow reversals. As described below, violations of the water quality objectives for dissolved oxygen in the DWSC occur regularly between Channel Point and Disappointment Slough 14 miles downstream.

The regulatory document that defines the beneficial uses and water quality objectives applicable to the San Joaquin River Basin is *The Water Quality Control Plan for the Sacramento River Basin and the San Joaquin River Basin, Fourth Edition* (Basin Plan). The Basin Plan water quality objectives applicable to the impaired portion of the DWSC require that the minimum dissolved oxygen concentration not be less than 5.0 mg/l, nor less than 6.0 mg/l between Channel Point and Turner Cut from September 1 through November 30 each year. These objectives are intended to protect warm freshwater fish species (striped bass, sturgeon, and shad) habitat, migration and spawning and to protect cold freshwater fish species (salmon and steelhead) habitat and migration.

Hourly average dissolved oxygen concentrations have been compiled by the California Department of Water Resources (DWR) since 1983 from a continuous dissolved oxygen meter installed at the northern end of Rough & Ready Island (see Figure 1). Table 1 demonstrates that the frequency of violations of the 5.0 mg/l objective measured at this DWR monitoring station, on the average, since 1983 are highest during the months of June through October. Oxygen concentrations less than 5.0 mg/l, however, have occurred during all months of the year. Also, it can be seen that the frequency of violations are worse in dry years, like 1991 through 1993 and less frequent during wet years like 1998.

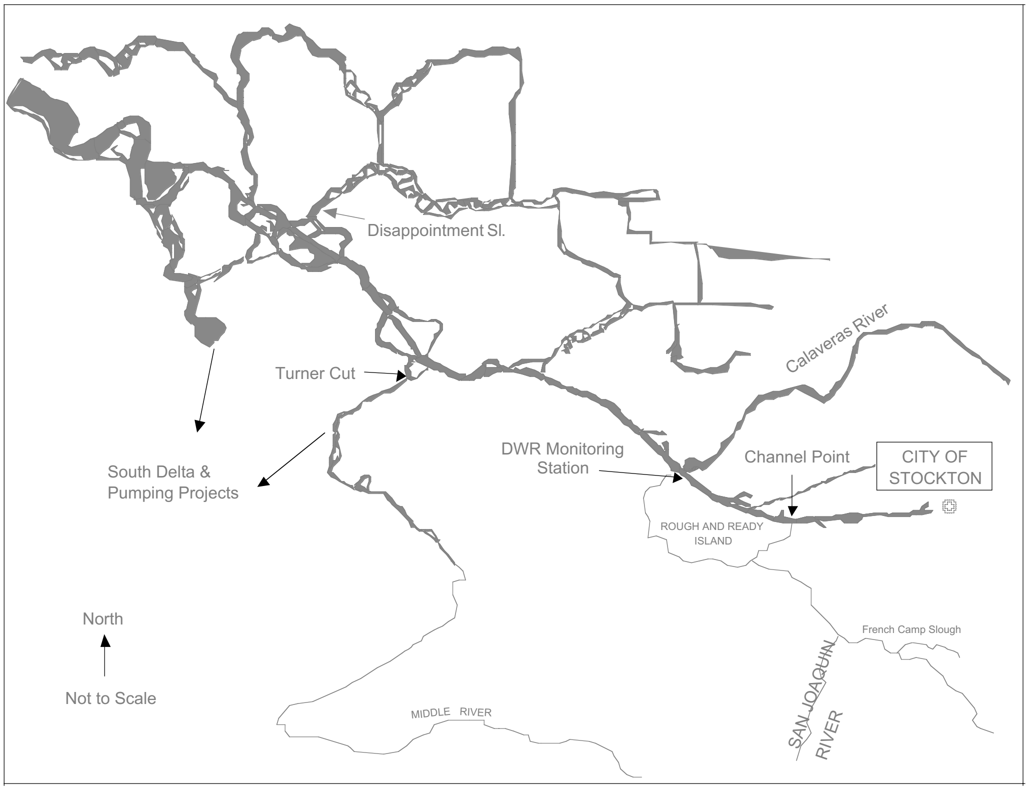


Figure 1 – Map of Stockton Deep Water Ship Channel in vicinity of the dissolved oxygen impairment between Channel Point and Disappointment Slough.

Synoptic dissolved oxygen measurements at 13 locations in the DWSC were also taken by DWR on bimonthly boat cruises between July and December of each year since 1983. These dissolved oxygen measurements followed a typical sag profile with concentrations dropping immediately downstream of Channel Point and then rising again further downstream. The dissolved oxygen minima on this sag profile occurred most frequently at sampling locations nearest the north end of Rough & Ready Island and appear to vary both in location and magnitude as a function of flow. At higher flow rates the dissolved oxygen minima location moved further downstream and decreased in severity. Data indicates that dissolved oxygen concentrations below the water quality objectives were almost non-existent when flows were above 2500 cubic feet per second.

In January 1998, the Regional Board adopted a 303(d) list identifying this dissolved oxygen impairment as a high priority. Low dissolved oxygen concentrations may act as a barrier to upstream spawning migration of Chinook salmon and may stress and kill other resident aquatic organisms. Regional Board staff has committed to submitting a TMDL report to U.S. EPA by June 2003 and preparing a formal TMDL and implementation plan for adoption as a Basin Plan amendment by June 2004. This Basin Plan amendment will require an environmental impact and alternatives analysis that is functionally equivalent to the California Environmental Quality Act (CEQA) process.

Table 1 – Percentage of dissolved oxygen measurements below 5.0 mg/l at the DWR monitoring station (upper number in cell). The lower italicized number represents the minimum dissolved oxygen concentration recorded for that month. A blank cell indicates that all oxygen measurements that month were above 5.0 mg/l and "n/a" indicates the oxygen meter was

inoperative.

	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	Average
January	n/a			29 *4.4*		51 *3.5*								15 *4.1*				4 *4.7*	5 *4.7*	5
February	n/a					52 *3.3*			<1 *4.7*	21 *3.1*		2 *4.8*		n/a				11 *3.9*		6
March	n/a					52 *3.8*	65 *3.7*	1 *4.8*	8 *4.3*	100 *2.1*	25 *3.7*									14
April	n/a	1 *4.4*	6 *4.4*				<1 *4.9*	5 *4.6*	37 *4.4*	60 *1.9*	8 *4.7*	<1 *4.9*								6
May		7 *3.9*		5 *3.1*	44 *3.5*			3 *4.7*	34 *4.2*	29 *3.8*	2 *4.8*						n/a			6
June		84 *3.0*	48 *3.3*		43 *3.6*	3 *4.8*	37 *4.1*	11 *4.5*	1 *4.9*	43 *3.7*	29 *3.6*	61 *4.0*		8 *4.8*	14 *3.6*		<1 *4.9*	11 *2.9*	69 *2.5*	27
July		91 *2.8*	78 *3.5*	21 *4.5*	3 *4.6*		2 *4.8*	<1 *4.8*	5 *4.7*	39 *3.7*	54 *3.7*	80 *3.7*	2 *4.8*	63 *3.4*	74 *3.1*		48 *3.0*	61 *2.9*	75 *2.3*	34
August		62 *4.0*	15 *4.2*	9 *4.8*		10 *4.4*		<1 *4.9*	14 *4.4*	97 *2.8*	87 *2.6*	63 *3.4*	61 *3.0*	94 *2.0*	88 *3.3*		20 *3.1*	28 *2.7*	73 *3.0*	37
September		2 *4.7*			29 *3.9*	62 *2.3*	38 *2.4*		55 *1.8*	100 *0.5*	81 *2.6*	16 *4.3*	6 *4.6*	89 *2.5*	83 *2.4*		43 *1.8*	1 *4.8*	61 *2.9*	36
October							14 *4.2*		99 *0.4*	77 *1.3*	23 *1.6*	46 *3.2*		15 *3.7*	44 *2.2*		100 *1.7*			23
November					<1 *4.9*					6 *4.7*				18 *4.3*	2 *4.7*		93 *3.8*			3
December											1 *4.8*				11 *4.5*		39 *3.8*	12 *4.7*	n/a	4

Causes of Dissolved Oxygen Impairment
A Steering Committee of watershed stakeholders was given the opportunity by the Regional Board to organize funding and performance of scientific studies as needed to assist the Regional Board in developing a load allocation and implementation plan. Beginning in 1999, the group has performed a number of focused studies into the nature and causes of the dissolved oxygen problem in the DWSC. In June 2002 the Technical Advisory Committee, with support from CALFED, conducted a 2-day peer review workshop on the most recent of these studies. The peer-review consisted of 6 nationally recognized academics in algal growth, water quality modeling, and engineering. The peer-reviewers generally concurred with the group's conceptual model of the oxygen demanding mechanisms in the DWSC along with a list of remaining uncertainties and data gaps.

There was general consensus on number of key factors contributing to the low dissolved oxygen impairment in the DWSC as follows:

- Nutrients present upstream of the DWSC in the San Joaquin River watershed contribute, along with other environmental factors, to algal growth in the river as it flows downstream toward the DWSC. Upon arrival in the deeper, slower moving DWSC, the algae generated upstream die and decompose, creating an oxygen demand in the DWSC.
- Ammonia and other oxygen demanding substances discharged from upstream municipal wastewater facilities oxidize in the DWSC and reduce oxygen concentrations.
- The greater depth and volume of the DWSC significantly slows flow and increases the impact of oxygen demanding reactions within it. The geometry of the DWSC also reduces the ability of the DWSC to sustain algae entering from upstream.
- Upstream diversions and routing of flow in the Delta has further reduced and slowed flow within the DWSC, further aggravating the oxygen demanding mechanisms described above.
-

Further Source Control Studies
Although there is general consensus on the causes of the problem within the DWSC, the question

of how to implement a solution is much less clear. One conclusion of the recently completed studies and peer-review was that more data and study is required to understand the mechanisms that contribute to algae growth in the San Joaquin River watershed upstream of the DWSC. A new program of upstream studies are currently being developed by the watershed stakeholders to understand the sources of substances and environmental factors within the watershed contributing to algae growth and to begin investigating if and how nutrient, algal, or other controls in the watershed may be effective in reducing loads of algae into the DWSC. These studies will also include consideration of the redirected effects of such controls on other water quality issues both in the upper watershed and in the estuary downstream of the DWSC.

Due to the size and complexity of this impairment and the need to study potential control measures in greater detail, a phased TMDL implementation approach is being pursued. A phased approach will allow some implementation actions in the DWSC to proceed, based on our current understanding of the problem, while further study of potential upstream control measures can be studied.

Comprehensive Nutrient Management Plan Content and Policy

Robert Fry	Dan Johnson
State Agronomist	State Water Management Engineer
USDA-NRCS	USDA-NRCS
680 N. Campus Dr. Ste. E	430 G St. #4164
Hanford, Ca. 93230	Davis, Ca. 95616
559-584-9209 x 108	530-792-5625
Robert.Fry@ca.usda.gov	Dan.Johnson@ca.usda.gov

Introduction: The "Guide for Preparing a Comprehensive Nutrient Management Plan (CNMP) for Confined Animal Facilities in California" (Technical Guidance) was prepared using these primary considerations:

1. When completed a CNMP will be adequate as a manure management plan for all California regulatory agencies and Natural Resources Conservation Service (NRCS) cost sharing programs
2. It efficiently integrates environmental considerations into the management system of the operation
3. It is based on consensus and knowledge from recognized technical sources in Ca.
4. It contains a process and standards for certifying CNMP providers
5. It is a plan the producer will apply, not a paper work exercise
6. Training for producers and professional service providers will be integrated and consistent statewide
7. It is forward looking not fault finding
8. When legally possible, it will be a private document kept at the facility
9. It is compatible with California Dairy Quality Assurance Program (CDQAP).

To achieve these goals a broad group participated in writing the guidelines for the CNMP. The group consists of representatives from: Western United Dairymen, State Water Resources Control Board, Regional Water Quality Control Boards 5 and 8, Merced County, U. S. Environmental Protection Agency, University of California Cooperative Extension, NRCS, and San Joaquin Valley Unified Air Pollution Control District. Others contributed as well, including private consultants. The next phase will be pilot testing and broad review by producer groups, consultants and others. A revised version of the process will then be prepared.

There are several benefits of preparing and implementing a CNMP. Among them are regulatory compliance, improved manure handling efficiency, eligibility for cost share programs, protection of water quality, reduced commercial fertilizer use, and perhaps improved animal health.

The Technical Guidance will be available on the California NRCS website, or may be requested from NRCS in Davis, California.

Preparing and Implementing the CNMP: The initial CNMP process identifies and logs the long-term goals of the producer regarding manure management and facility improvements. Actions that must be taken for compliance or are desired by the producer are scheduled. Actions that are needed to make incremental progress toward other goals are also scheduled. Decisions can not be hurried, and should not be made until enough information is available. The Producer's perspective may change as the planning and data collection process unfolds. The CNMP is typically revised annually to consider new information, changing conditions, and to prepare a plan for steps to be taken in the coming year. The producer and the planner will probably meet several times to complete the initial plan, and at least annually to prepare revisions until implementation is complete.

A key concept in CNMP preparation is the use of "Stages". Staging verifies the need to phase new manure management practices into the operation over a period of years. This amount of time is needed for several reasons. Before decisions can be made new information must often be gathered. Some management practices require structural improvements to be in place, such as irrigation systems, settling basins, storage ponds, and others. Financial limitations must be considered.

The CNMP Guidance identifies 5 Stages leading to complete implementation of manure management. They are described in the complete Technical Guidance. Below is a brief description of Stages 1 and 5.

"Stage 1" actions for manure management include:

- Stop obvious excessive applications of manure
- Roughly estimate the balance between crop use and nitrogen applied by field
- Reduce applications where clear imbalances are found
- Apply manure evenly to the individual fields
- Apply liquid and solid manure to as many fields as possible
- Apply pre-plant manure as close to planting as possible.
- Assess runoff and erosion from all fields receiving manure
- Begin keeping records of nutrient applications and crop yield
- Begin sampling manure, tissue, water, and soil. Retain and organize test results.
- Prepare a Whole Farm Nitrogen Balance in order to determine if there is enough land available to utilize the manure produced by the herd. If not, plan to restore balance.

Stage 1 actions for facility management focus on identifying and improving conditions of high risk for discharges to surface and groundwater, and include:

- Assess corral drainage and maintenance
- Assess waste storage capacity
- Assess manure collection and treatment system
- Assess silage and feed storage areas
- Assess manure to field distribution system
- Implement improvements for high priority items
- Begin to assess whether facilities will support improved manure management, considering such things as:
  - Irrigation system ability to deliver pond water to enough fields
  - Adequate mixing of fresh water and pond water to assure good distribution
  - Storage capability to hold pond water until crops require fertilization
  - Storage capability to hold pond water and dilution water if needed

Stage 5 includes quantification and timing of all manure applications. Amounts are planned based on historic crop yields, reasonable nutrient use efficiency, and organic nitrogen mineralization characteristics. Rates are reduced based on other known sources of nitrogen such as nitrate in irrigation water or manure applied in previous years. Timing applications will account for plant uptake patterns and factors that affect mineralization, particularly time and temperature. Figure 1 illustrates the type of calculations that would be used to estimate the amount and form of manure to apply. Figure 2 illustrates a simple application plan that considers plant uptake patterns.

Some producers will struggle with this fairly complex process. It is a desirable goal, but with practical limitations for some. Producers implementing Stage 5 will realize the full benefit of manure management and best protect water quality. Producers implementing other stages will also substantially improve management, in most cases.

Producer's Role: Preparation of the CNMP will require active participation of the producer. A consultant cannot independently prepare a viable plan. The producer will be responsible for implementing the plan. It is important that the actions called for are well thought out by the producer. Some decisions involve large investments. All decisions can not be made at the start of the process. The producer will want to consider alternative actions before making decisions. Regulation may establish objectives for the plan, but the producer will usually decide how to meet the objectives.

Certification: Certification is required for persons who prepare CNMP for use in NRCS cost share programs. If those people are private consultants they are referred to as "Technical Service Providers" (TSP) by USDA. There are also state-mandated certification requirements for providers of certain types of plans. Producers want assurance that people hired to prepare a CNMP are qualified to prepare a plan that meets the requirements in the Technical Guidance. Producers may prepare a plan for review of a certified person. Existing professional certification programs, such as CCA, PE, CPAg, etc are useful to establishing foundation knowledge and experience in most cases. Preparing a CNMP requires some specialized knowledge not always required for some professional certification programs. It is the goal of the California CCA Board to establish a formal certification process for manure management.

There are four categories of certification required to complete a CNMP. They are: 1) Conservation Planner, 2) Manure and Wastewater Handling and Storage, 3) Land Treatment, and 4) Nutrient Management. One person may certify in all four categories, but a multidisciplinary team is recommended. Requirements for certification are in Appendix J of the Technical Guidance or at http://www.ca.nrcs.usda.gov/rts/Plan/index.htm.

Integration of physical facilities design and land application: To achieve overall management goals facilities must be designed to support the manure application methods in use. For liquid manure, pond sizing, solids separation, and liquid distribution are the key concerns. Ponds need to be sized to meet two needs. First, storage must be adequate to allow applications to be delayed until there is a crop need for fertilization. This may be a period from last application to the summer crop until the following winter or summer crop requires fertilization. Pre-plant applications, when needed, should occur close to planting and be a reasonable amount compared to crop need. This is a constraint for some. During this period rainfall and manure liquids must be stored. Second, there must be space to allow manure to be diluted in the pond if necessary. Dilution is important to avoid crop damage and to avoid plugging pipelines. For a target application amount the flow rate leaving the lagoon is based on the concentration of the manure and the irrigation time. If the irrigation time is long and the concentration is high the flow rate will be low. This may lead to plugging. This may be avoided by pumping water into the pond to dilute the manure or, when properly managed, higher manure flow rates can be used during only a part of each irrigation set.

A good separation system makes manure management easier. Among other benefits, good separation can reduce the risk of pipeline plugging, reduce the risk of damage to crops receiving liquid manure, and reduce the amount of organic nitrogen deposited near the irrigation valve. A high concentration of organic nitrogen near the valve may lead to high nitrate leaching. The area near the valve is often subject to high water application rates and leaching. Cleaning separation basins is less expensive than cleaning entire storage ponds. Heavy solids in storage ponds reduce storage capacity, and when cleaned out are difficult to properly distribute widely enough to avoid excessive applications to fields receiving the material.

Irrigation systems must be designed to assure liquid manure can be distributed to all necessary cropland, and that the liquid manure is mixed with the irrigation water. Additionally, a method to measure and control flow rates must be built into the liquid manure delivery system. This provides the ability to deliver a desired amount of material to the fields. If irrigation water and manure approach each other from opposite directions in the pipeline mixing will not occur. The result will be poor distribution of manure to the field. High concentrations will occur on parts of the field, and low concentration on others. This result defeats the value of estimating and accurately applying a desired amount of nutrient. Mixing the manure with irrigation water as it leaves the pond, or pumping it to another point where it is mixed may also solve this. A dedicated pipeline may be needed. Other aspects of the irrigation system must also be sound. For example, the slopes and flow rates should be appropriate for the soils on surface irrigated fields. Tailwater systems may be needed to improve water application efficiency and to capture sediment and runoff carrying manure that would otherwise leave the field and enter surface water off site.

Other Considerations: The CNMP is used to document alternative uses for manure, and plans for emergency response, dead animal disposal, and preventative maintenance. Alternative manure uses include shipping offsite, composting, methane generation, etc. These are accounted for in the Whole Farm Nutrient Balance. Some counties may require addressing dust and vector control in the CNMP. Reducing ammonia volatilization may be required in the future.

References: "Guide for Preparing a Comprehensive Nutrient Management Plan (CNMP) for Confined Animal Facilities in California", USDA-NRCS, December 2002

"Using Dairy Lagoon Water Nutrients for Crop Production", Marsha Campbell-Mathews, UCCE, Stanislaus County, Ca

Figure 1 Stage 5 worksheet for estimating application rates

Field or Fields		1,2,3	
Crop		Winter Forage	Silage Corn
Planted land area	acres	210	
Soil Drainage Class	a,b,c,or d	b	
Soil OM <= to 2%?	y or n	y	
Plant Date	Date	1-Nov-02	15-May-03
Planned or actual harvest N removal	lb N/acre	150	250
Planned or actual harvest P removal	lb P_2O_5/acre		
Planned or actual harvest K removal	lb K_2O/acre		
Plant Available Nitrogen (PAN) not applied with manure or fertilizer			
Irrigation water N	lb N/acre	10	35
Legume (alfalfa) N credit	lb N/acre	50	0
Previously applied manure	lb N/acre	15	30
Other	lb N/acre	0	0
N needed from manure and fertilizer	lb N/acre	75	185
Net nutrients to be applied, by source			
Liquid manure	lb N/acre	50	140
Solid manure	lb N/acre	25	20
Fertilizer N	lb N/acre		25
Planned N from manure and fertilizer	lb N/acre	75	185
Planned P from fertilizer	lb P_2O_5/acre		
Planned K from fertilizer	lb K_2O/acre		
Total nutrients to apply, by source, including losses, N based			
Liquid manure total N	lb N/acre	96	256
Solid manure total N	lb N/acre	116	61
Fertilizer N	lb N/acre	0	31
P to be applied, manure + fertilizer	lb P_2O_5/acre	0	0
K to be applied, manure + fertilizer	lb K_2O/acre	0	0
Losses as % of total N for each source			
		Volatilization	Denitrification
	Liquid manure	5%	10%
	Solid manure	0%	Leaching
			10%
% PAN for each source, by crop			
	Liquid Manure, % PAN	52%	55%
	Solid Manure, % PAN	22%	33%
	Fertilizer, % PAN	80%	80%

Figure 2 Stage 5 worksheet for estimating application dates

Field(s)	1,2,3							
Total acres	210							
Crop	Winter Forage				Silage Corn			
Plant date	01-Nov-02				15-May-03			
Total N to Apply lb/ac	75				185			
Liquid Manure N lb/ac	50				140			
Solid Manure N lb/ac	25				20			
Fertilizer N lb/ac	30				25			
Estimated application date	Estimated N uptake lb/ac	Planned Net N lb/ac	Estimated total N lb/ac	Form	Estimated N uptake lb/ac	Planned Net N lb/ac	Estimated total N lb/ac	Form
October			0				0	
		25	116	s			0	
November			0				0	
			0				0	
December			0				0	
			0				0	
January	25		0				0	
			0				0	
February		30	57	l			0	
			0				0	
March		20	38	l			0	
	50		0				0	
April			0				0	
			0				0	
May			0			20	93	s
			0		45	25	31	f
June			0			25	48	l
			0		60	35	67	l
July			0			30	57	l
			0		60	30	57	l
August			0		20	20	38	l
			0				0	
September			0				0	
			0				0	
	Crop Need	Planned Application	Other		Crop Need	Planned Application	Other	
N lb/ac	75	75	75		185	185	65	
Total N Applied lb/ac	150				250			

Merced County Regulations for Dairy Management

Jeff Palsgaard, M.S., Director
Merced County
Division of Environmental Health
777 W. 22nd St.
Merced, CA 95340
Phone (209) 381-1087 FAX (209) 384-1593
E-mail jpalsgaard@co.merced.ca.us

Merced County contains 335 dairies and the milk industry is the largest agricultural commodity totaling $625.7 million dollars in 2001. The total number of dairy animals in Merced County in 2000 was 429,696, with an average milk cowherd size of 608. Beginning in 1998, dairies in the Central Valley began to receive a significant opposition from environmental groups related to the environmental impacts of dairies. The State Attorney Generals Office became involved and many counties, including Merced, were threatened with a lawsuit if the county did not conduct environmental impact reports (EIR) on dairies. In January 2000, the Merced County Board of Supervisors directed the Division of Environmental Health to revise our current Animal Confinement Ordinance and prepare a program EIR on the impacts of animal confinement facilities (primarily dairies) in Merced County.

Merced County Animal Confinement Facility EIR

Merced County began preparing an EIR relating to the impact of dairies in Merced County in January 2000. The first draft of the EIR was released in March 2001 for public review. In May 2001, a number of court rulings in other jurisdictions identified significant issues that required the draft EIR be revised and recirculated. In February 2002 the second draft of the EIR was circulated for public review. Public hearings were held and on October 22, 2002 the Merced County Board of Supervisors certified the EIR as complete and adopted the revisions to the Animal Confinement Ordinance. No legal challenges were filed during the 30-day appeal period.

The EIR identified 14 significant and unavoidable environmental impacts of dairies:

1. Ammonia and hydrogen sulfide emissions from project operations.
2. Greenhouse gas emissions (methane) from project operations.
3. Adverse odor from project operations.
4. Loss and/or degradation of riparian habitat.
5. Groundwater degradations from project operations.
6. Land use conflicts with adjacent rural residences.
7. Cumulative air quality impacts.
8. Cumulative biological resource impacts.
9. Cumulative hydrologic and water quality impacts.
10. Cumulative land use impacts.
11. Cumulative transportation impacts.

12. Fugitive dust emissions from construction activities.
13. Reactive organic gases and nitrogen oxides from dairy operations, farm equipment and increased traffic.
14. PM_{10} emissions from fugitive dust during project operations.

The significant unavoidable impacts were either mitigated or overriding considerations were developed.

The EIR concluded that very little sound scientific data was available on air emissions from dairies. The primary air concerns were PM_{10} (particulates), ammonia and reactive organic gases (ROG).

Merced County Animal Confinement Ordinance

Merced County developed an Animal Confinement Ordinance in 1983 regulating dairies on a complaint basis. Because the ordinance was almost 20 years old and the current environmental controversy of dairies, a revision was prepared working closely with all parties, including the dairy industry.

The major revisions of the ordinance include the following:

1. All facilities must complete a Comprehensive Nutrient Management Plan (CNMP) by December 31, 2006.
2. An annual report must be submitted by all facilities beginning in 2002.
3. A permit is required for the construction of retention ponds or settling basins.
4. A registered civil engineer or engineering geologist must design new retention ponds and settling basins.
5. The minimum liner permeability for separation basins and retention ponds is 1×10^{-6} cm/s.
6. An inspection of the facility must be conducted by the County Department of Environmental Health at least once every 3 years (once every 2 years in sensitive areas).
7. Dead animals must be removed within 72 hours and should be shielded from public view.
8. Groundwater monitoring may be required.
9. New facilities constructed after the effective date the ordinance must reduce total ROG emissions below 10 tons per year and PM_{10} emissions below 15 tons per year by January 1, 2008.
10. Dust control measures shall be maintained on unpaved roads within the dairy facility.
11. Closed facilities must remove all manure with 120 days.
12. Manure and soil must be monitored.
13. Application of manure must be at agronomic rates for crops.
14. New single-family residences shall be prohibited from being constructed within 1,000 ft. of an existing facility (waivers may be issued by the Planning Commission).
15. New facilities shall be located at least 1,000 ft. from existing off-site residences.

The major component of the ordinance is the requirement for a CNMP. The CNMP is a grouping of conservation practices and management activities which, when combined into a system, will ensure that both production and environmental goals are achieved. The CNMP must follow the guidance in the California CNMP, which is being developed by the Natural Resources Conservation Service (NRCS). The document will include an evaluation of the facility to determine how manure is being handled and applied. Areas of improvement will be noted and a schedule for completion of necessary items will be developed. Two staff have been hired for enforcement of the ordinance and assisting dairymen in compliance issues.

The goals and objectives of the EIR and ordinance are to: 1) To increase environmental protection for water, air and sensitive urban and rural land uses, 2) To maintain the continued viability and sustainability of the dairy industry and 3) To develop a program to assure facility compliance.

Other Dairy Related Activities

Merced County has been active in many other areas of dairy management including the following:

1. Merced County currently has a $20 million dollar loan program for dairies to fund improvements that will protect surface water and groundwater. Fifteen (15) million dollars has been loaned to 73 dairies in the last 3 years.
2. The County has obtained a $600,000 grant from the State to study air emission issues and develop mitigation measures, which will begin in February 2003. UC Davis will be conducting the study.
3. The County has obtained a $252,000 grant from the State to field test the California CNMP that has been developed by NRCS. UC Davis will be coordinating the field-testing.
4. Merced County has developed an operational assistance document to help dairymen comply with Local, State and Federal regulations.

Copies of the Merced County Animal Confinement Ordinance and other information can be obtained from the County website located at http://www.co.merced.ca.us.

Constructed Wetlands for Treating Winery Process Wastewater: Applications and Field Results

by

Heather L. Shepherd and Mark E. Grismer

Komex-H_2O Science
Sebastopol, CA 95472
heather@inreach.com

Hydrologic Sciences
UC Davis 95616
megrismer@ucdavis.edu

Introduction

Constructed wetlands (CWs) offer a relatively new approach for the treatment of winery process wastewater. CWs have been investigated extensively for 25-30 years for use in treating municipal wastewater. The rationale for using CWs for treating wastewater is that wetlands are amongst the most biologically active terrestrial ecosystems. Because high biological activity enhances the potential for efficient wastewater treatment*, natural* wetlands may be thought of as natural bioreactors. *Constructed* wetlands are created for a specific purpose, in this case wastewater treatment, and may defined as "designed and human-made complex(es) of saturated substrates, emergent and/or submergent vegetation, animal life and water that simulates natural wetlands for human use and benefits" (Hammer and Bastian, 1989). These design features reduce environmental damage to existing wetlands while allowing for greater system control to achieve effective treatment.

Wastewater is generated during many wine-making operations, mostly having to do with clean-up. During the harvest, when grapes are transported, crushed and pumped, wastewater results from floor, grape-bin and equipment wash-downs. During racking, wine and lees spills are washed down. Barrel washing after bottling also generates a great deal of wastewater. The wastewater produced may be considered "soft" in that it does not contain appreciable difficult or "toxic" constituents. However, while the quality and quantity of wastewater varies considerably throughout the year it generally has a very high BOD (Biochemical Oxygen Demand) and solids content.

The above-mentioned factors give properly designed CWs strong potential for use in treating the high-strength, biodegradable wastewater from the wine industry. Nonetheless, until recently CWs had not been used extensively in the wine industry, and not at all for primary treatment. However, the nature of winery wastewater is such that good treatment can be expected and CWS offer several advantages in treating winery wastewater including; (1) the ability to accept the seasonal wastewater typical of the wine industry, (2) "free" aeration as oxygen transported to the root through the aerenchyma of wetland plants may "leak" to the surrounding substrate, and (3) reduction of odors as the plants reduce circulation of foul odors, especially if subsurface systems are used. They are also, from many perspectives, more aesthetic than other treatment systems.

Pilot studies conducted at UC Davis resulted in effective winery wastewater treatment performance (Shepherd et al, 2001a) and subsequent installation of the first full-scale treatment wetland at a winery in 1998. Since then five additional CWs have been installed for treating wastewater at wineries in California. Preliminary monitoring of these CWs indicates effective treatment in the field, although in most cases the CWs have not reached mature growth (Grismer et al., 2003).

This paper presents an overview of design considerations in developing constructed wetland treatment systems for wineries, followed by a brief summary of field performance data from three participating wineries.

Common Types of Constructed Wetlands

The two dominant type of CWs used for treating wastewater are the free-water surface (FWS) and the sub-surface flow (SSF) wetland. Combination wetlands may also be used for some specific purposes, as well as vertical flow CWs. However, as FWS and the SSF CWs are most prevalent, and most applicable to winery wastewater treatment, the discussion here is limited to these types.

Free Water Surface Constructed Wetlands

In FWS CWs the water surface is exposed to the atmosphere enabling removal of volatile compounds. In these systems the water flows through the stems of the emergent (plant species that grow with their "feet wet" and emerge from the water surface) vegetation rooted in the soil layer. Treatment occurs as the water flows through densely growing stems of emergent plants on which bacteria attach. The CW may or may not be lined with impermeable material. If it is not lined, wastewater treatment and disposal may be achieved via percolation. The water is usually not deep to facilitate diffusion of oxygen into the water, and to discourage the formation of layering across the depth of the water column. Typically water depths range from a few centimeters (inches) to 1.0 meter (3 feet), and are most commonly 0.3m – 0.6m (1ft – 2 ft) deep.

FWS CWs are best suited for secondary treatment of winery wastewater, depending on the choice, efficacy and reliability of primary treatment such as a facultative pond. FWS CWs may also be selected if the operator intends to dispose of the treated wastewater via evaporative means. In addition, FWS CWs provide greater habitat value (due to presence of free water, habitat for invertebrates and other food sources for water fowl and other wetland inhabitants), if that is a consideration in the project.

Sub Surface Flow Constructed Wetlands

In SSF CWs, water remains below the substrate surface. The advantages of SSF CWs include minimizing odors and control of mosquito reproduction. Research has shown that SSF CWs offer more complete and consistent water treatment. Also, because the surface is not inundated with water, repairs and maintenance are more easily conducted.

SSF CWs may be used for primary or secondary treatment of winery wastewater. Use of SSF CWs for primary treatment is recommended only for smaller wineries in which there is a significant amount of time without wastewater generation to allow the CW bed to recover. When the SSF CW is used for primary treatment, pretreatment of the winery wastewater consisting of either settling or screening fine solid material is essential. SSF CWs are typically lined to prevent percolation to the ground water and migration of soil into the substrate. Unlined SSF CWS can be designed for inclusion of percolation disposal when SSF CWs are used for polishing.

The substrate depth is typically 0.3-1.0 m (1-3 ft) and is typically gravel or small rock when used for treating winery wastewater. Polishing SSF CWs may use sand or soil as the substrate.

Typical Applications

CWs may be used as either "primary" treatment following a pretreatment of clarification (settling or screening of solids), or as "secondary or tertiary" treatment following primary treatment. As secondary treatment, the CW may be used for removing the BOD remaining after a treatment pond or "package plant" reactor. As tertiary treatment the primary purpose is nutrient removal. As the nitrogen levels in winery waste are generally low, nutrient removal is not a dominant concern. A final application is the use of a CW for evaporative disposal. This approach may be combined with secondary treatment, or planned as a separate system.

Costs

Costs incurred in the development of a CW system are similar to those incurred by other treatment approaches. Design costs include site analysis, planning and conceptual designs and, usually, some form of construction drawings. Costs for design can range from about $5,000 to about $30,000 (or more), depending on the complexity of the design.

In all cases permitting at the Regional Water Quality Control Board is required, although the required documents vary from one region to another. Many counties also require some form of permitting, usually at least a grading permit and in some cases from other departments. Other agencies such as the Coastal Commission or the Department of Fish and Game may also become involved with permitting. In all cases a CEQA (California Environmental Quality Act) review is required. Costs associated with permitting range from about $5000 to about $20,000 (or more) depending on the complexity of the project, the nature of the site, and the number of agencies involved.

Material costs include any lining material, substrate, conveyances and plants. Costs depend, of course, on the size and application and are therefore provided for comparisons only. Generally, constructed wetlands cost between about $3 and about $8 per square foot to construct, excluding excavation, grubbing and labor. On a per gallon basis, constructed wetlands used for treatment cost from a very low of about $2.50 per gallon of wine to a high of about $12 per gallon of wine.

Other costs to consider include excavation, grubbing if necessary, conveyances (depending on project location), the possibility of pumping and labor.

Considerations

When determining whether a constructed wetland should be part of the treatment system for a winery one should consider the area requirements, desired location, the depth to seasonal ground water at the site and the degree to which the constructed wetland will be "cared for" by winery personnel. Figure 1 illustrates a subsurface flow CW under construction.

The area required for a treatment CW is about 1 to 2 feet of surface per gallon of wine produced. Add to this any need for access and berms (to isolate the CW from run-off). The area required for an evaporative CW depends on the climatic conditions at the site.

The location may be in a visible area as these systems are pleasant in appearance. However, a treatment CW has some associated odors, especially during the peak harvest. Thus the location determination should consider dominant wind direction as well as proximity to the winery. In addition, proximity to creeks or drainages is a concern in that the treatment wetland must usually be located outside the 100-year flood line. Finally, while it is tempting to locate a CW in a low area, a treatment CW must be separated from shallow groundwater to prevent contamination of the groundwater, and to prevent the system from "floating" during the wet season. A tertiary or evaporative CW may, in some cases, be located in a low area or swale.

While the CW is a very robust approach to treating winery wastewater, there are some requirements for care. First, the system should be observed regularly (weekly or daily during harvest, weekly or biweekly, or during use, otherwise) for general plant health, the development of puddles, and the efficacy of the wastewater distribution system. The plants are usually selected based on their ability to tolerate the water flow and quality. None the less, it may happen that a substance toxic to the plants is released. The system should thus be observed for sudden changes in plant color or health. Puddles are readily observed on the surface of subsurface flow CWs. Their presence may indicate flow impedance like clogging, a problem with the outflow system (perhaps the outlet needs to be lowered) or excessive flow from the winery. Finally, if the system is designed to include a distribution of flow at the inlet, it is important that this is maintained. Often a few of the distribution orifices becomes clogged and required a quick clean-out.

Annual maintenance is also required: It is important that the system hydraulics be tested annually for at least the first several years to ensure that the system is operating as designed. This is especially important for subsurface flow systems and should be included in an annual budget.

Figure 1: Newly constructed wetland for primary treatment of winery wastewater

Performance

Seven full-scale subsurface flow CWs have been constructed in California for primary or secondary treatment of winery wastewater. Each system is unique in configuration, maturity and performance. Treatment performance, design configuration and comments for three of the existing full scale SSF CW systems is provided in Table 1.

COD removal: The results of monitoring on three wineries indicate that effective treatment is achieved in each. At Site One the CW provides secondary treatment following a facultative pond and lowers the BOD from about 300 mg/L to 20 mg/L. During the summer months water from the storage pond is recirculated through the CW to filter algae and remove nutrients prior to irrigating the vineyard. When this practice is pursued, the BOD is as low as 5 mg/L at the CW outlet.

The CWs at Sites Two and Three were installed in August of 2001. In the first season of operation, before plants have matured, the CW at Site Three removed 90% of the COD and while that at Site Two removed 97% of the COD. It is anticipated that the removal efficacies will increase as the plants mature in the next year.

***TDS problems*:** In two cases, TDS increased as treatment proceeded. This is largely due to the concentrating effects of evapotranspiration on the water, and little can be done other than source TDS reduction or reverse osmosis to lower the TDS if this is a concern. The data from Site One, however, indicates that the use of recirculation may help to reduce TDS presumably via removal of the nitrogen-containing portion of the TDS that is supplied to the plants when they are in need of nutrients for growth. Further study is required to verify this as a regular mechanism for TDS reduction. Additional studies on salt uptake using halophytic plants are underway at a fourth site.

Other constituents have also been monitored. In all cases pH is neutralized. The dissolved oxygen (DO) is generally low, but not zero at the outlet (the average for all systems is 1.7 mg/L DO). Settleable solids are in all cases removed and total nitrogen, relatively low to begin with in winery wastewater, is also removed, although the removal efficacy is quite variable and dependent on temperature and season with more removal in the late spring and summer growing seasons.

Conclusions:

CWs have been shown to achieve significant removal of COD and other constituents of winery wastewater. TDS generally increases through treatment, but may be managed through re-circulation. Increased concern regarding the influence of land application of treated winery wastewater on groundwater quality may lead to an increased need to manage TDS, and experimentation with re-circulating the wastewater has commenced.

Although options and choices exist for the design of CWs for treating winery wastewater, extreme care is required when the system is constructed to ensure that the design specifications are followed. Failure to follow the design may result in complete failure of the CW. None the less, when properly designed and constructed, constructed wetlands provide an effective approach to the treatment of winery wastewater.

Winery	Crush Tonnage	Dimensions (m)	Pretreatment	Influent COD (mg/L)	Effluent COD (mg/L)	Influent TDS (mg/L)	Effluent TDS (mg/L)	Comments
Site One	1200	37 x 7.5 1 m deep	Rotary screen filtration and facultative pond	580	53	330	235	Secondary treatment CW primary treatment in facultative pond
Imagery	2000	54 x 7.5 1 m deep	Rotary Screen Filtration and facultative pond	NA	NA	NA	NA	CW designed for "show". WQ not monitored.
Site Two	300	16.5 x 3.6	Rotary Screen Filtration	4500	120	615	858	2 -step feed. Slope 0.5%. Carefully constructed. 11-day retention
Site Three	375	24.2 x 10.6 1 m deep	Septic tank	12067	1246	830	960	1-step, with second step to be added. Carefully constructed 13 day retention

Table 1: Water quality summary for three existing CWs for treating winery wastewater in California

References

Crites, R. and G. Tchobanoglous. 1998. *Small and Decentralized Wastewater Management Systems*, McGraw-Hill Book Company, New York, NY.

Grismer M. E., M. Tausendschoen and H. L. Shepherd. 2001. Subsurface Flow Hydraulic Characteristics of a Constructed Wetland for Treatment of Winery Effluent. Water Env. Research 73(4):466-477.

Grismer M.E., Ross, C.C., Valentine, G.E., Smith, B.M. and Walsh, J.L. 2001. Literature Review: Food Processing and Fermentation Industry. Water Env. Research. CD-ROM.

Grismer M. E., M. A. Carr and H. L. Shepherd. 2003. Evaluation of Constructed Wetland Performance for Winery Wastewater. Water Env. Research. In-press.

Grismer, M.E., M.A. Carr and H.L. Shepherd. 1999. Literature Review: Fermentation Industry. Water Env. Research. 71(4):805-811.

Grismer, M. E. and H.L. Shepherd. 1998. Literature Review: Fermentation Industry. Water Env. Res. 70(4):637-642.

Bastian, R.K. and D.A. Hammer. 1993. The Use of Constructed Wetlands for Wastewater Treatment and Recycling. Chapt. 5, pp. 59-68 in G.A. Moshiri (Ed.), *Constructed Wetlands for Waste Quality Improvement*. Boca Raton, FL. Lewis Publishers

Proceedings from the 2nd International Specialized Conference on Winery Wastewaters; Bordeaux, France. May 5-7, 1998. Cemagref-DICOVA.

Shepherd H. L., M. E. Grismer and G. Tchobanoglous. 2001a. Treatment of High-Strength Winery Wastewater using a Subsurface Flow Constructed Wetland. Water Env. Research 73(4):394-403.

Shepherd, H.L., G. Tchobanoglous and M.E. Grismer. 2001b. Time-Dependent Retardation Model for COD Removal in a Subsurface Flow Constructed Wetland for Winery Wastewater Treatment. Water Env. Research 73(5):567-606.

USEPA, 1988. Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. U.S. Environmental Protection Agency Design Manual EPA/625/1-88/022.

AGRICULTURAL USE OF SPENT PROCESS WATER

Nat B. Dellavalle
Dellavalle Laboratory, Inc.
www.dellavallelab.com
ndellavalle@dellavallelab.com

Water is used to process fruit and vegetables from apples to zucchinis. Water is used to move tomatoes from trucks through flumes to processing equipment. All sorts of fruit and vegetables and the equipment used to process them must be washed. Wine and brandy making equipment also needs to be washed.

Spent wash and process water must be discharged somewhere. Residues from distillation, and other processes as well as potassium stripped from grape juice or wine may be discharged along with the spent process water. Municipal sewage treatment plants process, treat and discharge water. Dairies discharge manure water. All of these spent process waters have one thing in common. Federal and state laws and regulations define them as “wastewaters.”

Waste is defined as useless, without value, to be discarded. A business rewarded with profit or punished severally with bankruptcy is inclined to discard “waste” at the lowest possible cost. Clearly too much water in the wrong place at the wrong time can pose problems. The same applies to any constituent in water. Most of us recognize that unmanaged “waste” disposal has lead to problems. The problems in turn have led to state and federal regulations. But are these spent process waters without value? A name other than wastewater is in order. The term, “waste” implies lack of value, something to be discarded at the least cost. When we call something waste we tend to treat it as though it has no value. The name of something with value should reflect something more than “waste." Thus I use the term “spent process water.”

Spent process water contains constituents that are agricultural inputs, hardly without value. First and foremost is water itself. Farmers pay dearly for this critical agricultural input. Even the same State that regulates “waste” mandates more efficient use of water. Most effluents contain valuable nitrogen. Application of that nitrogen along with spent process water can eliminate nutrient application cost adding more value. Other plant nutrients may be included adding more value. Effluents contain organic matter, an important soil amendment. More value. Farmers spend money adding organic matter to their soil. Worldwide, public policy is to sequester carbon in soils.

Steps in utilizing food processing, municipal and dairy effluents for agricultural use include: taking inventory, writing a crop plan with nutrient, water and organic matter budgets and following a monitoring program. The most important and critical step is *management*. Spent process waters should be managed with the same intensity used to manage a food processing facility, dairy or municipal water treatment plant.

Before evaluating properties unique to an individual spent process water, consider the standard agricultural water properties: salinity (EC), calcium, magnesium, sodium (SAR) chloride, boron, carbonate, bicarbonate, and nitrate. Consideration for most will be no different than with any other irrigation water. Properties unique to individual effluents include volume, organic matter, total nitrogen, ammonic nitrogen, acidity, salt, and potassium. Each requires management to prevent the nuisances and environmental impacts subject to regulation.

Water volume is an irrigation management factor. Limiting applied water to crop requirements will minimize leaching of soluble constituents to underlying ground water. The fraction of the crop requirement met by spent process water can be manipulated to regulate the application rate of an individual constituent.

Five day Biological Oxygen Demand (BOD_5) is used to estimate easily decomposable organic material. Organic mater decomposition consumes oxygen. Where oxygen is depleted anaerobic conditions result. Under anaerobic conditions decomposition of organic matter produces malodorous volatile products that are regulated as a public nuisance. Anaerobic soil conditions deny plant roots needed oxygen and can result in plant damage including death. Limiting application rates to the capacity of the soil system to supply oxygen, incorporation into soil and allowing time for aerobic decomposition to occur can avoid undesirable results. Waste Discharge Requirements issued by Regional Water Quality Control Boards limit BOD_5 application.

Organic nitrogen, ammonic and nitrate nitrogen are common constituents of spent process waters. Organic and ammonic nitrogen can be metabolized to form nitrate. However, nitrogen in excess of plant requirements can be leached in to ground water where it is a public health concern. Nitrogen in effluent can be managed just like nitrogen in fertilizer by applying only the amount that will be utilized by crop plants.

Acidity is a concern because heavy metals are soluble in acidic solutions and heavy metals are regulated in drinking water supplies. Application of acidic effluent to the soil surface does not automatically impact ground water. Soil solution acidity in the short run will be influenced more by soil properties than by irrigation or effluent properties. Soil properties and their management are important considerations. Acidity in most food processing effluent results from organic acids that decompose in soil reducing effective acidity. Soil acidification occurs under many farming systems, so monitoring soil pH and periodic lime applications are required to maintain agronomic productivity. At the same time heavy metal leaching will be limited.

Salinity is estimated using Electrical Conductivity (EC_e) , Total Dissolved Solids (TDS) or Inorganic Dissolved Solids (IDS). Unlike natural waters, spent processing water can contain organic dissolved solids like sugar that contribute to TDS but not salinity, thus the use of IDS. Management of effluent salinity may differ from management of irrigation water salinity in that effluent can contain salts not present in irrigation waters. Many spent food-processing waters contain potassium salts. Potassium contributes to EC, impacts soil much like sodium but unlike sodium is a plant nutrient.

Table 1 is an example of an inventory of constituents in spent processing water from a fruit dry yard. It also contains other information needed for management. The dry yard processes and packs dried tree fruit. Effluent is applied to one acre of turf and a cropped area consisting of about 3.3 acres. Turf and barley will be used to recover the nutrients. The size is hardly economic, but it does utilize the effluent and prevent ground water degradation. The inventory consists of daily discharge rates, operating days per month and effluent characteristics, reference evapotranspiration and useful rainfall. Useful rainfall is estimated using a method from the California Department of Water Resources to estimate that fraction of rainfall available for crop use. Average seasonal effluent characteristic values are used here but specific values for each month could be used where appropriate. Effluent characteristics presented are limited to BOD_5 and total nitrogen. Other characteristics could be included.

Table 2 is the first estimate of loading balances for effluent volume, BOD_5, and total nitrogen on one acre of turf. Effluent applied based on the crop water requirement results in excessive BOD_5 and nitrogen loading. The Central Valley Regional Board is currently limiting BOD_5 loading to 600 pounds per acre per day. Note the column headed "Effluent Balance." This is effluent discharged but not applied to the turf area that is available for another cropped area.

A second estimate presented in Table 3 is based on application to meet crop nitrogen need. BOD_5 is now much less than 600 pounds per acre per day, nitrogen loading is much more reasonable and substantially more effluent is available for a second cropped area.

Table 4 presents application of effluent remaining from Table 3 to a 3.3-acre parcel that is to be used for barley. Nitrogen applied may be a little high and BOD_5 exceeds 600 pounds per acre per day. A third estimated that considers application of more effluent to the turf area is in order. Additional effluent would exceed the monthly nitrogen requirement. However, as long as the total amount of applied water does not exceed the crop water requirement, no leaching would occur. Nitrogen applied in addition to monthly needs could be utilized during subsequent months when only irrigation water is used to meet crop need. No more examples are presented but the process is illustrated.

Monitoring would include measuring applied water, testing applied water for constituents of concern, weighing the crop harvested and calculating a ratio between applied and harvested nutrients. The Regional Board may require monitoring soil and ground water characteristics over time.

The most important and critical step is *management*. Spent process waters should be managed with the same intensity used to manage the food processing facility, dairy or municipal water treatment plant. Without uniform application and attention to balancing applications to crop requirements, problems will result. With sufficient management water quality objectives can be met. In many situations much of the cost of managing spent process water can be recovered by capturing the value of plant nutrients, organic matter and water.

Table 1. DRY YARD INVANTORY

WATER, NITROGEN & BOD BUDGETS USING TURF, BARLELY AND SUDANGRASS

Senario Turf and Barley - Sudan grass
Application to turf based on turf water requirements.

Month	Average Discharge [1/] gal/day	Days per Month [2/]	Average Rainfall Historical [3/] in/month	Useful [4/] in/month	ET Grass [5/] in/month	ET-Barley & Sudan [5/] in/month	BOD Ave. Test [6/] mg/L	TN Ave. Test [6/] mg/L
January			2.10	1.43	0.96	0.99		
February			2.30	1.62	1.71	1.85		
March			1.90	0.52	2.94	4.00		
April			0.80	0.00	4.70	4.19		
May			0.40	0.00	6.53	4.92		
June	12,000	22	0.10	0.00	7.33	8.50	12,600	140
July	12,000	23	0.00	0.00	7.65	9.19	12,600	140
August	12,000	20	0.00	0.00	6.77	7.35	12,600	140
September			0.10	0.00	5.13	2.57		
October			0.50	0.00	3.46	0.00		
November			1.00	0.40	1.63	0.00		
December			2.10	1.43	0.92	0.00		
Total/Ave.	12,000	65	11.30	5.41	49.73	43.56	12,600	140

1/ Estimated average effluent discharge: 12,000 gpd.
2/ Operating days per month.
3/ Average rainfall for Tulare County, CA (Source: NCDC Cooperative stations between 1931 and 1995.
4/ Effective Rainfall = Usable rainfall calculated using DWR estimation method.
5/ DWR data
6/ Average values obtained from July-August 2002 reports.
7/ Effluent discharged = (average daily discharge)(operating days per month)
8/ Acre-inches applied = (gallons applied)/(27,154).
9/ Inches applied = (acre inches)/(acres).
10/ Crop need = (crop ET)/(irrigation efficiency)
11/ Effluent applied = the lessor of crop need or effluent discharged less effective rainfall.
12/ Irrigation water applied in addition to effluent to meet crop need.
13/ Effluent balance = (effluent discharged or available) - (effluent applied)
14/ BOD Loading = (effluent applied)(BOD test)(0.226)
15/ BOD lbs/ac/day Loading = (BOD applied per month)/(acres)(calander days per month)
16/ Nitrogen Loading = (effluent applied)(N test)(0.226)(50% denitrification)
17/ BOD lbs/ac Loading = (N applied per month)/(acres)
18/ Efflluent available is based on effluent balance from the first field irrigated.

Table 2 DRY YARD WATER. BOD AND NITROGEN BALANCES

First field irrigated **Application to meet water requirements for turf.**

Turf			
Sprinkler Irrigation Efficiency	80%	1	acres

Month	Effluent Discharged [7]			Crop Need [10]	Effluent Applied [11]	Water Applied [12]	Effluent Balance [13]	BOD Loading		Nitrogen Loading	
	gal	ac-in [8]	in [9]	in	in	in	in	lbs/mo [14]	lbs/ac/day [15]	lbs/mo [16]	lbs/ac [17]
January				1.20		1.20					
February				2.14		2.41					
March				3.68		3.68					
April				5.88		5.88					
May				8.16		8.16					
June	264,000	9.72	9.72	9.16	9.16	0.00	0.56	26,084	**869**	171	**171**
July	276,000	10.16	10.16	9.56	9.56	0.00	0.16	27,223	**878**	179	**179**
August	240,000	8.84	8.84	8.46	8.46	0.00	1.26	24,091	**777**	158	**158**
September				6.41		6.41					
October				4.33		4.33					
November				2.04		2.04					
December				1.15		1.15		0			
Total / Ave	**780,000**	**28.72**	**28.72**	**62.17**	**27.18**	**35.26**	**1.98**	**77,398**	**841 Ave.**	**508**	**508**

Table 3. DRY YARD WATER. BOD AND NITROGEN BALANCES

First field irrigated **Application to meet NITROGEN requirements for turf.**

Turf			
Sprinkler Irrigation Efficiency	80%	1	acres

Month	Effluent Discharged [7]			Crop Need [10]	Effluent Applied [11]	Water Applied [12]	Effluent Balance [13]	BOD Loading		Nitrogen Loading	
	gal	ac-in [8]	in [9]	in	in	in	in	lbs/mo [14]	lbs/ac/day [15]	lbs/mo [16]	lbs/ac [17]
January				1.20		1.20					
February				2.14		2.41					
March				3.68		3.68					
April				5.88		5.88					
May				8.16		8.16					
June	264,000	9.72	9.72	9.16	1.40	0.00	8.83	3,976	**128**	26	**26**
July	276,000	10.16	10.16	9.56	1.40	0.00	8.77	3,976	**128**	26	**26**
August	240,000	8.84	8.84	8.46	1.40	0.00	7.44	3,976	**128**	26	**26**
September				6.41		6.41					
October				4.33		4.33					
November				2.04		2.04					
December				1.15		1.15		0			
Total / Ave	**780,000**	**28.72**	**28.72**	**62.17**	**4.20**	**35.26**	**25.04**	**11,928**	**128 Ave.**	**78**	**78**

Table 4. DRY YARD WATER. BOD AND NITROGEN BALANCES

Second field irrigated **Application of remaining water to bare dry land for Barley**

Second field irrigated

Barley - Sudan grass
Furrow Irrigation Efficiency 68% 3.3 acres

Month	Effluent Available [18] gal	ac-in [8]	in [9]	Crop Need [10] in	Effluent Applied [11] in	Water Applied [12] in	Effluent Balance [13] in	BOD Loading lbs/mo [14]	lbs/ac/day [15]	Nitrogen Loading lbs/mo [16]	lbs/ac [17]
January				0.99							
February				1.85							
March				4.00		4.00					
April				4.19		4.19					
May						0.00					
June	746,076	8.33	2.52		2.52		0.00	23,707	**765**	132	**40**
July	785,676	8.77	2.66		2.66		0.00	24,967	**805**	277	**84**
August	666,876	7.44	2.26		2.26		0.00	21,192	**706**	235	**71**
September											
October											
November											
December								0			
Total / Ave	**2,198,628**	**24.54**	**7.44**	**11.03**	**7.44**	**8.19**	**0.00**	**69,866**	**759 Ave.**	**644**	**195**

Air Quality Challenges for California Agriculture - Present and Future

Matthew D. Summers, P.E.
California Department of Food and Agriculture

The agricultural sector has come under increasing scrutiny for its contribution to air pollution. As cities continue to sprawl into the rural landscape, the pressure increases on all industries to reduce air emissions. However, agricultural sources of air pollution are quite different than typical urban and industrial sources; they are area based, seasonal, diffuse, fugitive, and driven by biological processes and nature's calendar. Emissions estimates for agricultural sources are not well quantified and subject to a high degree of uncertainty. Innovative researchers are needed to better quantify the impact of agricultural activities on regional air quality and identify practical technological reductions. Growers, scientists, and engineers need to come together to characterize the problems and find viable solutions that preserve our air quality and agricultural open space.

Present air quality challenges that are particularly acute in the San Joaquin Valley and the Los Angeles Basin include the non-attainment of Ozone and Particulate Matter National Ambient Air Quality Standards (NAAQS). Ozone is the major component of photochemical smog that causes breathing problems, lung deformation and asthma. It also impacts plant growth and reduces productivity for many of the crops grown in California. Excessive ambient particulate matter causes breathing problems for those with lung ailments. Particles smaller than 10 microns (PM10) can be deposited deep within lungs and some types are carcinogenic. The NAAQS are minimum standards that are set by the United States Environmental Protection Agency to protect human health and regional air quality planning centers around achieving these standards.

The ingredients for production of ozone include oxides of nitrogen (NOx), ozone reactive organic gasses (ROG, sometimes called volatile organic compounds or VOC), and solar radiation (making ozone a summer-time problem). The majority of NOx is produced as a byproduct of fuel combustion. Agricultural sources would include diesel engines, boilers and waste burning. Opportunities to address these sources include the use of alternative fuels like biodiesel, finding markets for waste biomass, replacement of older engines and boilers, or the introduction of novel, low cost control systems. ROGs come from combustion, industrial solvents, biological sources and agricultural sources include the same combustion sources that form NOx, decomposition of plant and animal waste, and agricultural chemical formulations. Opportunities include nutrient management strategies, including stabilization and utilization, and possible reformulation of chemical delivery systems.

Particulate matter can be directly emitted as dust or a combustion product or can be generated by secondary chemical reactions. Fugitive dust is generally a late summer/fall issue for California agriculture when conditions are dry and harvest and tillage operations are in full operation. Opportunities exist for innovations in the stabilization of unpaved roads and modified practices or equipment for harvest and tillage. Particulate matter from combustion has the same opportunities for reductions as NOx and ROG. Secondary particulate matter is generated by chemical reactions of NOx, ROG and ammonia. Organic carbon particles can form from NOx and ROG. Ammonium nitrate particles form from NOx and ammonia and can be highly problematic in damp conditions. Agricultural sources of ammonia include animal waste, fertilizer application, and plant decomposition (nitrogen cycle). Opportunities to reduce ammonia emissions include nutrient management strategies, including stabilization and utilization.

Future challenges for regional and global air quality include addressing the accumulation of gasses that contribute to climate change. Emissions of concern that impact agriculture include fossil carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Combustion of fossil fuels and other energy inputs to agriculture generate carbon emissions but agriculture is in the unique position that plants also pull carbon out of the atmosphere. Developing opportunities to capture and sequester this carbon is an area in need of additional innovative research. Generation of energy from this plant stored carbon provides other opportunities to reduce the generation of new fossil based CO_2. Animal production can generate both methane and nitrous oxide emissions from enteric fermentation and manure disposal. Nutrient management strategies or technologies like anaerobic digestion could help to address these emissions.

The challenge to agricultural research community is to help develop a better understanding of emissions from agricultural production and then to identify ways to reduce emissions of concern. The goal is to develop sound practices and technologies that can help improve air quality but do not significantly add to the costs or risks of production. In many instances there may be opportunities to reduce costs or generate new revenue. Farmers, researchers and regulators should cooperate to identify these opportunities and work to implement practices that are protective of our air resources.

Atmospheric Ammonia Profiles Over Various Crops in the San Joaquin Valley

Charles F. Krauter, Dave Goorahoo and Matt Beene
Center for Irrigation Technology, Plant Science Department
College of Agricultural Sciences & Technology
California State University - Fresno

Ammonia in the atmosphere, near the soil surface has been identified as a precursor to a potential air quality problem, $PM_{2.5}$. When NH_3 in the air combines with an oxide of nitrogen or sulfur (NO_x and SO_x), a small particle, classified by the EPA as $PM_{2.5}$, is formed. These particles, along with fine dust, soot and smoke, are currently being evaluated by local, state and federal air quality agencies as a potential health hazard. Agricultural activity has been identified as a major source of ammonia emissions, though a complete inventory of specific agricultural sources is still incomplete in California. The authors have completed a study of ammonia emissions related to fertilizer applications and are currently studying the seasonal effects of various crops on the levels of ammonia in the lower atmosphere.

A variety of crops have been monitored on a regular basis from land preparation through planting, growth, harvest and post-harvest activity. The effect of the particular crop and growth stage on the levels of atmospheric ammonia are currently being evaluated but certain trends have become apparent. There are differences in the ammonia levels due to elevation above the soil or crop surface, temperature, humidity, crop type and stage of growth. There is a strong diurnal difference with most of the ammonia found in the atmosphere during the day. Ammonia samples have also been taken near dairies and over the crops fertilized with dairy lagoon effluent.

PM_{10} Emission Factors for Harvest and Tillage of Row Crops

Teresa Cassel, Krystyna Trzepla-Nabaglo, Robert Flocchini
Crocker Nuclear Lab, U.C. Davis

Introduction

California's San Joaquin Valley is one of the most productive agricultural regions in the United States. In 1997 agriculture contributed $26.8 billion to the state's economy[3]. The United States Environmental Protection Agency has designated the San Joaquin Valley a serious non-attainment area for PM_{10}, particulate matter with an aerodynamic diameter less than 10 micrometers. This means the valley exceeds the National Ambient Air Quality Standards (24-hour average of 150 µg/m3 and annual average of 50 µg/m3) for PM_{10} and required local policy is being drafted in an attempt to meet them. PM_{10} particles bypass the body's defense mechanisms and penetrate into the respiratory system. These particles have been linked to death by cardiac and respiratory disease.

The seasonal variations in measured concentrations and compositions of PM_{10} in the valley are illustrated in Figure 1, obtained from data collected during the 1995 Integrated Monitoring Study[4]. The relatively higher PM_{10} concentration measured in Corcoran in early November is typical of the late fall season when PM_{10} exceedences are most common in the valley (Fig. 1a). Source contribution profiles are based on the ionic and elemental composition of the particulate matter sample collected. The dominance of fugitive dust from mobile and agricultural sources in the fall leads to the hypothesis that agricultural sources may make a significant contribution to the non-attainment status of the SJV. Figure 1b shows a typical winter source contribution profile in which secondary particulate matter dominates and fugitive dust sources are negligible in the rainy season.

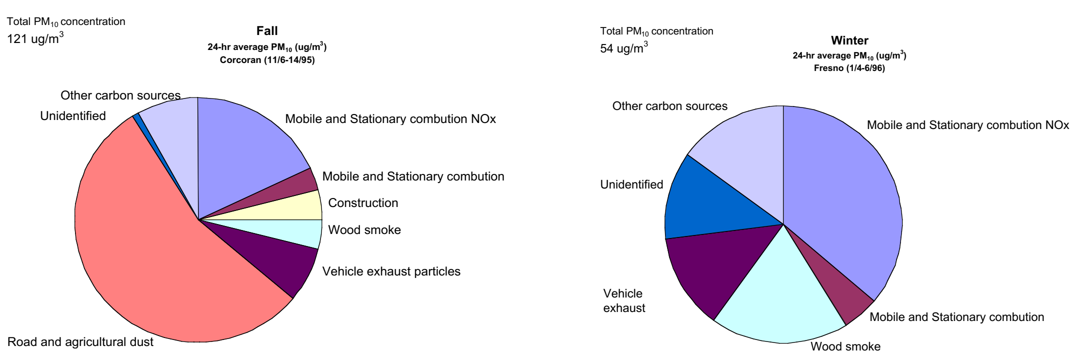


Figure 1: Source contributions to ambient PM10 in the San Joaquin Valley in the fall and winter. From Magliano, et al., 1999.

Emission inventories are compiled by the California Air Resources Board (CARB) to quantify the relative contributions of all possible sources of PM_{10} in a specific region to the annual average PM_{10} concentration in that region. Emission inventories are also used by the Districts, the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) in the case of the valley, to plan for attainment of the air quality standards. The SJVUAPCD is currently preparing a PM_{10} attainment plan, which must include strategies to lower the annual average

[3] Johnston and Carter, 2000-CalAg54;4 16
[4] Magliano, K.L, et al., 1999-AtEnv33:4757-4773.

PM_{10} concentration in the valley by 5% per year. According to the 2001 emission inventory, farming operations are the second most significant source of PM_{10} in the valley (Fig. 2).

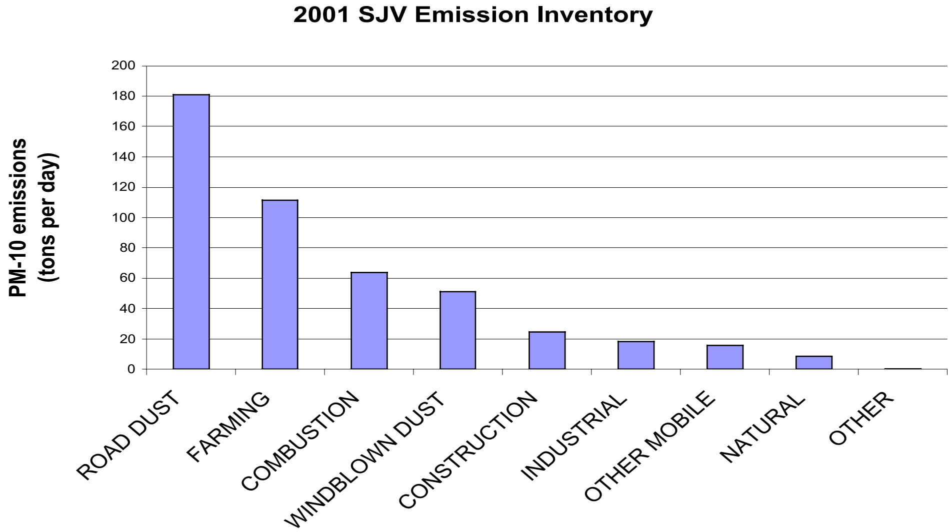


Figure 2: PM_{10} emission inventory for the San Joaquin Valley, 2001. (adopted from download at www.arb.ca.gov)

An accurate PM_{10} emission inventory is critical to the development of an effective PM_{10} attainment plan. Until recently, PM_{10} emissions from all farming operations were estimated using a single emission factor, which was derived from studies of unpaved road emissions.[5] This paper presents measured emission factors for a variety of farming operations. To investigate the applicability of these emission factors to the wide range of farming practices employed in California, specific tillage procedures such as discing, floating, and land planning were compared for different crops. Emission factor response to relative humidity and soil moisture was also investigated to allow for assignment of available emission factors to crops that were not measured based on the seasonal timing of crop harvest.

Methods

All field measurements were made under actual field conditions. While sampling was coordinated with cooperative growers, special treatment of the fields to accommodate PM_{10} sampling was not requested. A combination of upwind/downwind source isolation and vertical profiling methods were used to quantify PM_{10} emission factors, as described in Holmén et al. (2000)[6]. Measurements were made between 1996 and 2000 by comparable methods using one upwind and at least one downwind vertical profile. The lidar (light detection and ranging) instrument was utilized in a majority of field tests from 1997 through 2000 to provide detailed information about plumes generated during these agricultural operations, specifically their heights, shapes and dynamics. Aerosol samples and meteorological data were collected at the heights indicated in Table 1. While PM measurements made at the top of the towers were actually between 8.5 and 10 m above ground level, they are all referred to by the nominal height of 9 m. When possible, two or three towers were used in different locations downwind of the source to better characterize the plume and provide analysis of sampling uncertainty. Soil

[5] U.S.E.P.A., 1995. AP-42.

[6] Holmén et al. At. Env. 35:3251-3277.

samples were collected from the region of the field over which the tractor traveled each time either the operation or the soil conditions changed.

Measured variable	Year	Height (m)
PM_{10} concentration	96-99	1, 3, 9
	2000	1, 3, 5, 9
Air temperature	96-00	0.5, 1, 2, 4, 7.5
Wind direction	1996	2
	97-00	4
Relative humidity	96-00	2
CNL elastic lidar (1064 nm)	97-00	2D vertical scans from ground level to 100 m

Table 1: Description of equipment used to measure PM_{10} emission factors and heights of deployment during research conducted between 1996 and 2000.

PM_{10} emission factors for agricultural operations were quantified on the basis of the area of land worked. Three different methods – the line, block and logarithmic profile models – were used to fit the PM_{10} vertical concentration profiles as described previously[4]. A fourth model, the box model was used to describe the PM_{10} flux in cases of uniform downwind vertical concentration profiles. Measurements of PM_{10} mass concentration above MDL at a minimum of three sampling heights were required for calculation of emission factors. The choice of the appropriate model for each downwind concentration profile type was based on analysis of simultaneous lidar data collected during some of the field tests.

For each model, a horizontal PM_{10} flux was calculated as the product of the net (i.e., downwind – upwind) PM_{10} concentration [mg m^{-3}], *C(h),* and the average horizontal wind speed [m s^{-1}], *U(h)*, at ten equally spaced height intervals [m], *dh*, between z_o and the top of the plume, H. The plume height was defined by the intersection of the downwind profiles with the average upwind concentration. The flux was integrated over the height of the plume using Simpson's Rule, and normalized by the time of the test, *t*, the upwind width of soil worked during the test period, *w*, and the angle between the measured wind direction and the direction perpendicular to the field edge, θ, to compute the PM_{10} emission factor [mg m^{-2}].

$$E = \int_{z_0}^{H} \frac{U(h)C(h)t\cos\theta}{w} dh \qquad \text{Equation 1}$$

Uncertainties in the calculated emission factors were estimated using error propagation techniques[7] for the line, block and logarithmic fit models. The PM_{10} measurement uncertainties and the test period wind speed standard deviation at each measurement height were used to estimate the uncertainty in the horizontal flux at each of the ten model heights.

Results and Discussion

Valid measurements of PM_{10} concentrations and meteorological parameters made between 1996 and 2000 produced 135 calculated emission factors for agricultural operations in row crops in the San Joaquin Valley. Data presented in Table 2 are compiled by commodity for harvest operations only. Emission factors for land preparation operations are more dependent on seasonality and resulting soil moisture than crop specificity, though the timing of some operations is based on the previous crop such that crop and season are not independent variables.

[7] Coleman, H.W., Steele Jr., W.G., 1989. "Experimentation and Uncertainty Analysis for Engineers".

Source	Emission factor (mg/m^2)	Factor Uncertainty (mg/m^2)	Standard deviation (mg/m^2)	Number of tests	Relative Humidity (%)	Soil moisture (%)
Cotton harvest						
picking	107	13	87	3	62	15
stalk cutting	42	7	37	4	57	12
Wheat harvest						
harvest	665	40	441	16	29	3
Tomato harvest						
picking	785	48	195	4	41	9
Land preparation						
Root cutting	24	2	10	4	70	14
Discing	229	15	160	19	57	12
	744	47	522	25	45	4
Land Planing	1466	113	1180	14	38	2
Floating	119	8		1	53	11
	1945	127	1277	16	40	3
Ripping	39	4		1	58	8
	723	45	537	17	36	3
Weeding	124	14	100	11	51	6

Table 2: Average PM_{10} emission factors and emission factor uncertainties for specific agricultural operations. Average soil moisture and relative humidity data show data groupings for seasonal comparison.

One example of seasonal and crop dependent differences in emission factors is the discing operation. Forty four measurements of PM_{10} emission factors were made on fields previously planted to cotton, garbanzos, melons, tomatoes, and wheat. When the fields were disked in November and December, following cotton, soil moisture was significantly higher (13%) than in June through September, following the other crops. One notable exception was when discing followed melons, a crop that adds moisture to the soil, for which average soil moisture was 11%. Grouping the discing emission factors measured under high soil moisture conditions and those with low soil moisture produces the two emission factors presented for discing in Table 2. Figure 3 demonstrates the effect of soil moisture on PM_{10} emission factors for discing by presenting individual test data for comparison of discing following wheat and cotton.

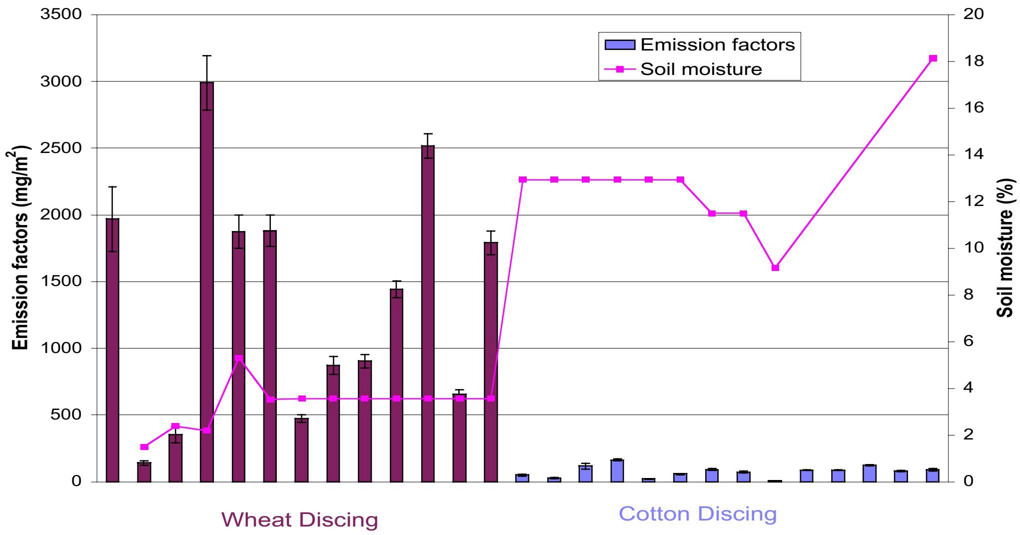
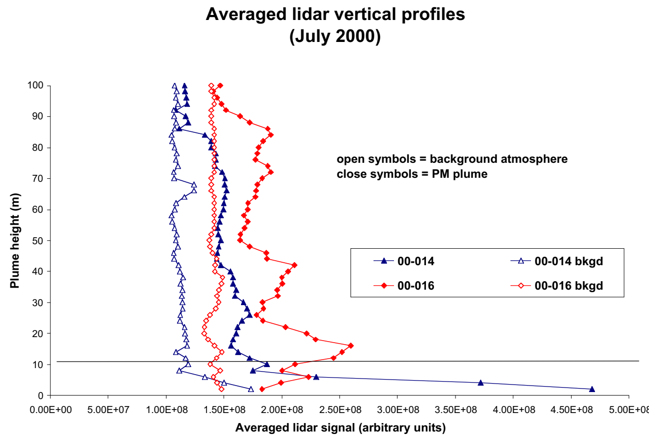


Figure 3: PM_{10} emission factors for discing, and soil moisture, following wheat and cotton. Error bars represent two times the calculated uncertainty for each emission factor.

Two very similar land preparation operations, land planning and floating, had essentially indistinguishable PM_{10} emission factors that appear to be independent of crop, with one interesting exception. In these experiments, land planning was preformed using a steel implement with a single, adjustable bucket and floating was done with a wood framed implement with two or three metal blades that scraped the surface flat. As can been seen in Table 2, floating and land planning conducted under similar conditions of soil moisture yield similar PM_{10} emission factors. This is generally true regardless of the previous crop on the field. The average measured PM_{10} emission factor for land planning following garbanzos was 1704 mg/m^2 (n=7, st. dev. =1042) and following tomatoes was 1229 mg/m^2 (n=7, st. dev. =1318). Similarly, the average measured PM_{10} emission factor for floating following tomatoes was 1704 mg/m^2 (n=1) and following wheat was 1569 mg/m^2 (n=15, st. dev. =1277). The one exception noted in this study was a single measurement of PM_{10} emission factor for floating following melons, when the soil moisture was 11% and the emission factor was only 119 mg/m^2. It seems likely that the high soil moisture in this case accounts for the unusually low emission factor for melons, but additional testing is necessary to demonstrate this effect conclusively.

The measured PM_{10} emission factors presented in Table 2 indicate that the type and timing of agricultural operations determine emissions, as can be demonstrated using lidar data. Figure 4 contains two graphs showing the averaged vertical profiles obtained from 2D vertical scans collected during land preparation in two different seasons. In these profiles, the height of the PM plumes measured downwind of the source can be estimated as the point at which their vertical profiles intersect the vertical profiles of the related background lidar signal, since this is the point at which the signal returns to background. The overall extent of the PM plume is a function of it's height and the magnitude of the difference between signal intensity during measurements of the plume and the background. Such that the area described by the two vertical profiles, intersecting at the top of the plume and with the x-axis as their base represents the flux of PM from the source.



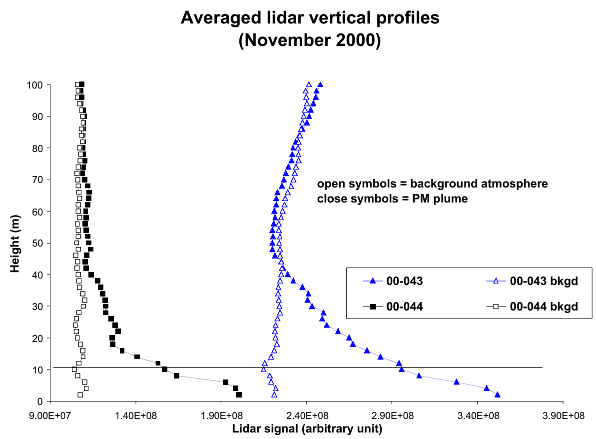


Figure 4. Averaged lidar vertical profiles for land preparation in July and November of 2000. Note, the plumes generated in July reached the heights of over 90 m, while the plumes in November were not higher than 50 m. Data were collected on the same soil (same location) during the same operation (discing). Horizontal lines at 10m represent the highest measurements conducted using PM_{10} samplers.

While PM_{10} emission inventories are not currently temporally resolved (they are computed on an annual basis), a review of the timing of specific operations may indicate the importance of agriculturally derived PM_{10} emissions to regional exceedence of PM_{10} concentration standards. For example, late fall exceedences are not likely due to tomato or wheat harvest operations although they have fairly high emission factors, since they only occur during summer months. Conversely, floating and land planning operations may make substantial contributions to regional non-attainment status as they are generally preformed in the late fall. These observations indicate that revisiting crop calendar development may be beneficial to determine more specifically when the various land preparation operations are conducted following different crops.

Limitations and Benefits of Remote Sensing Technology

John Ojala

USDA-ARS, Western Integrated Cropping Systems Unit
Shafter Research & Extension Center
17053 N. Shafter Ave., Shafter, CA 93263
Tel:661.746.8002; FAX:661.746.1619; Email: jcojala@pw.ars.usda.gov

Abstract

Remote sensing is a promising method to characterize and spatially identify specific field agronomic conditions on a routine basis. Remote images provide extensive information about within-field spatial variability compared to traditional field scouting methods. Remote images are readily modified into field application maps for use in precision crop management and for variable rate application of fertilizer, soil amendment, pesticide, and cultural farming inputs. Several methods are available to unmix spectra and estimate specific crop conditions and soil properties. A brief overview of reflectance properties of plants and soils, ratio methods for unmixing spectral information, and agronomic properties that can be estimated by remote sensing are presented. On-farm trials indicate that remote images can be successfully utilized for precision applications by commercial farm operations. Limitations that hinder adoption of remote images for production agriculture include data availability (processing, timing, delivery), scale, image interpretation, and uncertainty in cost/benefit.

Spectral Response of Plant Leaves and Canopy

Typical leaf spectral curves show low reflectance across the visible region of the spectrum, a small reflectance peak in the visible green, a steep increase in reflectance at the 'red edge', and water absorption bands (1.45, 1.95 and 2.5 _m) in the short-wave infrared region. Leaf pigments, such as chlorophyll, carotenoid and anthocyanin, strongly influence reflectance within the visible band (Bauer, 1985). Reflectance in the NIR is largely influenced by cell size, number of cell layers and leaf anatomy. Thermal bands (8 to 14 _m) are sensitive to leaf temperature, which is related to water loss through transpiration. Stress conditions affect leaf reflectance differently in each of these bands. Under field conditions, factors such as plant geometry, background, and incident light conditions strongly influence spectral reflectance in addition to leaf stress (Myers et al., 1983). Consequently, field measurements of leaf reflectance may not resemble laboratory measurements of similar plant stress conditions.

Vegetation Indices/Nitrogen Stress

Spectral ratios are one method used to unmix spectral data and delineate crop conditions, such as crop nitrogen status, vegetation biomass, crop water stress, crop damage, and soil properties. Vegetation indices were created to represent the type, amount and condition of vegetation in a scene independent of the soil background (Jackson, 1991). The ratio vegetation index (RVI) was the first index to be defined and was originally developed to estimate leaf area index (LAI) of a forest canopy (Jordan, 1969). The RVI is the ratio of near infrared (.800 _m) to red (.675 _m) wavelengths. The normalized difference vegetation index (NDVI) was proposed by Deering (1978) to improve sensitivity within sparse vegetation canopies, but it saturates sooner than RVI at high vegetation densities. Many additional vegetation indices, some interrelated, have been proposed since these early models. Vegetation indices are typically used as general indicators of biomass and plant health and estimate canopy characteristics such as leaf area index, phytomass, green weight, dry weight and percent cover (Jackson, 1984). Reflectance models that are related to biomass should correlate well to the progressive uptake of nitrogen, and other nutrients, during the growing season. Stone (1996) demonstrated this concept by estimating total plant nitrogen using red (.67 _m) and near infrared (.78 _m) spectra, and developed a spectral index that recommended a nitrogen application rate for nitrogen deficient winter wheat. These are similar to Jordan's (1969) bands used to calculate RVI. A good predictor of nitrogen content was found by using a log transform of the inverse reflectance in the short-wave infrared band (Yoder, 1995). He also found that the best predictor of leaf chlorophyll content was reflectance in the visible bands. Raun (2002) calculated a fertilizer response index (RI) from an NDVI ratio of non-nitrogen limiting areas to target strips within the field. The RI was multiplied to a yield index to estimate potential yield from added nitrogen.

Canopy reflectance in the green (.545 _m), red (.660 _m), and near infrared (.800 _m) bands have been correlated to plant nitrogen levels and nitrogen deficits (Fernandez, 1994; Buschmann, 1993). These bands are narrow and may be sensitive to soil reflectance. Blackmer (1994) used green (.550 _m) reflectance for detecting nitrogen deficiency in corn. He also detected late-season nitrogen deficient regions within a field by green (.550 _m) canopy reflectance (Blackmer, 1995). Blackmer (1996) later reported reflectance near .550 _m and .710 _m detected nitrogen deficiency better than when compared to other wavelengths. A ratio of the .550-.600 _m band to the .800-.900 _m band improved detection of nitrogen deficiency compared to other wavelengths for irrigated corn. Chappelle (1992) proposed nitrogen deficiency could be detected earlier in the season by using a ratio of crop reflectance to a field reference, and defining absorption maxima and minima related to nitrogen levels. Field trails with nitrogen deficient corn showed increased reflectance in the red (R) region and decreased reflectance in the near infrared (NIR) region (Walburg, 1982). The amount of nitrogen applied in this trial was directly related to NIR/R radiance ratio. Visible red reflectance increased and near infrared reflectance decreased as nitrogen decreased, similar to studies with sugarcane (Jackson, 1981). In comparison, laboratory studies have shown that mineral nutrient deficiencies increase reflectance in the visible wavelengths, but varied with specific nutrients in the near and middle infrared region of the spectrum (Al-Abbas, 1974).

Plant Water Stress

Current irrigation scheduling techniques rely on measurement of soil moisture or meteorological data to estimate changes in soil water supply or crop water use. These estimates are then used in a water budget approach toward scheduling irrigation. Irrigation scheduling with remote sensing relies on the principle that reflectance from a plant canopy provides information directly related to plant water status, and that this information can be used to determine when a crop needs an irrigation (Clarke, 1997). However, it is recognized that water stress can involve interactions with factors other than soil water availability, such as the presence of specific disease or soil properties that influence soil water availability or supply. Irrigation in these situations by any method may not improve crop response.

Four methods were proposed by Jackson (1986) to measure plant water stress: stress-degree day (SSD), canopy temperature variability (CTV), temperature-stress-day (TSD), and crop water stress index (CWSI). The SSD method measures canopy-air temperature difference near the time of maximum heating (after noon). Jackson (1984) summarized research from several sources that suggest soil water deficits could be detected simply by the increase in variance of canopy temperature within a field. The TSD method is the difference in canopy temperature between a stressed crop and a non-stressed reference crop. Other methods are also being evaluated that could eventually be used for irrigation scheduling. These include using non-linear relationships between vegetation indices, stomatal conductance, photosynthesis, and PAR

(Sellers, 1987 and Verma, 1993). Hyperspectral measurements of crop canopy using a field spectrometer have used the red edge reflectance to detect early water stress in rice (Shibayama, 1993).

Crop water stress index is based on the principle that a well-watered crop transpires more, and therefore has cooler leaves in the canopy, than a crop that is water stressed. Crop water stress index values range from 0 to 1 and are derived from temperature differences between air and surface, vapor pressure deficit and data for a specific crop. Ground-based, remotely sensed thermal data can be used for calculating CWSI, and is the basis for hand-held instrumentation. Airborne remote sensing in thermal bands can detect leaf temperature and relative differences in canopy temperature within a field that are caused by water stress or impaired transpiration, and could be used in calculating CWSI. Remote sensing of crop canopy temperature could detect the extent and severity of drought conditions and irrigation needs (Jackson, 1984). Exposed soil in sparse canopies (early crop development) often provides interfering reflectance and creates error in calculating CWSI. Moran (1994) and Clarke (1997) proposed using a vegetation index along with thermal radiative data to develop an empirical method of estimating water stress when there is low ground cover. Clarke (1987) used this technique with airborne sensors and successfully detected regions within a drip-irrigated muskmelon field that were incorrectly irrigated due to clogged emitters and system water leaks. Thermal sensors in airborne and satellite instruments would be useful tools for estimating CWSI.

Remote sensing can also be utilized to estimate crop coefficients during the growing season. Crop coefficients are the ratio of a specific crop's ET to a reference crop's ET. Bausch (1993) proposed using NDVI to estimate crop ET using local meteorological information. This method offers increased accuracy in ET estimates for specific fields and a means to measure field variability.

Soil Properties

Soil reflectance is strongly influenced by organic materials, soil minerals, physical properties, and moisture content of the soil surface (Myers et al., 1983). Passive visible and near infrared radiation is absorbed or reflected at the soil surface (Liang, 1997). Soil position and geometric properties (aspect, surface roughness, structure), solar illumination properties, and instrument detection geometry appear to be important properties influencing soil surface reflectance, making it difficult to discern inherent soil properties. Absorption bands occur for water absorption (1.4 and 1.9 _m), carbonates (1.9, 2.0, 2.16, 2.35, and 2.55 _m), gypsum (1.8 – 2.5 _m), silicates (1.4, 2.2 _m), and ferric and ferrous iron. (Myers et al., 1983; Baumgardner et al., 1985). Microwave reflectance has been used to detect soil moisture content because of the sensitivity of these bands to dielectric properties of soil and water. Thermally sensitive bands may also be used to estimate surface moisture content and texture. Ground penetrating radar can depict sub-surface boundary layers, such as argillic horizons, and can be sensitive to several meters of soil depth. Soil spectral curves can be difficult to separate from each other, but have been shown to depict soil properties of moisture content, iron oxide and organic matter. Reflectance in the broad visible range (e.g., soil color) is largely influenced by minerals, organic matter, calcareous regions, salinity, moisture, structure and particle size (Myers et al., 1983). Cultural practices used for many agronomic crops produce periods of signal dominance for both soils (early and late-season) and crops (mid-season), interspersed with mixed signals caused by changes in litter, canopy cover, and irrigation during the growing season. These signal dominance periods are common for many cultivated crops. They are opportunities to obtain reflectance spectra from largely unmixed scenes, and therefore to detect inherent soil properties or canopy condition.

Application to Precision Crop Management

Remote images were utilized on a commercial farming operation to identify soil management regions within fields. Images were acquired early spring when soils were bare, dry and contained little surface residues. Regions of calcareous soil that had high spatial variability within fields were categorized into management zones. Fertilizer and soil amendments were variably applied over several years to these areas and cost/returns from each crop were estimated for the soil management units. Yield and return to risk varied between management zones and were used as a basis for making farming input decisions. The risk/benefits of utilizing remote images for precision crop management needs additional research to evaluate short and long-term economic risks and returns for commercial farming operations.

Benefits and Limitations

There are many satellite and airborne remote sensing systems, with a wide array of multispectral and thermal bands, that measure radiant energy reflected by agricultural soils and crops. However, these systems continue to have issues of scale, timing, data processing, image delivery, interpretation, and cost that have delayed widespread adoption for agricultural applications. Ground resolution by all but a few of the satellite images does not match the accuracy of variable rate application equipment that is currently used for precision crop management. Image processing is a complex process that is beyond the technical ability of most agriculturalists. Images often become available late, after crop harvest, making it difficult to use this information for seasonal decisions. Recently, commercial vendors have been helping to overcome these deficiencies by offering high-resolution satellite images, off-nadir scenes, maps that depict specific soil properties or crop conditions, and relatively quick availability. Digital Globe's QuickBird satellite provides 0.6 m ground resolution for panchromatic images, and 2.4 m ground resolution for multispectral images. Space Imaging's Ikonos satellite offer images with 1-meter panchromatic and 4-meter multispectral resolutions. New technologies, methodologies, and research efforts are resolving these issues so that remotely sensed images can be successfully utilized by commercial farming operations.

Farm managers will routinely utilize remote images when they become readily available, reveal field conditions that are useful for making management decisions, provide a return on the risk of investment, and are easily integrated into a precision crop management system. Ultimately, the goals of remote sensing are to dynamically model the complex interactions between electromagnetic energy, soil surfaces and crop canopy, to accurately identify important agronomic conditions, and to use this information to sustain soils, improve management decisions, and enhance crop production.

Literature Cited

Bauer, M.E. 1985. Spectral inputs to crop identification and condition assessment. Proceedings of the IEEE, 73:1071-1085.

Al-Abbas, A.H., R Barr, J.D Hall, F.L. Crane and M.F. Baumgardner. 1974. Spectra of normal and nutrient deficient maize leaves. Agron J. 66:16-20.

Bauer, M.E. 1985. Spectral inputs to crop identification and condition assessment. Proc IEEE 73:1071-1085.

Baumgardner, M.F., L.F Silva, L.L. Biehl, and E.R. Stoner. 1985. Reflectance properties of soils. *Advances in Agronomy,* 38:1-44.

Bausch, W.C. 1993. Soil background effects on reflectance-based crop coefficients for corn. Remote Sens. Env 46:213-222.

Blackmer, T.M. and J.S. Schepers. 1994. Techniques for monitoring crop nitrogen status in corn. Commun Soil Sci Plant Anal.25:1791-1800.

Blackmer, T.M., J.S. Schepers, and G.E. Varvel. 1994. Light reflectance compared with other nitrogen stress measurement in corn leaves. Agron. J. 86: 934-938.

Blackmer, T.M., J. S. Schepers and G.E. Meyer. 1995. Remote sensing to detect nitrogen deficiency in corn. In Proc. Site-Specific Mgmt. For Agric. Sys. 27-30 March 1994, Minneapolis, MN, ASA-CSSA-SSSA, Madison, WI, pp. 505-512.

Buschmann, C. and E. Nagel. 1993. *In vivo* spectroscopy and internal optics of leaves as basis for remote sensing of vegetation. Int. J. Remote Sens. 14:711-722.

Clarke, T.R. 1997. An empirical approach for detecting crop water stress using multispectral airborne sensors. HortTechnology 7(1):9-15.

Fernandez, S., D. Vidal, E. Simon and L. Lole-Sugranes. 1994. Radiometric characteristics of *Triticum aestivum* cv. Astral under water and nitrogen stress. Int. J. Remote Sens 15:1867-1884.

Jackson, R.D., C.A. Jones, G. Uehara and L.T. Santo. 1981. Remote detection of nutrient and water deficiencies in sugarcane under variable cloudiness. Remote Sensing Environ 11:327-331.

Jackson, R.D. 1984. Remote sensing of vegetation characteristics for farm management. SPIE Vo. 475 Remote Sensing:81-96.

Jackson, R.D. 1986. Detection and evaluation of plant stresses for crop management decisions. IEEE Transactions on Geoscience and Remote Sensing GE-24(1):99-106.

Jackson, R.D and R.H. Alfredo. 1991. Interpreting vegetation indices. Preventive Veterinary

Medicine 11:185-200.

Jordan, C.F. 1969. Derivation of leaf area index from quality of light on the forest floor. Ecology 50:663-666.

Liang, S. 1997. An investigation of remotely sensed soil depth in the optical region, Int. Journal of Remote Sensing 18(16): 3395-3408.

Moran, M. S. 1994. Irrigation management in Arizona using satellites and airplanes. Irrig. Sci 15: 35-44.

Moran, M.S., Y. Inoue and E.M. Barnes. 1997. Opportunities and limitations for Image-Based Remote Sensing in Precision Crop Management. Remote Sens. Environ. 61:319-346.

Myers, V.I., M.E. Bauer, H.W. Gausman, W.G. Hart, J.L. Heiman, R.B. MacDonald, A.B. Park, R.A. Ryerson, T.J. Schmugge, and F.C. Westin. 1983. Remote sensing applications in agriculture, Manual of Remote Sensing, 2nd edition, (R.N. Colwell, editor), American Society of Photogrammetry and Remote Sensing, Falls Church, Virginia. pp. 2111-2228.

Raun, W.R., J.B. Solie, G.V. Johnson, M.L. Stone, R.W. Mullen, K.W. Freeman, W.E. Thomason, and E.V. Lukina. 2002. Improving nitrogen use efficiency in cereal grain production with optical sensing and variable rate application. Agron. J. 94:815-820.

Sellers, P.J. 1987. Canopy reflectance, photosynthesis and transpiration. II. The role of biophysics in the linearity of their interdependence. Remote Sens. Environ. 21:143-183.

Shibayama, M., W. Takahashi, S. Morinaga, and T. Akiyama. 1993. Canopy water deficit detection in paddy rice using a high resolution field spectrometer. Remote Sens. Environ. 45: 117-126.

Stone, M.L., J.B. Solie, W.R. Raun, R.W. Whitney, S.L. Taylor and J.D. Ranger, 1996. Use of spectral radiance for correcting in-season fertilizer nitrogen deficiencies in winter wheat. Trans. ASAE 39:1623-1631.

Verma, S.B., P.J. Sellers, C.L Walthall, F.G. Hall, J. Kim and S.J. Goetz. 1983. Photosynthesis and stomatal conductance related to reflectance on the canopy scale. Remote Sens. Environ. 44:103-116.

Walburg, G., M.E. Bauer, C.S. Daughtry and T.L. Housley. 1982. Effects of nitrogen nutrition on the growth, yield and reflectance characteristics of corn canopies. Agron. J. 74:677-683.

Yoder, B.J. and R.E. Pettigrew-Crosby. 1995. Predicting nitrogen and chlorophyll content and concentrations from reflectance spectra (400-2500 nm) at leaf and canopy scales. Remote Sens. Environ 53:199-211.

Aerial Imagery that Links Soil Variability to Poor Crop Performance

Richard E. Plant[1] and Daniel S. Munk[2]

Departments of Agronomy and Range Science and Biological and Agricultural Engineering
University of California
Davis, CA 95616
[2]University of California Cooperative Extension
Fresno, CA 93702

Introduction

Remotely sensed reflectance data, obtained either by satellite or aircraft, can provide at relatively low cost a set of detailed, spatially distributed data on plant growth and development. Such data may form a useful component of site-specific crop management programs (Moran et al., 1997, Plant et al.,2000). Crop canopy reflectance in the red and near infrared regions of the electromagnetic spectrum provides a means of estimating the photosynthetic status of the crop. Remotely sensed electromagnetic reflectance data are generally expressed in the form of vegetation indices, which are algebraic combinations of the measured canopy reflectances of different wavelength bands. One of the most commonly used vegetation indices is the normalized difference vegetation index, or NDVI (Tucker, 1979).

A number of comparative studies of vegetation indices as indicators of crop health and yield have been conducted (Tucker, 1979, Wiegand et al, 1991). Researchers have found a relationship between vegetation index values summed over a season and yield. Denison et al. (1996) found a significant correlation between seasonally integrated NDVI and corn yield. Wiegand et al. (1991) found a direct relationship between the summation over the season of PVI values and yield in salt-affected irrigated cotton in Texas. Emitted electromagnetic radiation has been frequently used to detect water stress, both using a hand-held infrared gun and using aerial imagery. Idso et al. (1982) developed the concept of the crop water stress index based on infrared thermometry.

The demonstrated relationship between vegetation index measures and crop condition indicates that remote sensing may provide useful information for crop management. In order for remote sensing data to be of direct, practical use in tactical management, however, it is necessary to establish a relationship between remotely sensed data and measures of crop status recorded directly on the ground. One method of measuring crop status in cotton production is by plant mapping. A number of relationships between plant map data and crop status have been established. These are discussed by Kerby and Hake (1996). Two of the most important late season management decisions in California cotton production are the timing of the final irrigation and the timing and amount of chemical defoliation (Kerby and Hake, 1996). The recommended management decision making process for each of these involves the use of plant mapping data (Hake et al., 1996). Determining the appropriate time of the final irrigation makes use of an index called *nodes above white flower*, or NAWF. The recommended means of determining the date of defoliant application uses an index called *nodes above cracked boll*, or NACB.

A major problem in California is the gradual accumulation of soil salinity. Approximately 4.5 million acres of irrigated cropland in California, primarily on the west side of the San Joaquin Valley, are affected by saline soils or irrigation water. Much of this land is used in cotton production, in part because of cotton's relatively high salt tolerance. Cotton is relatively sensitive to salinity at emergence due to effects on the soil structure, but is less sensitive once the plant is established (Hake et al, 1996). The tendency of saline and sodic conditions to occur in patches makes soil reclamation and ideal practice on which to apply site-specific management. In this paper we review the relationship between NDVI and water stress, nitrogen stress, plant map indices, and soil electrical conductivity based on experiments conducted in commercial cotton fields in California. The objective is to provide practical information that can be used to aid in the incorporation of remote sensing into a crop management program.

Effect of crop stress on NDVI

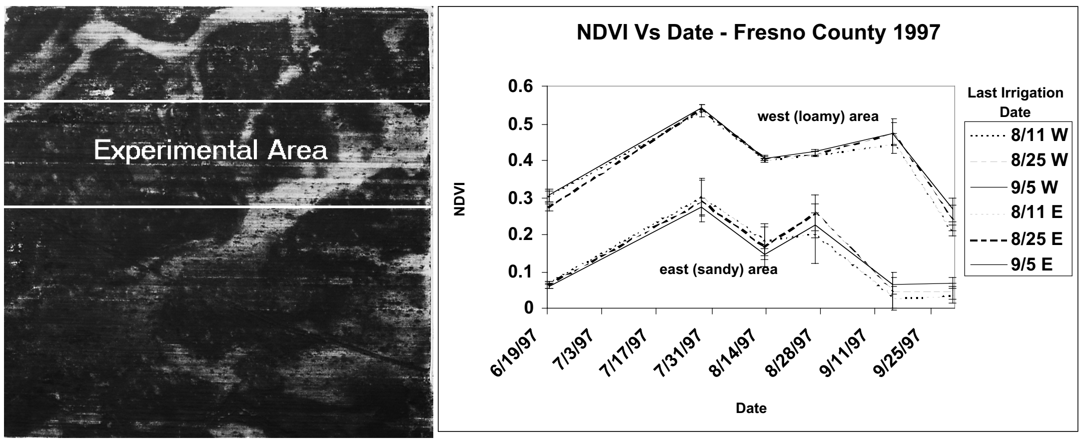
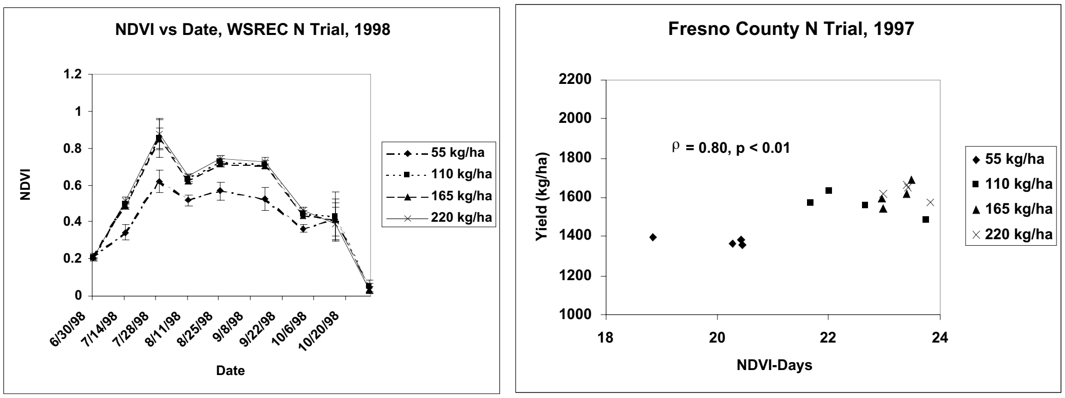


Fig. 1 (a) Gray scale image of the commercial field in Fresno County in which the 1997 irrigation stress experiment was conducted. The location of the experimental plots is indicated. The light areas indicate sandy soil. (b) NDVI for loamy and sandy soils.

Water Stress. An irrigation experiment was conducted in a commercial field in 1997. The field, which was located in Fresno County, had very heterogeneous soil properties. Fig. 1 shows a gray scale image of a false color infrared aerial photograph of this field taken on August 26, 1997. The field soil type was predominantly Traver sandy loam with two large sandy streaks, appearing as the lighter regions in Fig. 1. The sandy soils are classed as Hesperia sandy loam. As the figure shows, a portion of each experimental plot was located in a sandy streak on the east side of the plots. Fig 2 shows plots of mean NDVI vs. date for the loamy and sandy areas of the experiment. Two properties are evident from a comparison of NDVI values from the two soil textures on the same dates. The first and most obvious is that the NDVI in the sandier area was considerably less than that in the loamy area. The second is that the end-of-season decline in NDVI occurred earlier in the sandy area than it did in the loamy area. Both of these phenomena may be attributed to the reduced water holding capacity of the sandy soil on the east side of the plots, although other differences in soil properties may play a role as well.

Nitrogen Stress. Experiments were carried out in 1997 and 1998 to measure the relationship between NDVI and nitrogen stress in cotton. NDVI-days had a low response to the 55 kg ha^{-1} treatment that was not matched by yield. Plants in the 55 kg ha^{-1} plots were visually observed to be stunted. Fig. 2a Shows NDVI vs. date for the 1998 WSREC experimental site, which is typical of those in which a significant difference in NDVI-days exists. Mean NDVI in response to the lower treatment level is reduced during all of the growing season except at the end of the season. Fig. 2b shows a scatter plot of lint yield vs. NDVI-days for the 1997 Fresno County site, the only one which had a significant yield difference attributable to nitrogen level.



(a) (b)

Fig. 2 (a)Mean NDVI vs. date for the 1998 WSREC nitrogen rate experiment. Error bars indicate 95% confidence intervals. (b) Scatter plots of plot lint yield vs. NDVI-days for the Fresno site.

Relationship between NDVI and Plant Map Indices

Nodes Above White Flower. Plant et al (2000) found a relatively weak positive correlation between NDVI-days and NAWF in which the variability was sufficiently great that the relationship is not statistically significant.
Nodes Above Cracked Boll. Nodes above cracked boll data were recorded in five fields. In every case but one there was a strong correlation, as measured by the coefficient of determination, between NACB and NDVI.

Relationship between NDVI and Soil Salinity

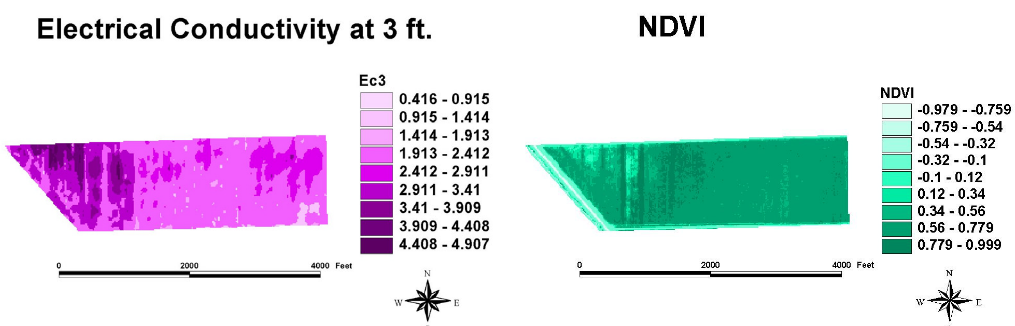


Figure 3. Maps of bulk soil electrical conductivity at 3 feet and NDVI for a cotton field.
Figure 3 shows the relationship between bulk soil electrcial conductivity and NDVI in a salt-affected field in Fresno County. The precision of measurement of the NDVI is apparent in the clear visibility of drain tiles.

Discussion

Yield had a significant, consistent relation with NDVI-days in each of the experiments in which there were significant variations in yield that were consistent with the order of both the irrigation and nitrogen treatment levels. Thus, to the extent that crop yield is consistent with vegetative biomass (i.e., that harvest index is constant) the relation between yield and NDVI-days is consistent with theory. Factors such as pest consumption that reduce reproductive growth but not vegetative growth would reduce the harvest index and therefore distort the yield - NDVI-days relationship. Therefore, NDVI-days may be better considered as a measure of spatial variability in yield potential, that is, of the yield capable of being produced by the vegetative canopy.

Based on results of Plant et al. (2000) it appears that in the case of water stress significant NDVI effects appear approximately coincidentally with the stress effects themselves. There are several reasons why NDVI might be dependent on water stress. These include effects on leaf optical properties, canopy structure (e.g. due to wilting), reduction in LAI, and so forth. It is also possible that the wetness of the soil has an influence, although the impact of soil reflectance is reduced by the closed canopy in most of these trials. It must also be emphasized that the effect of water stress on NDVI may be primarily an effect of cumulative water stress rather than instantaneous stress. Thus, remotely sensed reflectance data may be of more use in strategic design of irrigation systems to achieve uniform crop moisture level than in day-to-day irrigation scheduling.

The early decline of NDVI in the sandy soil portion of the 1997 Fresno County irrigation experiment (Fig. 1) is consistent with the interpretation that NDVI declines more rapidly in sandy soil due to earlier senescence of the crop, which is in turn due to the reduced water holding capacity of the soil. The data are also consistent with the interpretation that the difference is due to differences in soil color, possibly associated with moisture differences.

In the nitrogen field experiments lint yield correlated with NDVI only in those cases in which a significant nitrogen effect was present. Indeed, two of the fields in 1998 showed significant NDVI effects in response to the lowest treatment level, but yield did not show a corresponding difference. Visual inspection of the fields indicated that the 55 kg ha^{-1} treatments were often stunted in appearance but that yield did not differ significantly in many of these sites. It appears that at least in the case of nitrogen deficiency NDVI may be prone to give false positive indications of potential yield loss. It should also be noted that the 1998 growing season was very short, which may have contributed to a reduced N response. In this sense the information may be regarded as a conservative early-warning indicator of potential problems. The timing of nitrogen stress is more difficult to measure than water stress. In those cases in which a significant NDVI difference was observed, this difference was present throughout the season except at the very end.

Where salinity is a problem, NDVI reflects very precisely the spatial extent of yield loss to salinity. This is likely due to the tendency of salinity stress to reduce emergence and vegetative development of the cotton plant.

Of the two late season plant mapping indices tested, NDVI was correlated but not strongly so with nodes above white flower (NAWF) and it was highly correlated in most cases with nodes above cracked boll (NACB). In all tests but one the coefficient of determination was at least 0.65. The NDVI values used in this test are the plot mean values, and therefore the correlation with plant mapping indices may be even greater on a location by location basis. The positive correlation indicates that the spatial distribution of late-season NDVI may be used to determine a directed sampling scheme for plant mapping indices, which may then be used to develop a spatial map of crop maturity. This can be used to more precisely schedule late season irrigation and defoliation.

Acknowledgement

This research was supported by Cotton Incorporated and the California State Support Program. We are grateful to Bruce Roberts, Brock Taylor, John Wroble, and Julie Young for their assistance with the project

References

Denison, R. F., R. O. Miller, D. Bryant, A. Abshahi, and W. E. Wildman. 1996. Image processing extracts more information from color infrared aerial photographs. *California Agriculture*, 50(3): 9-13.

Hake, S. J., T. A. Kerby, and K. D. Hake. 1996. *Cotton Production Manual*. Oakland, CA: Division of Agriculture and Natural Resources, University of California.

Idso, S. B., R. D. Jackson, P. J. Pinter Jr., R. J. Reginato, and J. L. Hatfield. 1982. Normalizing the stress degree-day parameter for environmental variability. *Agricultural Meteorology*, 27: 59-70.

Kerby, T. A., and K. Hake. 1996. Monitoring cotton's growth. in Hake, S. J., Kerby, T. A., and Hake, K. D., Editors. *Cotton Production, Publication 3352* pp. 335-355. Oakland, CA: Division of Agriculture and Natural Resources, University of California .

Moran, M. S., Y. Inoue, and E. M. Barnes. 1997. Opportunities and limitations for image-based remote sensing in precision crop management. *Remote Sensing of Environment*, 61: 319-346.

Plant, R. E., D. S. Munk, B. R. Roberts, R. L. Vargas, D. W. Rains, R. L. Travis, and R. B. Hutmacher. 2000. Relationships between remotely sensed reflectance data and cotton growth and yield. Transactions of the ASAE 43: 535-546.

Tucker, C. J. 1979. Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8: 127-150.

Wiegand, C. L., A. J. Richardson, D. E. Escobar, and A. H. Gerbermann. 1991. Vegetation indices in crop assessments. *Remote Sensing of Environment*, 35: 105-119.

Using Aerial Images to Make Precision Applications of Soil Amendments

James R. Gregory
Verdegaal Brothers, Inc.
13555 S. 11th Ave.
Hanford, California 93230
Telephone 559-582-8104, Fax 559-582-4274
E-mail: jgregory@verdegaalbrothers.com

Western soils have a lot of variability. Under certain conditions, soil amendments can be beneficial and are applied to improve the soil, improve leaching, and improve crop production. The decision to apply soil amendments can accurately be made through taking soil tests and interpreting the analysis.

Soil amendments, for the purpose of this presentation, are: gypsum, limestone, dolomite, sulfur, and sulfuric acid.

Recently, the application of soil amendments to agricultural fields with the aid of global position system (GPS) technology has been done. This new application technology is becoming increasingly accepted by growers and applicators for doing site-specific precision applications.

Parallel Swathing

Historically, the setting up of an open field for an application has been done manually by the applicator. The applicator first drives across the ends and perhaps the middle of the field at a right angle to the direction which the applicator would apply the material and drag a rope, to mark the placing of paper bags, which were placed at distances equal to the swath width of the application. When doing this, the placing of the paper bags would have to start on the same side of the field, so the rows of paper bags would be in line with each other. White paper bags are preferred, because white is relatively easy to see. This method of parallel swathing is rapidly becoming obsolete.

GPS equipment for parallel swathing is mounted in the cab of the applicator, and the receiver is mounted on the roof. A subscription to a GPS signal is necessary, where parallel swathing is done. There is an annual fee to be able to receive the GPS signal for parallel swathing.
The advantages include:

- The applicator saves time by not having to take the time to bag the field
- The pickup or service vehicle is not subject to dusty conditions of driving through the field to place the paper bags
- Greater accuracy

Parallel swathing is not required for orchard or vineyard applications.

Precision Placement

Historically, precision placement of soil amendments in selected areas has been subjective. Typically, the applicator applied soil amendments to areas within a field where the soil is a lighter color. Another indicator is where the crop has reduced growth. When the driver arrives in the area to be treated, the spray boom or spinner is turned on and the soil amendment is applied as the targeted area is traversed. Another method of identifying a specific area is for the grower to circle the designated areas with a disk, such as after harvesting a field. An area in an orchard vineyard can be identified by placing flagging tape on branches in the field, outlining the area to be treated.

Within the past year, there have been significant advances in precision placement of soil amendments. This technology is more time intensive in the planning of an application.

There are several software installations required in the Compaq iPAQ:

- GPS acquisition software
- A mapping program
- ActiveSync®, a Microsoft software, which synchronizes the desktop with the iPAQ

The process takes the following steps:

1. The first step is for the infrared images of the specific field to be ordered. A decision needs to be made of whether to obtain an aerial image or a satellite image.

   a. Smaller fields will require airplane images. Airplane images provide images of two meters per pixel accuracy. One firm flies the San Joaquin Valley from Highway 152 to Mettler several times a year. The images of the field can be ordered from these archives. Another company will photograph specific fields upon request.

      Airplane images require ground referencing. A consultant with a GPS mounted in a vehicle needs to make at least six GPS fixes near the field.

   b. Lansat satellite images have an accuracy of twenty to thirty meters per pixel. Digital Globe's QuickBird satellite can provide images from .61 meters to 2.44 meters per pixel accuracy, depending on the angle of the image when taken. Spot satellites (owned by the French) have 5 meters to 20 meters per pixel.

      Ground referencing is not required for satellite images.

      In both cases, the image is stored in a data file in a desktop computer. The infrared image is available to be examined.

2. A meeting with the grower is held, showing the image. Another option is that the image can be e-mailed to the grower. The grower then makes a determination that the image is an accurate depiction of the situation in the field. The management zones should represent based on the grower's knowledge of the field, the different zones in the field.

3. One of the maps generated has specific sites, which are numbered at random throughout the image of the field. These numbered locations can be referenced by latitude and longitude. The consultant or grower chooses which numbered sites to obtain soil samples.

4. Soil tests are taken from each of the zones. A hand held GPS is required by the sampler so that the samples can be taken from the specific sites identified. The same management zone can be found in several locations within a single field. Generally, one representative soil test is taken per management zone. However, more soil samples can be taken, if desired.

5. An additional meeting between the grower and consultant is required when the results of the soil test are received. The analysis will show how the management zones are different from each other. The soil tests results will give guidelines to which soil amendments are appropriate to apply and at what rates.

6. A decision is made of what soil amendment to apply, at what rate or rates, and in which specific management zones.

7. The field map is transferred from the desktop computer to the Compaq iPAQ. The different management zones that will be treated are color coded on the screen, for easier identification by the driver.

   Each management zone is identified by the acres contained in the zone. This is important for both the grower and the applicator. The grower can better predict the cost of the application and the applicator knows how many tons of soil amendment is required for the job.

8. The iPAQ is mounted in the cab where the driver can readily view the screen. A GPS card is placed in the iPAQ, and a signal from the GPS satellites is acquired. An external antenna on the tractor is used. The driver then knows where the tractor is in the field within an accuracy of several meters. The applicator applies the soil amendment to the field. The driver manually turns the application equipment on and off manually, as the management zone boundaries are crossed, as seen in the screen of the iPAQ

9. After the application is completed, the field file is archived on the desktop computer and a copy of the file is given to the grower, for future reference. The grower and consultant can re-evaluate specific management zone sites with soil tests at any time in the future, using the same image.

The rewards of site-specific management are that the grower can place soil amendments in needed areas of the field with a higher level of confidence. The grower can use this information to reduce the amount of soil amendments and save costs. Another strategy is to apply an increased amount of soil amendments to the targeted zones, where there is a higher degree of confidence the management zones would benefit from the application.

Practical Applications of Aerial Imagery for Vineyard Management

Ronald J. Brase
California AgQuest Consulting, Inc.
4325 N. Golden State, #105
Fresno, California 93722
(559) 275-8095; Fax (559) 275-5301; RonBrase@CalAgQuest.com

Aerial imagery of crops and soils has established itself as a useful tool in agriculture. This presentation will focus on the use of imagery as an analytical tool in vineyard situations and explore some of the specific applications where imagery has led to a clearer understanding of farming situations and helped identify and solve problems.

Temporal Resolution (real time vs. historical imagery)

Temporal resolution in the imagery world refers to turnaround time. This can be categorized as “real time” or “historical”. The goal of real time imagery is to have a short turn-around time (3 to 5 days) from the time of image capture to end user delivery. Real time imagery is intended to assist with real time decision-making in the areas of fertility, irrigation, and pest management. It is the type of imagery that is most heavily marketed.

Historical imagery (1 to 12 months old) is most useful for analysis of what has been occurring in a field situation and in resource planning. Historical imagery is considerably less costly and, depending on the field situation, can be a very cost effective approach providing the user with information for in-depth analysis. For instance, a series of images taken at mid-season for three consecutive years can be very effectively used to monitor and evaluate the progress of a problem situation.

Spatial Resolution (pixel size)

Spatial resolution refers to the size of the small colored squares or pixels that together, make up an image. The size of the pixels (normally expressed in meters) indicates the ground area included in each colored square. Pixel size can range from fairly large, 10 to 40 meters, to higher resolutions of 1 to 3 meters.

How detailed an image needs to be is directly related to its intended use. Low resolution (10 to 40 meters) is usually obtained from satellites and is useful for very broad area applications such as general crop or soil assessments, and land use categorizations. Lower resolution images can sometimes be used for variable rate applications of fertilizers and soil amendments, however, one must first verify that the reason(s) for variations in crop growth can be attributed to fertilization or the need for soil amendments.

Higher resolution (1 to 3 meters) is needed for any in-depth problem analysis such as:

a. Identifying the extent of soil pest infestations
b. Correlating crop growth with crop yield data
c. Quantifying the extent of specific nutrient deficiencies
d. Evaluating irrigation distribution uniformity problems
e. Selecting locations for making crop estimates

Field Verification
Knowing where the stronger and weaker growth areas are within a vineyard is interesting but it does not tell us the reason(s) for the growth differences nor what should be done to effect a change. Analysis of an image or series of images must be combined with knowledge of the vineyard, and verified with field assessments.

Case Studies
A series of case studies can be used to illustrate the range of applications for aerial imagery in a given vineyard situation.

Case Study: General survey
For the last five years, a series of early and mid season images have been acquired of the 1,600 acre French Camp Vineyard located near Shandon California. From these 1 to 2 meter resolution images, individual vineyard blocks that have become weaker over time have been identified. This has led to soil physical and chemical analysis and surveys for soil pests. Combining the results of the field verifications with the information from the series of images has led to medium and longer-term vineyard management decisions.

Case Study: Identifying the extent of soil pest infestations
The Simpson Vineyard is an eight-year-old, 150 acre overhead arbor vineyard used for dried-on-the-vine raisin production. Over the years, areas of lower crop production have been observed. Because the soils are generally sandy loams and the fact that the vines are own-rooted, soil nematodes were suspected as a cause. The soil and vine roots were evaluated in weaker, moderate, and vigorous areas of the vineyard. The locations of the soil and root sampling were logged with GPS coordinates and these were superimposed on a historical infrared image (2 meter resolution, taken 10 months earlier). A relationship between Root Knot nematode populations and the infrared image response was found, which had a correlation coefficient (R^2) of 0.60. A soil chemical treatment was applied only to the high nematode/weaker vine growth areas.

Case Study: Correlating crop growth with crop yield data
For the last several years, crop yields have been monitored at the Simpson Vineyard by weighing each bin of raisins harvested and recording the location from which each bin was harvested (i.e. the row and vine numbers). Using this data, a geo-referenced yield map was developed showing the individual segment yields within the vineyard.

The crop yield map was superimposed on the same 2-meter infrared image used for the soil pest analysis. A relationship between crop yield and infrared image response was found with a correlation coefficient (R^2) of 0.70. This is a very high correlation considering that the analysis included 727 bins of raisin produced from 75 acres of the vineyard. This conclusion was then used to quantify the cost/benefit ratios associated with soil chemical treatment of specific vineyard areas.

Case Study: Identify where to evaluate soils
Higher resolution (1 to 3 meters) is not necessary for all applications. A160 acre field located west of Fresno California had been cropped in cotton and wheat and was intended for planting to

vineyard. Areas from which soil samples would be taken were selected based on 20 meter satellite imagery. Actually, two images were used: one for the wheat taken in May and a second image for the cotton taken in July. Based on the images, seven areas of distinct crop growth were sampled. In each area, an assessment was made of soil physical and chemical characteristics. As it turned out, there were no real differences in soil chemistry or soil texture. There were, however, significant differences in sub soil compaction. This led to more extensive preplant deep tillage than had been planned.

Case Study: Quantifying fertilization needs
In a three year old, 40 acre Syrah winegrape vineyard in southern Madera County, areas of weaker growth became visible in the late spring of 2002. These areas also exhibited symptoms of a magnesium deficiency. From a 2 meter resolution infrared image, the full extent of the symptomatic vines was identified and magnesium fertilizer was applied to 10 acres. The vine growth patterns visible in the imagery correlated quite well with a soil conductivity map of the vineyard, indicating that weaker vine growth was associated with lighter textured soil. Again using the imagery, a variable rate application map was developed for three different rates of compost.

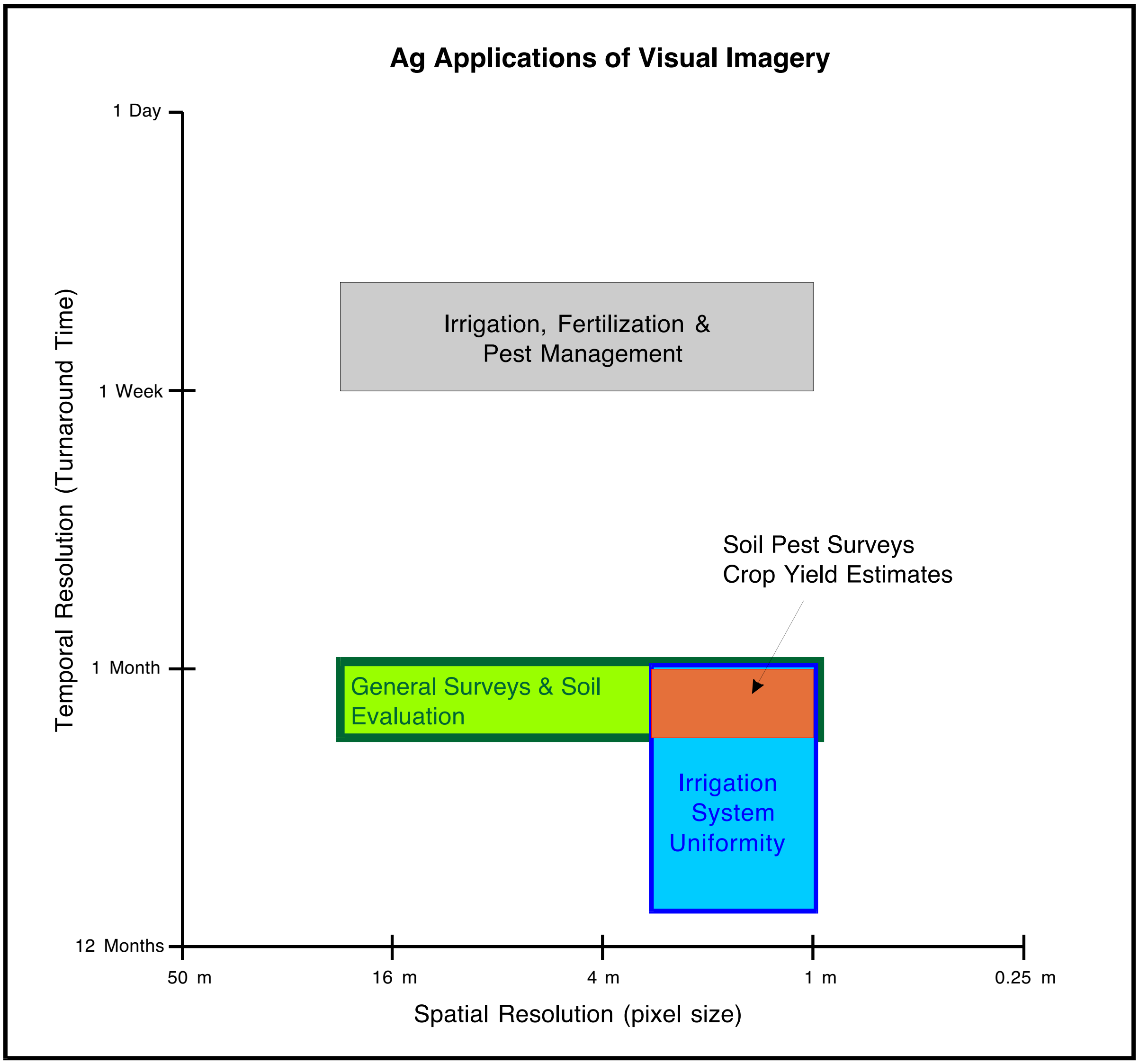
Case Study: Evaluating irrigation distribution uniformity
Several years of patchwork maintenance of older drip irrigation systems can result in poor distribution uniformities. This was the case for the 1,200 acre Lost Hills Vineyard owned by Golden State Vintners. When the layout of the irrigation system was superimposed on a 2 meter infrared image, it was found that lower vine vigor was correlated with low pressures in the irrigation system. A booster pump was rebuilt along with the implementation of a regular program of sub mainline pressure measurement and pressure regulating valve adjustments. This increased the distribution uniformities from the 40% range up to 80%.

At another 600 acre winegrape vineyard near McFarland California, the 2 meter infrared image also indicated a low distribution uniformity based on vine growth characteristics. However, in this case the problem was related to a combination of booster pump wear, poor water filtration, and clogged emitters resulting in low system pressures. The booster pump was rebuilt, the sand replaced in the media filters, and a rigorous program of line flushing implemented.

Case Study: Selecting locations for making crop estimates
Estimating crop size is critical in a winegrape vineyard when vine balance and fruit quality issues are important. Two meter imagery was used to judiciously select field locations for data gathering (counting and weighing clusters). The imagery was then used to extend the individual location data and to project yields for each vineyard block. Using this procedure, projected crop yields were within 5% to 10% of actual yields.

Commercial Availability
Aerial imagery is commercially available from either satellites or fixed wing platforms, with reasonably good turn-around times and in different resolutions. The cost of imagery increases for faster turn-around times and finer spatial resolutions. For a 2-month (or older), 20-meter resolution infrared, the cost is typically \$1 to \$3/acre. For a 2-meter resolution, 1-week turn around the cost for an infrared image can be \$5 to \$7/acre.

Temporal Versus Spatial Resolution
The intended use of an image should dictate the selection of temporal (turn-around) and spatial resolution (pixel size). Typical applications along with their temporal and spatial needs are:



The value and potential uses of aerial imagery are increasing. Currently, "historical" imagery (2 to 12 months old) can be used very effectively in analysis of field situations and problems. The use of "real time" (3 to 5 day turnaround) imagery is increasing as agriculturists become aware of its value and the reliability of acquisition increases.

SUITABILITY OF SEVERAL HALOPHYTES AND OTHER SALT TOLERANT PLANTS FOR DRAINAGE WATER RE-USE SYSTEMS: SOME OF WHAT WE KNOW THUS FAR.

Benes S.[1], Grattan S.[2], Cervinka V.[3], Finch C., Robinson P.[4], Getachew, G.[4] and Bartram J.[1]

[1]California State University, Fresno, Dept. Plant Science M/S AS72, 2415 E. San Ramon Ave. Fresno, CA 93740-8033. email: sbenes@csufresno.edu,
[2]University of California, Davis, Dept. of LAWR, [3]CA Dept. of Water Resources, Fresno office,
[4]University of California, Davis, Dept. of Animal Science.

Drainage water (DW) re-use is one of several management options available to address the salinity and drainage problems on the westside San Joaquin Valley. The control of root zone salinity and boron and the use of subsurface drainage to lower water tables are critical to the sustainability of Westside agriculture. Re-use, however, is limited by environmental regulations related to the disposal of the collected drain water. With the recent agreement between the federal government and Westlands Water District (WWD) on the retirement of at least 30,000 and possibly more than 100,000 acres, it is likely that a portion of the retired land will be used as a DW re-use site, similar to the 3,800 acre San Joaquin River Water Quality Improvement Project (SJRWQIP) managed by the Panoche Drainage District.

To date, a number of halophytes, salt tolerant forages, and trees (eucalyptus, casuarina, athel and pistachio) have been grown at several locations in the San Joaquin Valley under irrigation with DW of varying salinities and boron levels and under different soil conditions. Thus far, it appears that several of the halophytes and salt tolerant forages have good potential for irrigation with saline-sodic DW. The final choice is likely to depend on the salinities of the DW and soil, farmer preference, availability of seed or transplant materials, and the economic value, amongst other factors. Furthermore, with long term application of saline drainage water to the slowly permeable Westside soils, the soil salinities are likely to increase; consequently, both moderately tolerant (forages) and highly salt tolerant (halophyte) plant materials will be needed.

The halophytes grown at the sequential DW re-use site at Red Rock Ranch (RRR) include salicornia (*Salicornia bigelovii*), saltgrass (*Distichlis spicata* var. *stricta*), atriplex (*Atriplex lentiformis*), cordgrass (*Spartina gracilis*) and iodine bush (*Allenrolfea occidentalis*). At AndrewsAg (ANA; formerly Rainbow Ranch) two types of saltgrass (Nypa and a native *Distichlis*) and Allenrolfea are growing. Fivehook bassia (*Bassia hyssopifolia*) is present at both sites as a halophytic weed. Drainage water and soil salinities are much higher in the halophyte area at RRR for several reasons: (1) the water applied is the third re-use of the DW, (2) DW has been applied for seven years (since 1996), and (3) currently, there is no terminal site for salt evaporation due to problems associated with the high selenium present in the RRR drainage water. In comparison, at ANA the irrigation of the halophytes is only the second re-use of the DW, the plants have been irrigated with DW for only two years, and there is a terminal salt evaporation site. In 2000 and 2001, we conducted a fall sampling of the halophytes at RRR and in 2002, halophytes at RRR and ANA were sampled both in July and November. Biomass production and ion accumulation (particularly boron and selenium) will be discussed along with limited commentary on forage quality and water use (ET) data that were presented previously.

A variety of salt tolerant forages have performed well in the field under irrigation with saline-sodic drainage water. They include bermudagrass (*Cynodon dactylon*) at Westlake Farms, Jose Tall Wheatgrass (*Agropyron elongatum* var. *"Jose"*) and Creeping Wild Rye (*Leymus triticoides* var. "*Rio*") at RRR, and several new salt tolerant alfalfa varieties such as "*Salado*" and "*801S*" from America's Alfalfa (Nampa, ID) and "*SW9720*" from S&W Seed (Five Points, CA) that are growing at several DW re-use sites. The alfalfas are generally irrigated with less saline drainage water than are the grasses.

At RRR, Jose Tall Wheatgrass and Creeping Wild Rye have grown well under irrigation with saline DW having an EC of 9-13 dS/m and in soil with an ECe of about 14 dS/m. Boron concentrations in this DW were near 15 mg/L. The forage quality of the Jose Tall Wheatgrass and Creeping Wild Rye is acceptable for most livestock, other than lactating dairy cows, and along with other saline forages grown at RRR, they currently comprise the entire hay and silage ration being to black angus beef cattle by the RRR owner. Forage quality and ion accumulation in these forages will be briefly presented for comparison to the halophytes. Measurements of biomass production for the salt tolerant forages at RRR are underway, but will not be completed for presentation in the poster.

With regard to tree performance, eucalyptus in the more saline part of the tree interceptor strip (ECe = 20 – 25 dS/m) located between the 1st and 2nd re-use areas at RRR, showed severe boron toxicity symptoms in 2001 at the end of three years of DW irrigation (EC = 8-10 dS/m, boron = 15 – 20 mg/L). Boron concentrations in symptomatic leaves of the trees were 2500 - 3790 mg/kg. Similarly, pistachio (var. "*Atlantica*" on rootstock "*Pioneer gold*") growing in a less saline part of the interceptor strip developed severe boron toxicity symptoms in 2002 after three years of irrigation with the same DW. Boron concentrations for the pistachio leaf tissue, along with irrigation water salinity and B concentrations will be presented. This interceptor strip of trees was the only area within the RRR re-use site without subsurface drainage which probably accounts for the boron accumulation in the soil and the severe foliar injury. Drain tiles were installed in October 2002 and it is expected that the condition of the trees will improve.

In a shorter term (14 month) sand tank study irrigating eucalyptus (clone 4544) with drainage water, Shannon et al. (1997) reported boron toxicity symptoms and leaf boron concentrations of 839 and 1043 mg/ kg in their high boron (25 – 30 mg/L) / low salinity (2 and 6 dS/m) irrigation water treatments. Foliar injury was not reported by Oster et al. (1999), in eucalyptus irrigated for three years at a Tulare Lake Drainage District site with a less saline, lower boron DW (EC = 8.5 dS/m; boron = 3.9 mg/L) in plots receiving fall applications of gypsum (5 ton/acre). Boron concentrations in these eucalyptus leaves were much lower (390 – 540 mg/kg). Based on all these data, it appears that under long term exposure in the field, eucalyptus and pistachio trees will eventually pass their threshold for B tolerance unless soil drainage and management in the re-use sites are optimum.

The objective of this poster will be primarily to discuss the performance and suitability of halophytes in drainage water re-use systems, along with some commentary on the performance of salt tolerant forages and trees.

References

1. Grattan, S.R. and J.D. Oster. (2002). Use and Reuse of Saline-sodic Waters for Irrigation of Crops. *In* S. S. Goyal, S. K. Sharma, and D. W. Rains (eds.) Crop Production in Saline Environments. Journal of Crop Production, Vol. 2, Haworth Press, New York. (In press)

2. Oster, J.D. (2001). Forage Production using Saline-Sodic Drainage Water? Proceedings CA Plant & Soil Conference, CA chapter of the American Society of Agronomy. Jan. 20-21. Visalia, CA. pp. 33-37.

3. Oster, J.D., Macedo T.F., Davis D. and Fulton A. (1999). Developing sustainable reuse and disposal of saline drainwater on Eucalyptus. Department of Environmental Sciences, UCCE, Univ. of California, Riverside, CA, and Tulare Lake Drainage District, Corcoran CA. Draft Report 1/15/99. pp 64. of the Tulare Lake Drainage District Eucalyptus project.

4. Shannon M.C., Suhayada C.G., Grieve C.M., Grattan S.R., Francois L.E., Poss J.A., Donovan, T.J., Draper J.H., and Oster J.D. (1997). Water Use of *Eucalyptus camadulensis,* Clone 4544, in Saline Drainage Re-use Systems. Proceedings CA Plant & Soil Conference, CA chapter of the American Society of Agronomy. Jan. 15-16. Visalia, CA. pp. 20-28.

Irrigation Management and Calcium Application to Control Erwinia Diseases of Potato

Mohammad Yaghmour, and James Farrar
Department of plant science, California State University, Fresno

Contact information: Dr. James Farrar
Department of plant science
2415 East San Ramon Ave. M/S AS72
Fresno, CA 93740

Erwinia early dying is one of the diseases of potato caused by *Erwinia* species bacteria and is a serious concern for potato growers in Kern County, California. Other Erwinia diseases include soft rot, aerial stem rot, black leg, and lenticel rot. *Erwinia corotovora* subsp. *corotovora*, *Erwinia corotovora* subsp. *atroseptica* and *Erwinia corotovora* subsp. *chrysanthemi* wil cause Erwinia early dying. This research examined the influence of irrigation as a percentage of crop evapotranspiration (ET) demand and calcium fertilizers on Erwinia early dying. In the irrigation experiment the potatoes were irrigated with 75, 100, 150, and 200 percent of ET at Fresno and 75, 100, 150 percent at Kearney Agriculture Center in Parlier. Disease severity ratings and yields were not significantly different at either location. In the calcium experiment, supplemental calcium was applied 0, 100, 200, 400 lbs calcium per acre as gypsum at both locations. Higher levels of calcium fertilization resulted in higher tuber levels of calcium but didn't significantly decrease Erwinia early dying severity ratings or increase yields.

Seasonal Ammonia Emissions from Crops in the San Joaquin Valley, California

M. Beene[1], C. Krauter[1,2] and D. Goorahoo[1,2*].
[1]Plant Science Department; [2] Center for Irrigation Technology. California State Univ.-Fresno.
5370 N Chestnut Ave., Fresno. CA. 93740.
*Contact: dgooraho@csufresno.edu; Tel: (559) 278 8448; Fax: (559) 278 6033.

Air quality in California is a matter of increasing concern. The State Air Resources Board is completing an inventory of atmospheric constituents that may contribute to air quality problems. Among those constituents is ammonia (NH_3) that has been shown to form secondary particulates (PM2.5) when combined with oxides of N and S from combustion. Ammonia, the dominant gaseous base in the atmosphere and a principal neutralizing agent, remains one of the most poorly characterized atmospheric trace compounds. Among the factors influencing ammonia emissions are the capacity of soils, organic matter, and vegetation to act as both sources and sinks for atmospheric ammonia, and the variability in nitrogen fertilizer management practices.

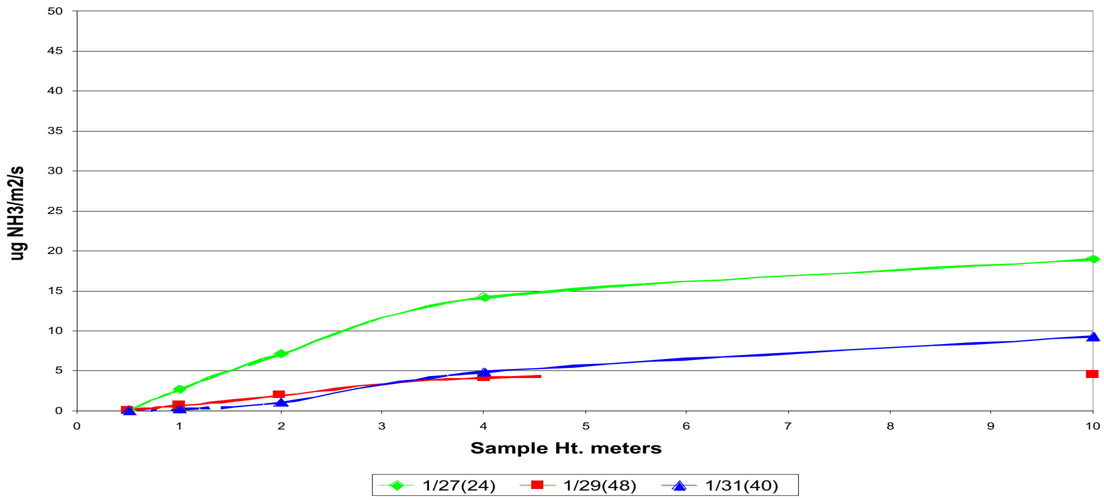
A study of NH_3 in the atmosphere from fertilization of crops was completed in 2001. Air sampling was conducted during selected fertilizer applications and correlated with various factors. The field data was used by project cooperators from the Ames Research Lab - NASA, in a state-wide model to estimate the NH_3 emissions from agricultural fertilization. Their model produced a map of estimated emissions by crop and a total, annual emission estimate of 12 x 106 kg NH_3. This is approximately 25% of the total estimated NH_3 emissions from all soils and vegetation in the State.

The objective of the current study, funded by the California Air Resources Board, was to characterize NH_3 emissions in the Central Valley of California from crops and natural vegetation through their entire seasons. The study will continue through 2004. An active sampling technique was used with denuders and anemometers co-located at four heights.

Some data from the first season of the study has been analyzed and is presented here. These are only two from a total of twenty locations sampled to date. Sixteen of the locations are on crop land and four are natural soils/vegetation communities. Most of the crops sampled are located on the 400 Ha farm/laboratory at the CSU Fresno campus. Many of the crops are grown for forage to support the campus dairy. An example is the barley described below.

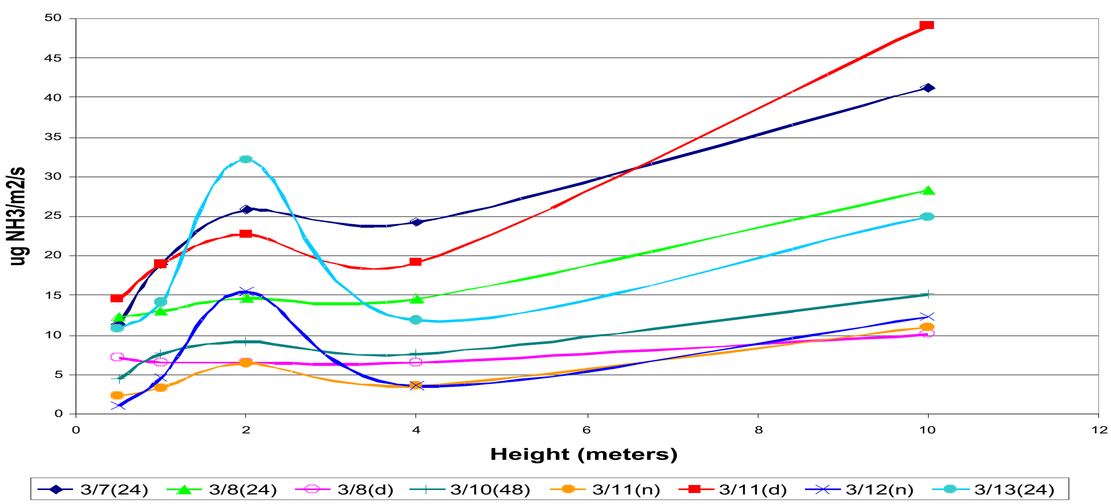
A barley crop grown to be green chopped for dairy forage was sampled in January, 2002 (Figure 1). The air temperature averaged 42.0 F and RH% = 79.6. The NH_3 values were relatively low due to high humidity and low temperatures. NH_3 concentrations were measured at 0.5m, 1.0m, 2.0m, 4.0m and 10.0m along with wind speed and wind direction.

Figure 1: Ammonia emissions for barley during January 2002.



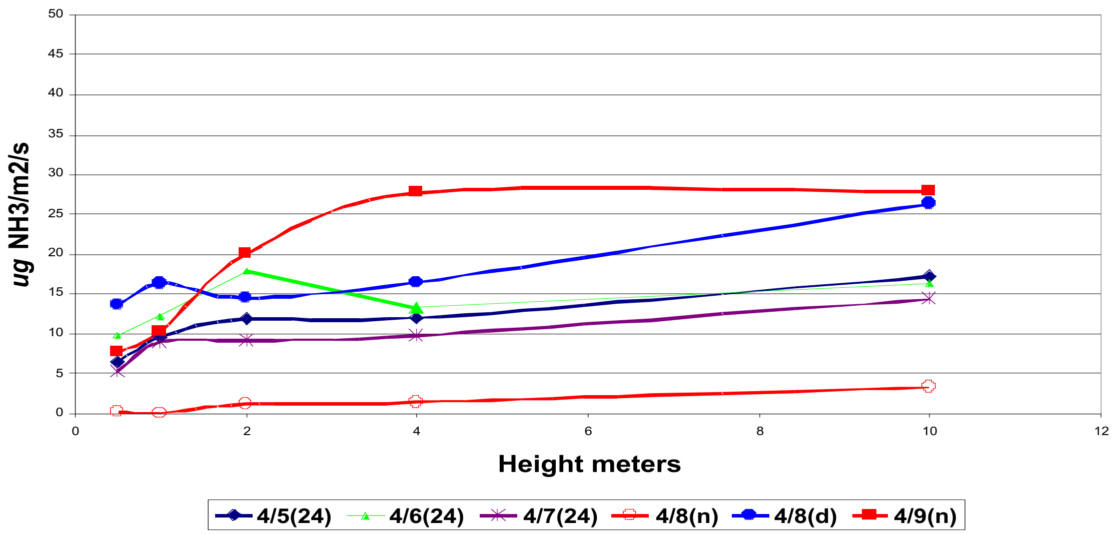
The barley crop was cut in mid March 2002. The high NH_3 flux during the day on 11th March compared to the low values for the previous night are characteristic of the diurnal differences in NH_3 emissions ((Figure 2). The only other **day** sample was 8th March, when the emissions were uncharacteristically low from 2 days of low temperatures and rain. The reason for the higher fluxes at 2m for several of these samples is unknown.

Figure 2: Ammonia emissions for barley during March 2002.



In early April the barley stubble was disked, fertilized and irrigated in preparation for a silage corn crop to be planted at the end of the month. Sampling was started just prior to disking on 6th April (Figure 3). The fertilizer application occurred on 8th April after the lowest NH_3 values the previous night. The NH_3 flux increased considerably after the fertilizer application, but the most significant increase in volatile NH_3 occurred the next day following an irrigation.

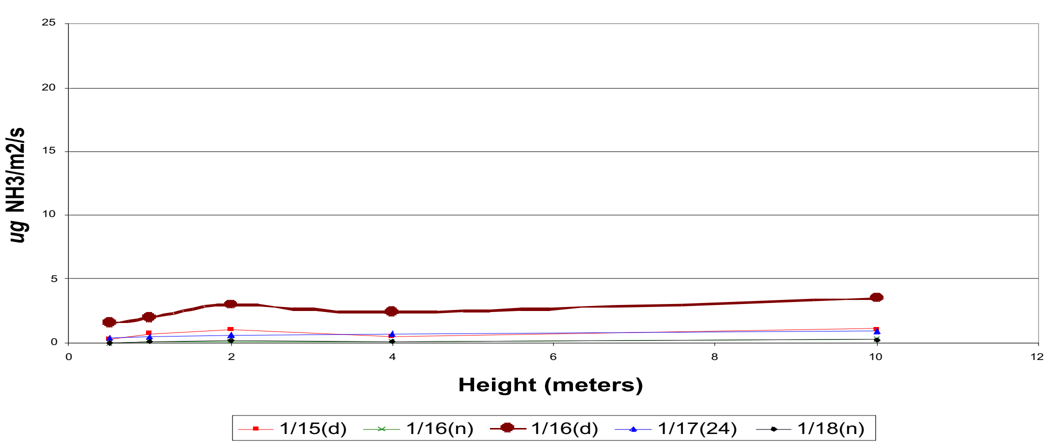
Figure 3: Ammonia emissions for barley during April 2002.



In addition to sampling crops to characterize NH_3 emissions related to agricultural practices, several natural vegetation sites have been located and sampled through the growing season and the following dormant period. A low elevation (300m), annual grass range was sampled on dates that were similar to the barley/silage corn field. The San Joaquin Experimental Range is a CSU Fresno field station of 2000 Ha located 40 km north of Fresno in the foothills of the Sierra Nevada. The range is grazed by the university's beef herd in the late winter and spring.

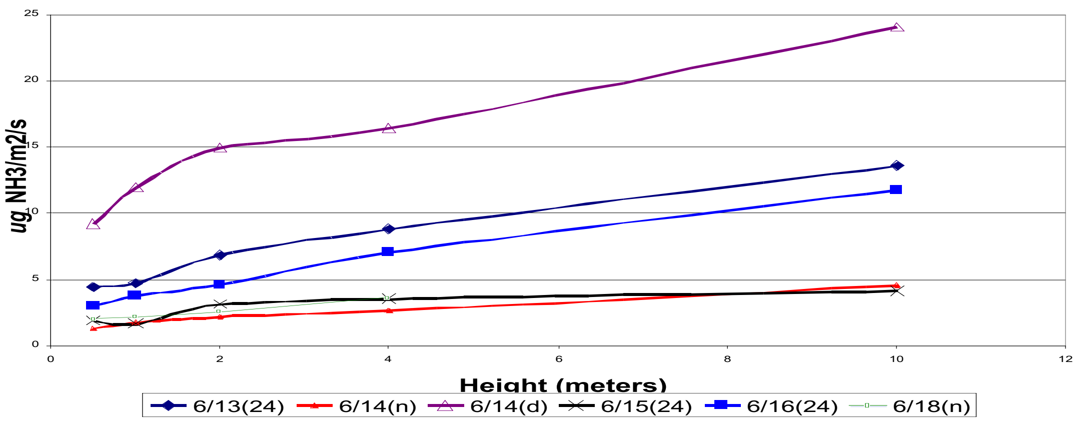
The growing season for the foothill rangeland begins with late fall rains that continue through the winter. The 2001-02 season started later than usual and the grasses were still rather short in early January when this sampling took place. The average temperature was 37^{o}F and the RH% = 88%. The sampling system was the same as that used for the barley crop. The NH_3 flux profiles are considerably lower than those in the barley measured at about the same time (Figure 4).

Figure 4: Ammonia emissions for rangeland grasses during January 2002.



By March the forage had grown considerably and the weather was both warmer (61^0F) and drier (68% RH). The area was grazed just prior to this sampling. Typical pattern of higher NH_3 flux profiles in the day and much lower values at night were observed for April 3rd (data not shown). The 2002 range season ended in late May. Three weeks later, the NH_3 flux profiles were somewhat higher than the previous sampling periods (Figure 5). That may be due to the warmer temperatures (75^0F) or, possibly the fact that the plant residue was beginning to decompose and release NH_3. The diurnal pattern was particularly evident for the June 14th day sample compared to the June 14th night profile (Figure 5).

Figure 5: Ammonia emissions for rangeland grasses during June 2002.



We have completed the field work for the first of two seasons. These sampling locations are only two of over twenty that will be monitored to characterize NH_3 profiles and emission factors. There are some preliminary conclusions that have begun to emerge and are illustrated by these two examples:

1. There is a distinct, diurnal difference in NH_3 emissions. Much more NH_3 is found in the atmosphere during the day. The most likely reason is higher temperatures that increase NH_3 emission and lower humidity that maintains it in the NH_3 form.
2. There is more NH_3 in the atmosphere in the spring and summer compared to winter for much the same reason as the diurnal differences.
3. There is more NH_3 in the atmosphere of the valley, near agricultural activity at all times. A contributing factor may be the urban areas surrounding the CSU Fresno farm/lab but similar NH_3 profiles have been monitored on crop land located far from urban activity.
4. The most interesting indication is, unfortunately, the most difficult to verify. The flux gradient from the ambient air to the ground surface is always positive. This is evidence that vegetation and the soil surface absorb NH_3 from the atmosphere. The stronger gradient during the day is further evidence since most stomata are only open during daylight. We are trying several modifications of the sampling method to monitor the effect of vegetation on the atmospheric NH_3 to better determine the relationship between NH_3 emissions and vegetation.

INFILTRATION IN SOILS IRRIGATED WITH SALINE-SODIC DRAINAGE WATERS: EXPERIMENTAL DESIGN AND DATA ANALYSIS TECHNIQUES

Dave Goorahoo[1,2], Sharon Benes[1,2], and Diganta Adhikari[2]
California State University, Fresno

[1]Dept. of Plant Science, 2415 E. San Ramon Ave. M/S AS72, Fresno, CA 93740-8033; [2]Center for Irrigation Technology, 5370 N Chestnut Ave. M/S OF 18, Fresno. CA 97340;
Contacts: sbenes@csufresno.edu (559)-278-2255; dgooraho@csufresno.edu (559) 278 8448; diganta@csufresno.edu (559) 270 6326. Fax: (559) 278 6033

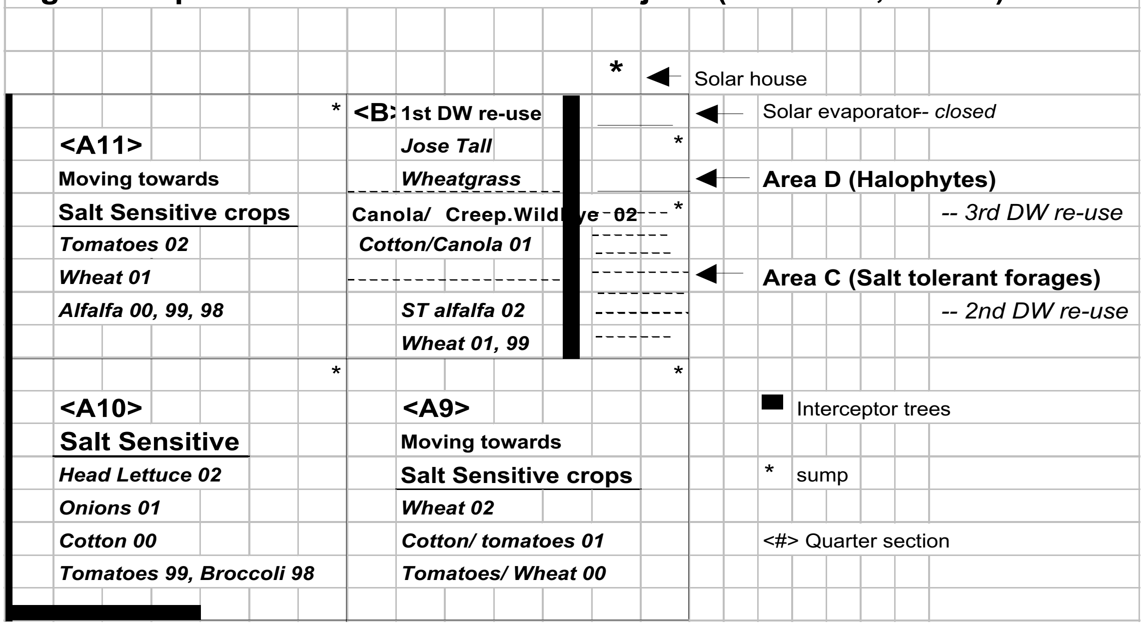
Historically, salinity in soil water in the plant root zone has been a constraint to irrigated agriculture. In California, it is estimated that 4.5 million acres are salt-affected—primarily on the Westside San Joaquin Valley (SJV). In addition to soil salinity, high water tables and boron toxicity are chronic problems for Westside SJV agriculture.

Drainage water re-use is considered to be one of the more sustainable and environmentally responsible options for drainage management because the salt, selenium and boron are managed on-farm and do not go off-site to compromise water quality in nearby water bodies (Grattan 1999**).** In 1996, an Integrated on-Farm Drainage Management (IFDM) system was developed as a demonstration project at the Red Rock Ranch (RRR) owned by John Diener. This farmer manages irrigation water, drainage water, salt, and selenium as resources within the boundaries of the farm. Drainage water is used to grow salt-tolerant crops, forages, and halophytes. No drainage water, salt or selenium is discharged into rivers or lakes.

In the RRR IFDM, (Fig. 1), high quality canal water is used to irrigate ***Area A*** (73% of the farm area) that is in transition from low value, salt tolerant, row crops to higher value, more salt-sensitive, vegetable crops. Drainage collected from A is applied to ***Area B*** (20 % of farm area) previously containing salt tolerant row crops, but now sown to forages. Drainage from B is applied to ***Area C*** (2% of area) which is a test area for a variety of salt tolerant forages and finally, the bio-concentrated drainage is applied to ***Area D*** (1% of area) where only highly salt-adapted (halophytic) plants are grown. The terminal effluent is then discharged into a solar evaporation system for rapid evaporation of water and precipitation of the salt. Markets are currently being sought for the evaporated salt. It is proposed that as compared to large acreage, evaporation ponds, this "bio-concentration" of drainage water results in less exposure of wildlife to high selenium drainage water and eventually economic return may be derived from the plants grown in the re-use areas.

For the past three years, one focus of our research at the RRR IFDM demonstration project has been the monitoring of seasonal trends in soil salinity. Soil sampling (0 – 5 ft. in 1 ft increments) has been conducted twice yearly in all areas (A, B, C, D). In Area A, leaching is occurring as indicated by the relatively lower salinity at shallow depths. However, in Area D (3^{rd} re-use of the drainage water), there is extremely high salinity (ECe) and sodicity (SAR) in the surface 12 in. (30 cm) of soil. Extremely high SAR values (>50) represent a sodium-saturated soil, which is prone to severe reductions in water infiltration and permeability (i.e. ponding), particularly when non-saline winter rains fall. Low soil permeability also contributes to the perched water table which also contributes to the inverted salinity profile (highest at surface and decreasing with depth) that is found in Area D.

Fig. 1. Sequential DW Re-use Demo. Project (640 acres, 260 ha)



A major objective of our current and future research at the RRR IFDM project is the evaluation of the effectiveness of surface applications of gypsum on infiltration rates.

Water infiltration is being measured in Area D (3rd re-use of DW; ECe 30 - 55 dS/m, SAR 56 - 99) where five years of irrigation with the saline-sodic drainage water has degraded the soil structure severely reducing infiltration. For comparison, infiltration is also being measured in Area A that has received only freshwater irrigation (canal or well water; soil EC $\leq$ 5 dS/m) and is cropped to agronomic plants (e.g. onions in A10 in 2001). In Area D, infiltration is being measured in plots containing three different halophytic plants (saltgrass, salicornia, and atriplex). These differ notably in that saltgrass provides a full vegetative cover over the soil, whereas Salicornia and Atriplex fields have exposed soil. Oster (2001) emphasized the benefits of a grass canopy which can reduce evaporation and accumulation of salt at the soil surface and protect soil aggregates at the surface from the mechanical disturbance of rainfall or sprinkler irrigation. Four replicate plots for each area and vegetation type were established and for each, duplicate plots with and without gypsum application (3 ton/acre) were added for a total of 32 plots. In each plot, measurements are taken from four infiltration rings to account for spatial variability within the plot.

Based on the findings from initial tests conducted in summer 2001, we chose double ring infiltrometers for our field measurements. We also collected 5 cm diameter soil cores from within the top 30cm of soil from the experimental subplots and intend to determine the saturated hydraulic conductivity of these cores in the laboratory. Currently, we are using various curve–fitting approaches to analyze the time and depth data collected from the ring infiltration measurements in 2002.

In our first approach we determine the steady rate infiltration (i_s), also referred to as *steady-state infiltrability* or as the *final infiltration capacity* (Hilllel, 1998). In this approach, the steady rate infiltrations are examined rather than the initial or "early time" infiltration. In general, soil infiltrability is relatively high in the early stages of infiltration, particularly where the soil is dry, but then it tends to decrease monotonically and eventually approaches an asymptotic constant infiltration rate (Figure 2). Hence, by comparing the "late time" steady rate infiltrations, care is taken to ensure that the values being compared are not influenced by the initial moisture content of the plots or by the differences in the ponding head in the ring infiltrometers. For the infiltration experiments conducted in summer 2002, we found that steady state infiltrability rates (i_s), which generally were attained after 2.5 to 3 hours, averaged at 2.1 cm h^{-1} and 1.7 cm h^{-1} for the gypsum plots in areas A and D, respectively. For the non-gypsum i_s values ranged from 0.7 to 1.0 cm h^{-1} for both areas.

In our second approach, cumulative infiltration (I) over cumulative time (t) will be determined using (Jury et al., 1991):

$$I = a t^b \qquad \textbf{Eqn. (1)}$$

where a and b are empirical constants (Figure 3). Derivatives of **Eqn. 1** will be taken at 2 and 4 hours to estimate infiltration rates i_2 and i_4, respectively.

In our final method, we will determine the sorptivity (S) of the soil according to (Bower, 1986):

$$I = S t^{0.5} + B \qquad \textbf{Eqn. 2}$$

where: S is a term that depends on the pore configuration of the soil, the initial water content of the soil, and the ponding head; t is cumulative time; and B is a factor related to the hydraulic conductivity and the elapsed time from water application. Values of S will be determined from the infiltrometer measurements by plotting I vs. $t^{0.5}$ for the portion of the test where I increases essentially linearly with $t^{0.5}$ and S is evaluated as the slope of the straight line portion of the curve (Figure 4).

The parameters outlined above will be monitored twice per year for the next three years. Estimated values, such as i_2 and i_4 rates, will be compared to measured values whenever possible. In addition, the parameters determined from each of the infiltration experiment (i.e. all 32 plots x 4 replicate rings per plot) will be analyzed using conventional statistical methods to determine any significant differences among treatments. These values are currently being processed and will be presented in the poster. Our primary objective is to detect the effects of gypsum application and crop growth on the hydraulic properties of the soils at RRR as they are irrigated with saline-sodic drainage waters. Ultimately, we will like to be able make recommendations to the farmer about both the rate and frequency of irrigations that will result in optimum water use efficiency.

It is our hope that by comparing infiltration rates in the drainage water re-use areas to those under conventional irrigation with non-saline water, we can begin to assess the long term impacts of irrigation with saline-sodic drainage water on soil structure and permeability, and eventually to formulate management plans that utilize gypsum or sulfur, and possibly organic amendments, to minimize soil degradation.

References:

Bower, H. 1986. Intake Rate: Cylinder Infiltrometer. Chapter 32 in *Methods of Soil Analysis Part 1- Physical and Mineralogical Methods*. Agronomy Monograph no.9. ASA-SSSA. WI. USA

Grattan, S.R. et al. (1999). Technical Report on Drainage Water Reuse. M. Alemi and J. Letey (Coordinators). San Joaquin Valley Drainage Implementation Program and the University of California Salinity/Drainage Program. California State Department of Water Resources 91 pp

Hillel, D. 1998. *Environmental Soil Physics*. Chapter 14. Academic Press. 771 pp. California, USA.

Jury, W.A., W.R. Gardner and W.H. Gardner. 1991. *Soil Physics*. 5th Ed. John Wileyand Sons. New York. NY. 328 pp.

Oster, J.D. (2001). Sustainable use of saline-sodic drainage water. Proceedings CA Plant & Soil Conference, CA chapter of the American Society of Agronomy and the CA Plant Health Association. Feb.7-8. Fresno, CA. pp. 1-8.

Figure 2: Example of measured infiltration rates with fitted trendline used to determine steady rate infiltration for a non gypsum plot in area A

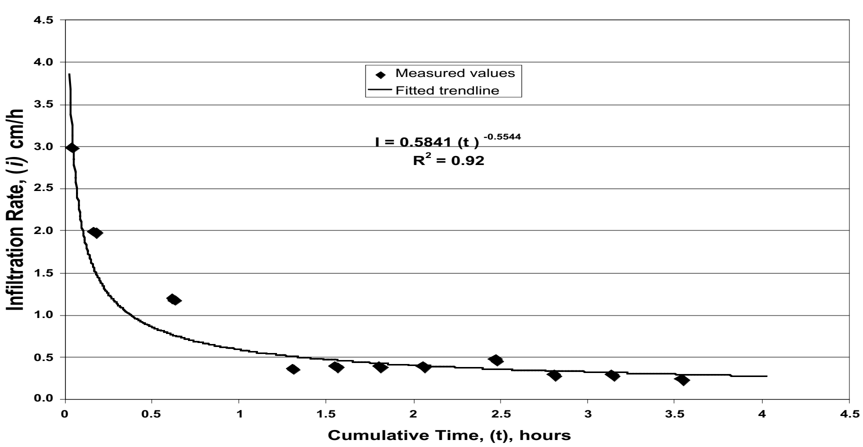


Figure 3: Example of measured cumulative infiltration with fitted trendline used to determine equation 1 for a non gypsum plot in area A.

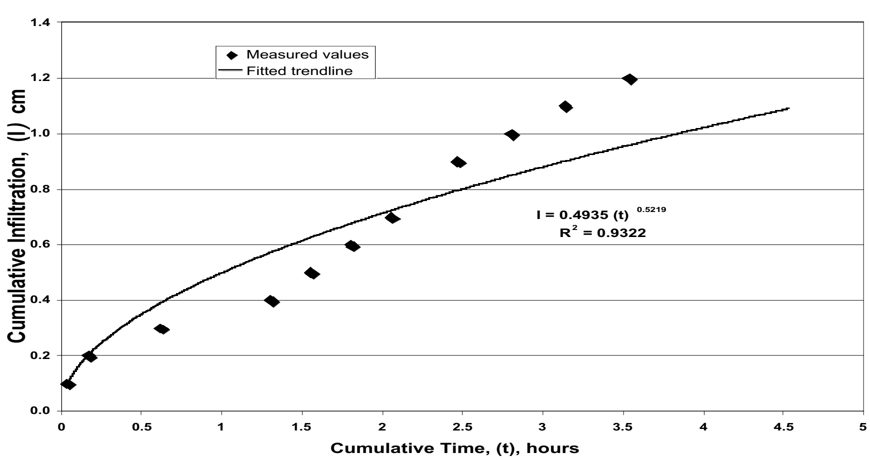
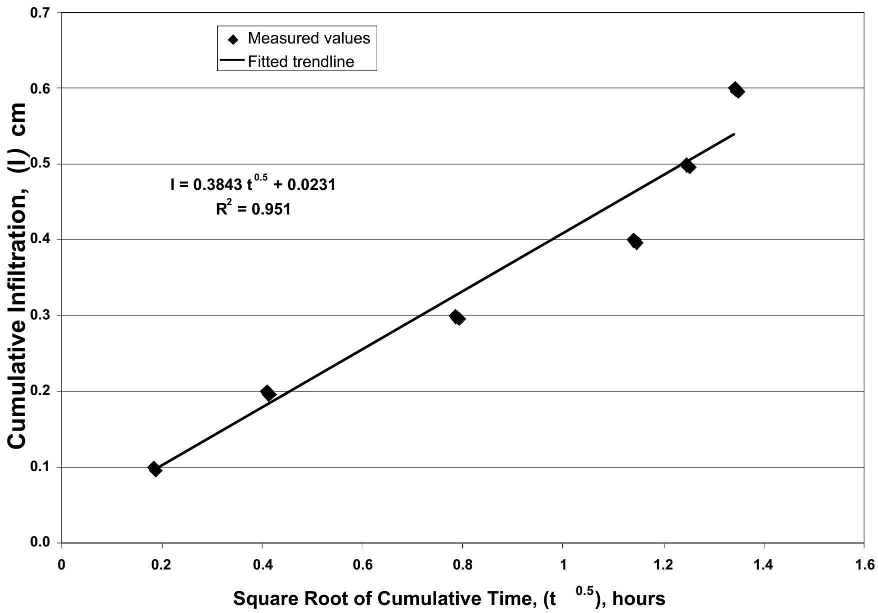


Figure 4: Example of measured cumulative infiltration with fitted trendline used to determine Sorptivity, *S*, for a non gypsum plot in area A.



Using Flow-through Wetlands to Remediate Se in Agricultural Drainage in San Joaquin Valley

Suduan Gao and Kenneth K. Tanji*
Department of Land, Air and Water Resources, University of California, Davis

* Dept. of Land, Air and Water Resources, University of California, One Shields Ave., Davis, CA 95616. Phone: (530) 752-5105; Fax: (530) 752-5262; E-mail: sugao@ucdavis.edu

Summary

Agricultural drainage water in some portions of the West Side of San Joaquin Valley contains elevated concentrations of Se that caused toxicity to waterfowl in Kesterson Reservoir in the 1980s and evaporation basins in 1990s. Currently in areas of limited to no opportunities to discharge irrigation return flows, the collected subsurface drainage waters are either disposed into evaporation ponds or reused as irrigation of salt-tolerant crops and halophytes. Accumulation of Se in surface water is still a concern because of its ecotoxicity risk. In 1987, the U.S. Environmental Protection Agency set the national chronic criterion for Se at 5 μg L^{-1} in aquatic systems. Later, Hamilton and Lemly (1999) recommended a national water quality criterion of 2 μg L^{-1} Se based on toxic effects on biota from recent studies.

To test if vegetated flow-through wetlands can be used to remove Se from agricultural drainage, the UC Salinity/Drainage Program, Tulare Lake Drainage District (TLDD), and the California Department of Water Resources supported a field study near Corcoran, California. An experimental flow-through wetland system was established in 1996 and run until February 2001 to investigate the potential of varying combinations of plants and water residence times to remove Se from saline subsurface drainage waters from croplands before discharge into evaporation ponds. The target Se concentration was ≤ 2 μg L^{-1} to minimize toxic impacts on waterbirds. The research team consisted of personnel from the University of California at Berkeley and Davis campuses, TLDD, and California Department of Water Resources.

The flow-through wetland system consisted of ten 15x76 m unlined cells which were continuously flooded and planted with either a monotype (7 cells) or combination of plants (2 cells). Vegetation included saltmarsh bulrush, baltic rush, smooth cord grass, rabbitsfoot grass, saltgrass, cattail, tule, and widgeon grass. One cell had no vegetation planted and served as a control. We have evaluated Se removal efficiency of the wetland system and carried out Se mass balance.

The inflow drainage water to the wetland was from an adjacent tile-drained farm and had average annual Se concentrations of 19 to 22 μg L^{-1} dominated by selenate (Se(VI), 95%). Average weekly water residence time varied from about 3 to 15 days for Cells 1 through 7 (target 7 days), from 19 to 33 days for Cells 8 and 9 (target 21 days) and from 13 to 18 days for Cell 10 (target 14 days). Average weekly Se concentration ratios of [outflow]/[inflow] ranged from 0.45 to 0.79 and mass ratio (concentration * water volume) from 0.24 to 0.52 for year 2000, indicating 21 to 55% reduction in Se concentration and 48 to 76% reduction in Se mass by the wetland, respectively. The non-vegetated cell showed significantly lower Se removal both in concentration and in mass compared to the vegetated cells indicating the important role of vegetation in Se removal. The fallen litter from plants produced an organic detrital layer over the mineral sediments that were in strongly reduced conditions promoting the reduction of oxidized forms of Se to immobilized elemental Se and organic Se. Selenite (SeIV) was also adsorbed onto underlying mineral sediments.

The global mass balance (input-output relations) showed that on the average about 59% of the total mass of inflow Se was retained within the cells and Se outputs were outflow (35%), seepage (4%), and volatilization (2%). Independent measurements of the Se retained within the cells totaled 53% of the total Se inflow: 33% in the surface (0-20 cm) sediment, 18% in the organic detrital layer above the sediment, 2% in the fallen litter, < 1% in the standing plants, and < 1% in the surface water. About 6% of the total Se inflow was unaccounted for in the internal compartments. The wetland cells lowered the Se concentration in treated drainage waters to about 4-8 μg L^{-1} Se in reducing potential damage to waterbirds but not achieving the target of 2 μg L^{-1} Se.

Study results have shown that flow-through wetland can remove significant amounts of Se from Se-contaminated water and the removal efficiency may be further improved by considering several factors such as modifying physical settings of the wetland, increasing water residence time and choosing effective plants. However, there is a major concern on the potential Se environmental ecotoxicity risks since a portion of the immobilized Se in the organic detrital layer could enter into the aquatic food chain. Moreover, reduction of Se in concentration and mass is accompanied by an increase in the proportions of reduced species such as selenite (Se(IV)) and organic Se (Se(-II)) in the standing water and outflow that are more toxic than Se(VI) at the same concentration for many aquatic biota. Further studies are needed in this area to minimize the potential impact of reduced Se forms on wildlife, particularly waterbirds that feed on Se contaminated macroinvertebrates and seeds of wetland plants.

EFFECTS OF BOD LOADING ON PERCOLATE WATER QUALITY FOLLOWING LAND APPLICATION OF FOOD PROCESSING WASTEWATER

***Investigators:* Florence Cassel S.[1*], Mary McClanahan[1], Shankar Sharmasarkar[2], and Dave Goorahoo[1]**

***Collaborators:* Ronald Crites[3], Jordan Smith[3], Jo Anne Kipps[4], and Stephen Klein[4]**

[1]California Water Institute, California State University, Fresno, CA
[2]Water Management Research Laboratory, USDA, Parlier, CA
[3]Brown and Caldwell, Sacramento, CA
[4]California Regional Water Quality Control Board, Central Valley Region, Fresno, CA

Application of food processing wastewater to agricultural lands is a widely used waste treatment and disposal technique. However, excessive application of wastewater can lead to subsurface and ground water degradation, because these wastewaters typically contain elevated levels of organic carbon, total suspended solids, nutrients, and minerals. Thus, it is necessary to evaluate the effects of various loading rates and irrigation application depths on the quality of percolated water, in order to demonstrate the long-term sustainability of these discharges. A three-month observational study of land application of tomato-processing wastewater was conducted in the Central Valley of California. The purpose of the field investigation was to determine the percolate water quality following application of wastewater at various biological oxygen demand (BOD) loading rates through surface irrigation. Three BOD loading rates were selected for the study: canal water (CONTROL), tomato processing wastewater (STRAIGHT), and a combination of tomato-processing wastewater and canal water (MIXED). Percolate waters were sampled with suction lysimeters installed at a 2 ft depth. Moisture content and redox potential were monitored continuously during the processing season. Results of this observation study showed that tomato-processing wastewater applied at the selected loading rates could leach into the groundwater. Elevated levels of NO_3-N, Cl, SO_4, Mn, Fe, and TDS were found in percolate waters below the root zone. The study also showed that removal of nitrogen and organics occur following application of wastewater. Reduced nitrate and TKN values were found under higher loading rates stressing the importance of BOD for denitrification of the applied total nitrogen. Elevated BOD loading did correlate to increases in alkalinity of the percolate waters. The significant increase in alkalinity and decrease in TDS with increasing BOD loading supports the dissolution of carbon dioxide during the aerobic decomposition of organics. Results also illustrated that the oxygen demand generated from the BOD loadings is taking place over several days.

* Corresponding author: 5370 N. Chestnut Ave., M/S OF18, Fresno, CA 93720; Tel (559) 278-2066; Fax (559) 278-6033; Email: fcasselss@csufresno.edu

A Preliminary Study of Relationship Between E-Coli, Total Suspended Solids and Ammonium in Dairy Lagoon Effluent

Genett Carstensen and Dave Goorahoo*

Center for Irrigation Technology, California State University, Fresno
5370 N. Chestnut Fresno, CA 93740.
* Contact: dgooraho@csufresno.edu (559)278-8448, gcarstensen@csufresno.edu (559)278-5289; FAX (559)278-6033

California is the number one dairy state, producing 20% of the nations milk supply. California's 2,150 dairy families house 1.55 million milk cows. Approximately one out of every six dairy cows in the U.S. lives in California. While the growth of this industry results in significant economic returns for the region, there is the issue of effective manure management. In dairy operations, manure is commonly handled as an effluent stream of liquid or slurry manure by means of hydraulic flushing - lagoon storage - irrigation system. In the process of flushing to the fields a series of cross contaminations have been known to occur that effect human health and water supply. Other major problems associated with the manure management are high solids and nutrient contents of the effluent stream, along with the bacterial contamination. While bacteria helps breakdown solids in the effluent stream, it can also be a major concern to dairymen in the form of sick cows and lost production.

For this study the effluent streams from two dairies were examined at several different locations around the dairy. These dairies differed in both sizes and management practices. For example, on the smaller dairy (approximately 500 head herd size) the effluent was periodically aerated prior to pumping to fields. On the larger dairy (1500 head herd size), there was no aeration and the effluent was generally stored for longer periods in multi-stage lagoons. Samples were collected and were tested to determine the Total Suspended Solids (TSS), pH, Electrical Conductivity (EC), Ammonium (NH_4) concentration and E-coli present. The major objective was to investigate if there is any correlation between E-coli levels and the relatively easily measurable parameters such as TSS, pH, EC and NH_4.

There was no observable trend between E-coli and either Total Suspended Solids and NH_4. However, the interaction of Total Suspended Solids and Ammonium showed a significantly positive ($p=0.001$) effect on e-coli population. On the small dairy, E-Coli counts decreased as the pH dropped from around 8.0 to 6.5 in flush lines and in both the primary and secondary lagoons. Furthermore, Total Suspended Solids, Ammonium and Ecoli showed a statistical difference between dairies. This indicates that dairy management practices may be the key to a less polluting dairy. Further work will focus on identification of specific management practices and their effect the various parameters measured in this study.

USE OF SUDAN GRASS AND EARLY SOIL TESTING TO OPTIMIZE NITROGEN MANAGEMENT FOR PROCESSING TOMATOES

Carlos Fandiño[1], Don May[2], Jeff Mitchell[3], and Sharon Benes[1]

[1]CA State University, Fresno; Dept. of Plant Science, 2415 E. San Ramon Ave. M/S AS72, Fresno, CA 93740-8033, cfandinol@hotmail.com, sbenes@csufresno.edu , (559)-278-2255
[2]UCCE Fresno County, cefresno@ucdavis.edu, tel: (559) 456-7553
[3]Univ. of California, Kearney Agricultural Center, mitchell@uckac.edu, (559) 646-6593

Processing tomatoes have been an important and profitable vegetable crop in California's Sacramento and San Joaquin Valleys for many years. In both 2000 and 2001, state-wide harvested acreage exceeded 250,000 acres. High profitability has lead some farmers to apply insurance rates of nitrogen fertilizer thereby creating the potential for negative impacts on groundwater quality and growers' earnings. Although new commercial varieties have been released, relatively few fertilizer response trials have been conducted on these varieties. Furthermore, most of the earlier trials did not take residual soil nitrogen into account in the calculation of fertilizer requirement. Re-evaluation of N fertilizer recommendations could therefore reduce environmental damage and increase profitability.

Fine-tuning nitrogen fertilizer rates and the use of a winter cover crop in a processing tomato rotation can minimize the negative environmental impacts from N application without affecting economic yields. This experiment evaluated tomato yield and quality in response to N fertilizer rates and the use of sudangrass as a cover crop to scavenge residual soil nitrogen. A presidedress soil nitrate test was employed to determine a critical soil nitrate value to be used in the development of N fertilizer recommendations.

Soil sampling was carried out before the N sidedress for the tomato, after sudangrass seeding and, after the tomato and sudangrass harvests. Leaf nitrate analysis was done on the tomatoes and the sudangrass. Sudangrass biomass and tomato canopy cover, yield and quality factors were measured.

Significant differences were found in tomato yield and soluble solids in response to N fertilizer rate. Sudangrass grown as a cover crop after the tomatoes and either removed or incorporated, did not significantly affect tomato yields and quality factors, but the interaction between N fertilizer rate and the sudangrass was significant. The most appropriate N fertilizer rate for tomato was 150 lbs of N $acre^{-1}$ and at this rate yields were higher when sudangrass was included in the rotation. The critical presidedress soil nitrate level was between 15.5 and 18 ppm of NO_3-N. Tomato tissue nitrate sufficiency levels calculated from this experiment were highest for the no sudgangrass plots were residual soil nitrogen tended to be highest and were lower for the sudangrass removed and sudangrass incorporated treatments where residual soil nitrate was lower.

It was concluded that the use of sudangrass as a cover crop in a tomato rotation can effectively scavenge residual soil nitrate and improve N utilization by the tomato. These results underline the importance of taking residual soil nitrogen into account during fertilizer response trials and in the utilization of N fertilizer recommendations from these trials.

Addition of Surfactants to Improve Irrigation Efficiency in Commercial Turf Systems

D. Goorahoo[1*], G. Carstensen[1], D. F. Zoldoske[1], S. Kostka[2], K. Mauser[2] and M. Franklin[2].

[1]Center for Irrigation Technology. California State Univ.- Fresno. 5370 N Chestnut Ave, Fresno, CA 93740.
[2]Aquatrols Corporation of America. 5 N. Olney Ave. Cherry Hill, NJ 08003

*Contact: Tel.- (559) 278 8448; Fax: (559) 278 6033 e-mail: dgooraho@csufresno.edu

There is increased competition for water supply with agriculture from expanding urban population and environmental restoration. In addition, the Turf industry must also adhere to strict environmental protection regulations. As a result, the "Green Industry" has been adopting Best Management Practices (BMPs) in order to enhance water use efficiency and thereby ensure its sustainability. Examples of the strategies currently used in establishing BMPs for the turf grass industry include: laser leveling of fields; lining of ditches; use of soil moisture monitoring devices; use of overhead or drip irrigation systems; use of wind and rain sensors; reuse of water on site; on-site water management analysis; early mornings and late night waterings; higher mowing during the hotter months; and, use of effluent water for irrigation.

Another approach being adopted by the turfgrass industry is the application of *non-ionic surfactants.* A SURFACTANT (SURFace ACTive AgeNT) or wetting agent is a compound that contains a hydrophilic (water loving) and hydrophobic (water hating) segments. *Non-ionic surfactants* are detergent-like substances that reduce the surface tension of water, which theoretically should allow it to penetrate and wet the soil more easily. Preliminary column and field studies with non ionic surfactants have demonstrated improved infiltration into soils and reduced soil water repellency. However, there is need for more field scale evaluations of different surfactants applied at various application rates.

The overall goal of the current research is the evaluation of systematic application of surfactants as a management strategy for commercial turf systems such as golf courses. Specific objective of the work presented here was to investigate the impacts of three surfactant formulations, applied at two rates, on steady rate infiltration, water storage in the root zone, and overall turf quality.

The trials comprised of two experiments: (1) A High Rate experiment; and, (2) A Low Rate experiment. A total of 32 experimental plots (2 meters x 2 meters) were used, with 16 plots for the High experiment and 16 plots for the Low experiment. The areas chosen for the experiments were based on the recommendations of the golf course superintendent. The High Rate experiment was conducted in an area characterized by lower water infiltration and by relatively poorer turf quality than the area used for the Low Rate experiment. Both experiments followed a completely randomized design with four treatments replicated four times.

Treatments for Low Rate Experiment: (1) L0- no surfactant, Control; (2) L1- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2; (3) L2- a commercially available non-ionic surfactant blend, applied once a month at 10mls/100m^2; and, (4) L3- an experimental surfactant formulation, applied once a month at 250mls/100m^2.

Treatments for High Rate Experiment: (1) H0- no surfactant, Control; (2) H1-a commercially available non-ionic surfactant blend, applied once a month at 25 mls/100m^2; (3) H2- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2; and, (4) H3- an experimental surfactant formulation, applied **twice** a month at 250mls/100m^2.

Infiltration studies were conducted in June, August and October in 2001, and in January 2002. Periodically, volumetric soil moisture readings within 0-20cm were taken two hours apart, and the relative change in moisture content determined. The golf course superintendent conducted visual ratings of the plots for color, density, uniformity, general growth vigor, and overall turf quality. A scale of 1 to 9 was used where: 1 to 3 = unacceptable; 4 to 6 = acceptable; and 7 to 9 = superior.

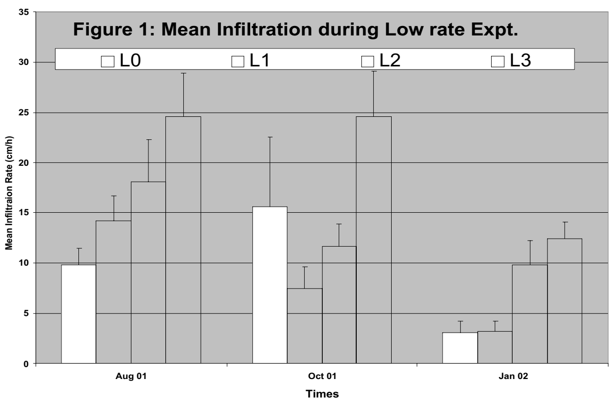
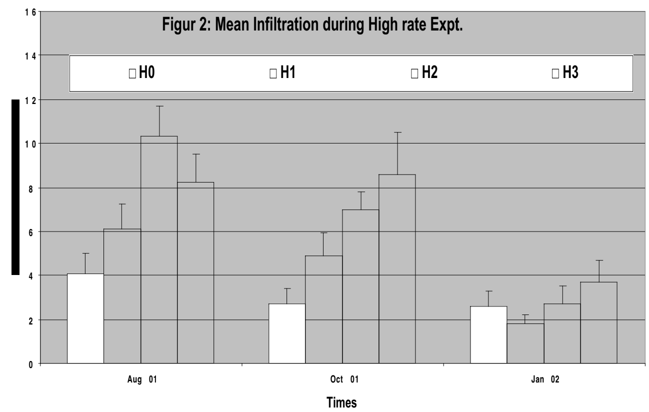


Figure 1: Mean Infiltration during Low rate Expt.



Figur 2: Mean Infiltration during High rate Expt.

Surfactant L3 resulted in the highest infiltration at low application rates (Fig 1). H2 and H3 significantly increased infiltration at the high rates (Fig. 2).

Date	L0	L1	L2	L3	H0	H1	H2	H3
Aug 01	7.1	1.9	11.5	6.8	7.3	11.9	6.3	3.0
Oct 01	7.1	1.7	12.4	6.9	9.6	5.3	8.2	5.8
Jan 02	5.0	2.6	9.4	6.8	5.5	11.3	12.5	8.6

Table 1: Average changes in root zone soil moisture content (%)

Treatment L2 resulted in the greatest changes in root zone moisture at Low application rates. For the High rates, treatments H1 and H2 resulted in greatest water losses (Table 1).

There was a general improvement in turf quality of all plots due primarily to visual improvements in color (Figs 3 & 4) and growth vigor (Figs 5 &6).

Figure 3: Mean color rating for Low rate experiment at (a) July 2001 and (b) May 20

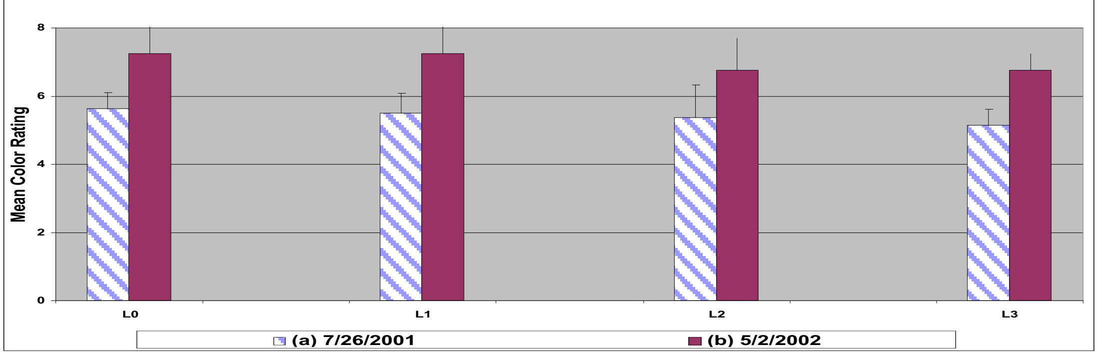


Figure 4: Mean color rating for High rate experiment at (a) July 2001 and (b) May 20

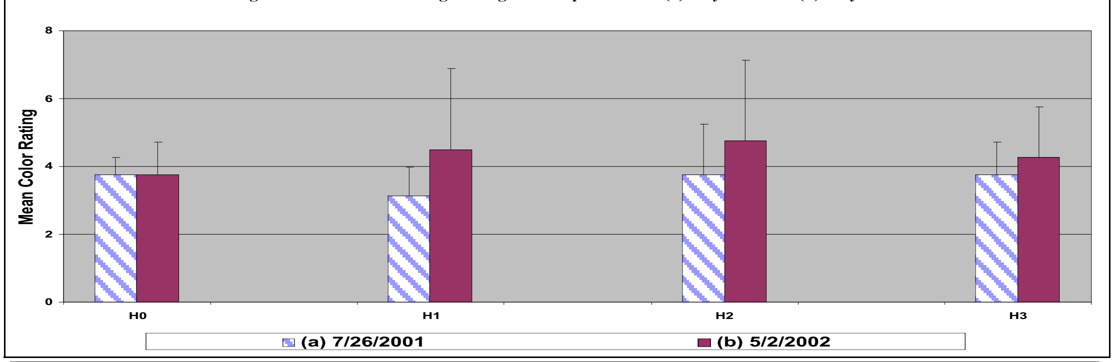


Figure 5: Mean growth vigor for Low rate experiment at (a) July 2001 and (b) May 20

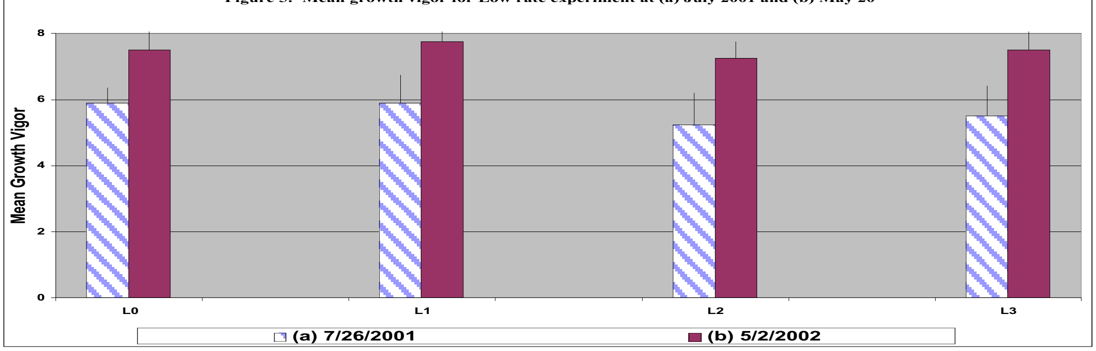
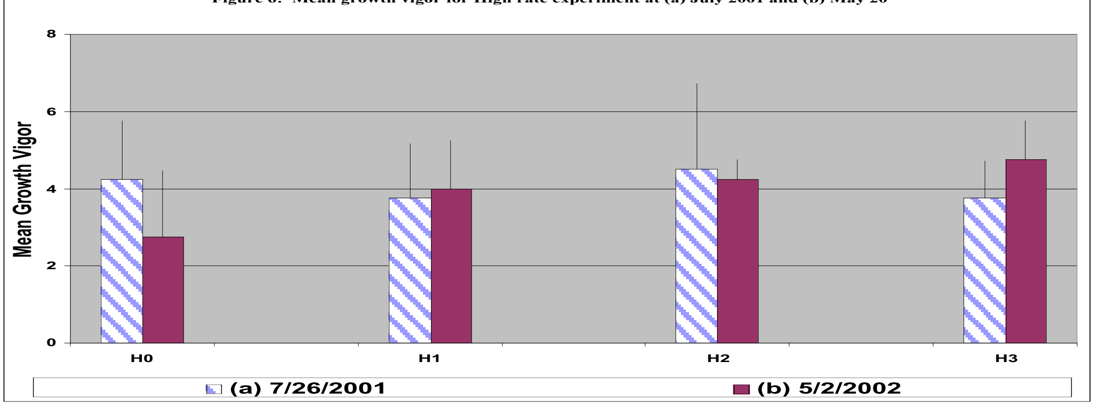


Figure 6: Mean growth vigor for High rate experiment at (a) July 2001 and (b) May 20



Conclusions and Recommendations:

- There was generally a positive effect of the surfactants on the overall improvement in turf quality.
- Surfactant addition significantly affected infiltration rates at both the Low and High application rates.
- The L3 surfactant resulted in the highest infiltration at low application rates.
- Both H2 and H3 surfactants significantly increased infiltration at the high rates.
- For the low application rates, the surfactant that resulted in the greatest increased infiltration also indicated the potential for maximum water use efficiency.
- For the high application rates, water loss from the root zone for the surfactant treated plots were either greater than or equal to that from the control plots.
- It is suggested that surfactant treatment L3 can be used on plots that are of relatively high quality to ensure maximum water use efficiency.
- It is recommended that for plots of relatively poor turf quality and reduced infiltration rates, at least one application of H2 or H3, and possibly up to a maximum of three consecutive monthly applications, at the rates used in the current study can be used to increase infiltration rates. More than three rounds of applications in consecutive months may result in water percolating pass the turfgrass root zone.