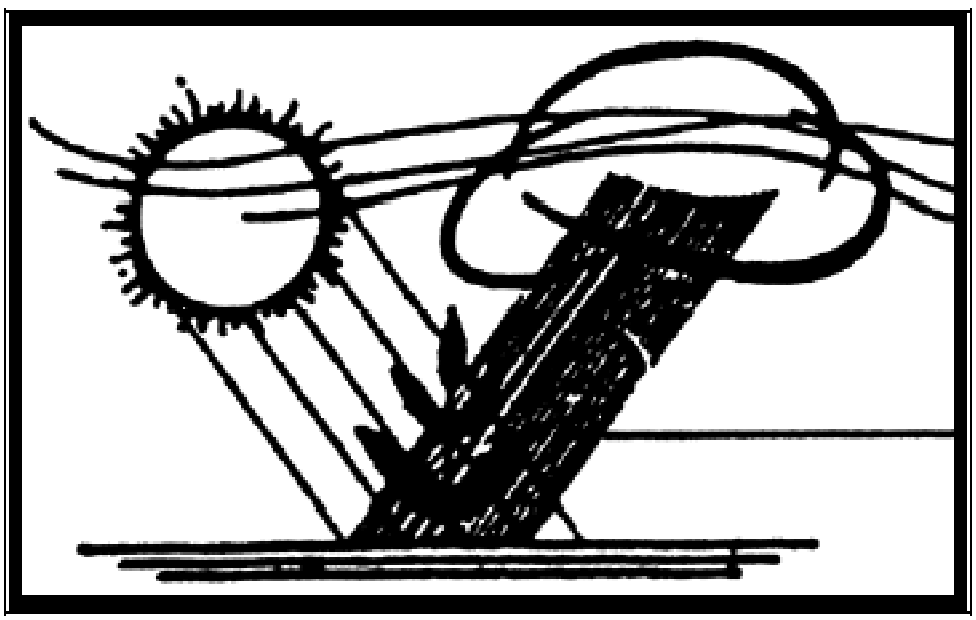
CONFERENCE PROCEEDINGS

2009
California Plant and Soil Conference

Biotechnology in California Agriculture



California Chapter of the American Society of Agronomy

Co-sponsored by the California Plant Health Association

February 3 & 4, 2009

Piccadilly Inn University Hotel
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CALIFORNIA PLANT & SOIL CONFERENCE
Biotechnology in California Agriculture

TUESDAY, FEBRUARY 3, 2009

10:00 **General Session Introduction** – Session Chair & Chapter President – Tom Babb, CA Dept of Pesticide Regulation

10:10 **Biotechnology 101: (some of) What You Need to Know in a Few Minutes –** Peggy Lemaux, Cooperative Extension Specialist, Agriculture and Biotechnology, UC Berkeley

10:40 **Biotechnology: Balancing Potential Environmental Cost with Probable Benefits –** Paul Gepts, Professor and Geneticist, Department of Plant Sciences, UC Davis

11:10 **Biotechnology: Real World Experiences in Alfalfa –** Dan Putnam, Cooperative Extension Specialist, Alfalfa and Forage Crops, UC Davis

11:30 Discussion

12:00 **Western Plant Health Luncheon Speaker**: Leonard Gianessi, director of the Crop Protection Research Institute – "**The Importance of Pesticides in California"**

CONCURRENT SESSIONS (PM)

I. **Cultural Practices that Affect Pest Management**

1:30 Introduction - Session Chairs: **Ben Faber,** UCCE Ventura Co.**; Suduan Gao,** USDA, ARS.

1:40 **Mulch Effects on Trees**– James Downer, UCCE Ventura Co.

2:00 **Cultural Practices to Reduce Pest and Disease Pressure in Vegetables-**Surendra Dara, UCCE Santa Barbara Co.

2:20 **Cultural Practices in Citrus/Avacado to Reduce Pests** – Ben Faber, UCCE Ventura Co.

2:40 Discussion

3:00 BREAK

3:20 **Farming without Fumigants - Myth or Reality** – Becky Westerdahl, UC Davis

3:40 **Challenges in Weed Management without Methyl Bromide** - Bradley Hanson, USDA, ARS

4:00 **What to Consider When Emission Reduction is Required from Soil Fumigation** – Suduan Gao, USDA, ARS

4:20 Discussion

4:30 **ADJOURN**

II. **Nutrient Management**

1:30 Introduction – Session Chairs: **Sharon Benes,** Fresno State**; Ben Nydam**, Dellavalle Lab, Inc.

1:40 **Timing of Nutrient Application -Table Grapes** – Jennifer Hashim, UCCE Kern Co.

2:00 **Grapevine Nutrition–An Australian Perspective -** Rachel Ashley, Foster Wine Estates (Beringer)

2:20 **How to Develop a Nutrient Management Program for Nut Crops** – Bob Beede, UCCE Kings Co.

2:40 Discussion

3:00 BREAK

3:20 **Timing of Nutrient Application– Stone Fruit** - Keith Backman, Dellavalle Lab, Inc.

3:40 **Fertilization of Perennial Tree Crops: Timing is everything!** – Carol Lovatt, UC Riverside

4:00 **Nutrient Management with Costly Fertilizers** – Jerome Pier, Western Farm Service

4:20 Discussion

4:30 **ADJOURN**

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

WEDNESDAY, FEBRUARY 4, 2009
CONCURRENT SESSIONS (AM)

III. Nitrogen Management

8:30 **Introduction** – Session Chairs: **Robert Mikkelsen**, IPNI and **Dave Goorahoo**, California State University, Fresno

8:40 **Process Based Models for Optimizing N Management in California Cropping Systems** – William A Salas, Applied GeoSolutions, LLC

9:00 **Quantifying Nitrous Oxide Emissions from N fertilizer Management Practices** – Johan Six, UC Davis

9:00 **Factors Affecting a Nitrogen Budget for California Cotton** – Bruce Roberts, California State University, Fresno

9:40 Discussion

10:00 BREAK

10:20 **Managing N on Organic Farms: A Grower's Perspective** – Tom Willey, T & D Willey Farm

10:40 **Evaluating Organic N Fertilizers using the Food Web Rating™ Approach** – Tim Stemwedel, California Organic Fertilizers

11:00 **Optimizing Nitrogen Management in Organic Farms with AirJection® Irrigation**.– Dave Goorahoo, California State University, Fresno

11:20 Discussion

IV. Commodity Boards

8:30 **Introduction** – Session Chairs: **Lori Berger,** CA Specialty Crops Council and **Joe Fabry**, Fabry Ag Consulting

8:40 **Tracking Commodity Inputs with Technology-** Joe Middione, Agrian, Inc

9:00 **Mitigating pesticides in sediments transported from irrigated agriculture–** Parry Klassen, CURES

9:20 **The High Cost of Aflatoxins-**Kelly Covello

9:40 Discussion

10:00 BREAK

10:20 **Ag Air Quality Issues in the SSJV** - Johnny Siliznoff, USDA, NRCS

10:40 **Management Practices and Water Quality: Conflict, Compromise and Considerations** – Kay Mercer, Agricultural Watershed Coalition

11:00 **Trends in the Grape Industry** – Nat DiBuduo, Allied Grape Growers

11:20 Discussion

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

CONCURRENT SESSIONS (PM)

V. Irrigation & Water Quality

1:30 **Introduction** – Session Chairs: **Larry Schwankl,** UC Davis, **Blake Sanden**, UCCE Kern Co.

1:40 **Irrigating Alfalfa with Limited Water Supplies –** Blaine Hanson, UC Davis

2:00 **Irrigating Stone Fruit with Limited Water Supplies** – Scott Johnson, UC Davis

2:20 **Drought Irrigation Strategies for Citrus, Almond, and Pistachio** – Dave Goldhamer, UC Davis

2:40 **BREAK**

3:00 **Managing Organophosphate Pesticide Residues Using Degradation Enzymes** – Terry Prichard, UC Davis

3:20 **Using Mating Disruption to Reduce Use of OP Insecticides in peaches** – Walt Bentley, UC IPM

3:40 **Using Aerosol Pheromone Puffers for Area-wide Suppression of Codling Moth in Walnuts** – Joe Grant, UCCE, San Joaquin Co.

4:00 Discussion and ADJOURN

VI. Dairy Management

1:30 **Introduction** – Session Chairs: **Brook Gale,** USDA, NRCS and **Rob Mikkelsen,** IPNI.

1:40 **Dairy Feed Management Basics to Reduce Nutrients to Cropland-** Joe Harrison, Washington State Univ.

2:00 **Dairy Lagoon Water Nitrogen Mineralization** - Aaron Heinrich & Stuart Pettygrove, UC Davis

2:20 **SSLAP, A Land Application Program, Matching Manure Mineralization to Crop Uptake-**David Crohn, UC Riverside

2:40 **BREAK**

3:00 **Infrastructure to Facilitate Nutrient Management** – Marsha Campbell-Matthews, UCCE Stanislaus Co.

3:20 **Progress Report on Dairy Management Plans to RWQCB Region 5** - Rudy Schnagl, RWQCB-Region 5

3:40 **Dairy Consultants Experiences in the Field: Panel Discussion** – CCA's & Consultants

4:00 **Discussion and ADJOURN**

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Poster Abstracts

California Chapter of American Society of Agronomy

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Year	President
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California Chapter of American Society of Agronomy

Past Honorees

Year	Honoree	Year	Honoree
1973	J. Earl Coke	1997	Jolly Batcheller
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1975	Milton D. Miller		Joseph Smith
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	Perry R. Stout	1999	Bill Fisher
1977	Henry A. Jones		Bob Ball
1978	Warren E. Schoonover		Owen Rice
1979	R. Earl Storie	2000	Don Grimes
1980	Bertil A. Krantz		Claude Phene
1981	R. L. "Lucky" Luckhardt		A.E. "Al" Ludwick
1982	R. Merton Love	2001	Cal Qualset
1983	Paul F. Knowles		James R. Rhoades
	Iver Johnson		Carl Spiva
1984	Hans Jenny	2002	Emmanuel Esptein
	George R. Hawkes		Vince Petrucci
1985	Albert Ulrich		Ken Tanji
1986	Robert M. Hagan	2003	Vashek Cervinka
1987	Oscar A. Lorenz		Richard Rominger
1988	Duane S. Mikkelsen		W. A. Williams
1989	Donald Smith	2004	Harry Agamalian
	F. Jack Hills		Jim Brownell
1990	Parker F. Pratt		Fred Starrh
1991	Francis E. Broadbent	2005	Wayne Biehler
	Robert D. Whiting		Mike Reisenauer
	Eduardo Apodaca		Charles Schaller
1992	Robert S. Ayers	2006	John Letey, Jr.
	Richard M. Thorup		Joseph B. Summers
1993	Howard L. Carnahan	2007	Norman Macillivray
	Tom W. Embelton		William Pruitt
	John L. Merriam		J.D. (Jim) Oster
1994	George V. Ferry	2008	V. T. Walhood
	John H. Turner		Vern Marble
	James T. Thorup		Catherine M. Grieve
1995	Leslie K. Stromberg	**2009**	**Dennis Wescot**
	Jack Stone		**Roland Meyer**
1996	Henry Voss		**Nat Dellavalle**
	Audy Bell		

California Chapter
American Society of Agronomy

2008 Chapter Board Members

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One-year term	Suduan Gao, USDA - ARS Blake Sanden, UCCE, Kern County Robert Mikkelsen, Potash & Phosphate Institute
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Three-year term	Dave Gorahoo, Associate Professor, Dept of Plant Science, CSUF Lori Berger, Executive Director, CA Speciality Crops Council Brook Gale, USDA-NRCS

2009 Honorees

Dennis W. Wescot

Roland D. Meyer

Nat B. Dellevalle

Dennis W. Westcot

Dennis Westcot was born in Santa Monica and raised on a small farm in a rural area of Southern California (Cherry Valley) when it was an all day affair to drive into town. The family fruit farm was located directly adjacent to the 3.6-million acre San Gorgonio Wilderness and Dennis spent many hours exploring this domain when he wasn't surfing off the California coastline. Dennis' parents worked off the farm and he took charge of many of the farming tasks and thus began his love for agriculture and the outdoors. His Davis yard is full of fruit trees and he still finds time to climb any mountain he can.

Dennis received his B.S. in Agronomy from then Cal Poly, Pomona in 1967. It was during this time that he became interested in water quality and salinity as Cal Poly began using municipal wastewater to irrigate the campus. His senior project tested use of this higher salinity water for crop production. In 1967, he began graduate school in Soil Physics at Iowa State University. Graduate school however was interrupted as the Vietnam War was in full swing and someone decided in 1967 that all single graduate students only needed one year to finish.

His time in the Army was a turning point. While stationed in El Paso, Texas as a bounty hunter (no more explanation needed), he met a young professor from New Mexico State University who was working on the impact of irrigation return flows on ground and surface water quality. Upon completing his service, he returned to graduate school in New Mexico and earned an M.S. Degree in Soil Physics in 1972 with a minor in Surface and Ground Water Hydrology. This laid the foundation for his future career.

Immediately after graduation Dennis began work with the Central Valley Water Quality Control Board as their Southern San Joaquin Valley Agricultural Specialist. During this time he coordinated development of the water quality control plan for the largest irrigated area in California (Tulare Lake Basin) and developed numerous water quality monitoring and testing programs for projects involving land disposal of municipal and industrial wastewater and the use of wastewater for irrigation.

In 1975, Dennis was recruited to develop the water quality program for the United Nations Food and Agricultural Organization (FAO). He and his family moved to Rome for a one-year assignment that turned into 7 years. He served as FAO's water quality and salinity specialist traveling to assist irrigation projects in over 40 developing countries. While at FAO, Dennis and UC Extension Specialist Bob Ayers (1992 honoree) prepared "Water Quality for Agriculture", an international handbook on dealing with higher salinity waters and other water quality problems. This handbook, now over 30 years old, is in its 5th printing and is available in 5 languages.

In 1982, Dennis returned to the Water Quality Control Board in its Sacramento Office where he was the principal policy and technical advisor on Bay-Delta issues, water quality, and salt management issues related to agricultural and other types of waste disposal activities within the Central Valley. During his 35 years at the Board, he managed the Board's Agricultural Unit whose role was to develop and implement point and non-point source water quality control programs for Central Valley agriculture. He has played a major role in the development of water quality standards, dairy waste disposal techniques and special studies on water quality and waste load assessments. These efforts include some of the nation's most extensive monitoring and assessment programs dealing with salinity, nitrate, selenium and other contaminants in surface and ground waters. His efforts have laid the foundation for how the State deals with agricultural surface and subsurface drainage problems, the impacts of drainage water disposal and reuse, drainage water reduction programs and animal waste management programs. Partially through his efforts, California agriculture leads the nation in water quality protection and sets the standard for the remainder of the country.

Dennis has been an active member of California ASA and has served on the Board, as its president (1996) and on the scholarship committee. Dennis retired from the Water Board in 2006 but does not sit still. He acts as a consultant in state and national policy and program development on water quality, including salinity control and dairy waste management. He has served as a consultant and advisor on salinity in the Nile Delta of Egypt and wastewater management in the Central Valley of Chile, the Mezquital Valley of Mexico and in the Jordan River Valley of Jordan. He has published numerous articles on water quality, salinity control, water quality assessments and agricultural water quality impacts including international guidebooks on Water Quality for Agriculture, Municipal Wastewater Reuse in Agriculture, Guidelines for Evaluating Water Quality Impacts from Tile Drainage Water Disposal and Monitoring Biological Contamination of Agricultural Water Supplies.

Throughout his career, Dennis has been supported by his wife Mary of more than 36 years and their 3 children. They are currently enjoying 6 grandchildren. At present Dennis is the Project Administrator for the San Joaquin River Group Authority, a joint powers authority of several water agencies that are coordinating the timing of flows in the San Joaquin River to increase salmon smolt survival and migration across the Delta.

Roland D. Meyer

Extension Soils Specialist Emeritus, Dept of Land, Air and Water Resources,
University of California, Davis

Dr. Meyer began his life on a diversified farm in Southeast Nebraska. He was active in 4-H and Future Farmers of America where he received the State Farmer and numerous other awards. Both his Bachelor (1958) and Master (1960) of Science Degrees were in Agronomy with an emphasis in soil fertility, from the University of Nebraska, Lincoln. His Master's research was on the gaseous nitrogen losses from fertilized Nebraska soils. After serving with the Nebraska Air National Guard he worked for Farmland Industries, Inc. in Kansas City and as a Fertilizer and Agricultural Chemical Fieldman in North Central Nebraska.

He continued his education at Iowa State University, Ames, where he conducted research on the yield and chemical composition of corn and nitrate movement in the soil as influenced by time of application and source of nitrogen. He was awarded the Doctor of Philosophy Degree in Agronomy-Soils with minors in statistics and plant physiology in 1973. He joined the University of Missouri Cooperative Extension as an Area Agronomy Specialist, located in Fulton, Missouri, where he was in charge of two soil testing laboratories and developed fertilizer and lime recommendations. He cooperated in the development of corn, soybean and pasture fertilizer management and soil conservation programs for a three county area in Central Missouri.

Dr. Meyer became an Extension Soils Specialist with the University of California Cooperative Extension in the fall of 1973 located in Davis. His major interest was that of promoting the implementation of improved fertility practices in agricultural production founded on information developed in applied field research. His research and extension program involved working with diagnostic approaches to guide the effective and efficient fertilization of alfalfa, other legumes in pasture systems and many other crops. Reevaluation of current and proposed new plant analysis guidelines along with photos of nutrient deficiencies for nitrogen, phosphorus, potassium, sulfur, boron and molybdenum were developed for alfalfa and published in several hardcopy and web based formats. Research on the amount and frequency of phosphorus and sulfur necessary to maintain highly productive winter pasture legumes was conducted over a number of years. Along with the effort to provide proper nutrition for plants there was a major emphasis to provide more desirable forage for animals. Both molybdenum toxicities and deficiencies exist in forages consumed by livestock and wildlife throughout California. Selenium concentrations in forages throughout California are known to be marginally adequate to deficient to meet domestic livestock and wildlife requirements. Research was conducted to increase the selenium concentration of alfalfa following the development of several new selenium fertilizers.

With the assistance of a number of Farm Advisors, a major research and extension effort was carried out on the use of fly and bottom ash from wood burning electrical power generation plants as a liming and potassium fertilizer source for agricultural crops. Since legumes such as alfalfa respond to limed acid soils, the influence of these ash materials upon animal feed value of legume forages was evaluated. Neither excessive molybdenum nor selenium were found to be present and in several situations found to be beneficial. Another significant contribution to agriculture was the evaluation of sewage sludge or biosolids applications to crops, particularly rangeland and other animal forage production sites. Elevated molybdenum and other nutrients were evaluated as possible detrimental components in forages following the application of these waste materials. Bottom ash applications were also demonstrated to be effective in the production of several timber species.

Dr. Meyer conducted a long term (18 years) research and extension program regarding the utilization of nitrogen, potassium and other nutrients by almond. Soil potassium supplies were shown to be depleted following several years of attaining high nut yields but little yield response occurred with potassium sulfate fertilization. Phosphate neutralization of manganese in acidic soil for the utilization of potassium by almond to enhance nut yield was demonstrated when compared to the use of potassium sulfate. Early career research on peaches indicated that greatly reduced amounts of fertilizer nitrogen were required for the production of peaches whether spring or fall applied on sandy soils using careful water management.

Working with several Farm Advisors in conjunction with organic producers it was demonstrated that several different legumes were able to supply adequate amounts of nitrogen through biological fixation of nitrogen for the fruit crops apple and peaches. The use of localized placement of gypsum as a calcium source to offset high soil magnesium in serpentine derived soils for the improvement of grape growth and production was demonstrated in the North Coast wine producing areas.

During the latter part of his career Dr. Meyer became involved in the effective utilization of various waste products including animal manures and food processing wastewater, and composts of these and other materials. These materials can serve as nutrient sources and soil amendments in agriculture, forestry and landscape settings, particularly for organic producers. Careful application of dairy wastes in the production of corn silage was demonstrated to result in yields equal to that of commercial nitrogen fertilizer with the benefit of nitrate moving to groundwater being significantly reduced.

Dr. Meyer has for thirty two years been engaged in research and extension activities concerning the efficiency, economics and environmental impacts of fertilizer application to California crops. Specific areas of interest have been the rate, placement, timing and frequency of nitrogen, phosphorus, potassium, sulfur and micronutrient applications to potatoes; strawberries—mostly in daughter plant production; a number of vegetables; wheat; barley; oats; corn; irrigated pastures and annual range clovers. Also the rate, timing and frequency of nitrogen, phosphorus, potassium and micronutrient application to grape, fruit and nut crops along with investigating the role of mycorrhizal fungi in the uptake of nutrients in these and other perennial plant species.

Of particular concern has been the development and use of plant tissue and soil testing to diagnose and evaluate the nutritional status of plants as influenced by fertilizer treatments. Along with the plant nutrient deficiencies, another major area of concern has been the role that various elements such as molybdenum, copper, sulfur, cobalt and selenium which are contained in forage plants play in animal nutrition. The frequency and rate of nitrogen, phosphorus, and sulfur fertilizer application to timber, Christmas tree and wood for paper or fuel producing species have been investigated.

Perhaps the highlight of his career has been travel to the countries of China, France, Germany, Greece, Hungary, Italy, Mexico, New Zealand and most notably spending a sabbatical leave in England to conduct research on the ammonia volatilization from urea and other nitrogen fertilizers applied in conjunction with animal urine. Each of his three children were able to join he and his wife Marilyn visiting and traveling in England, Scotland, Ireland and France. Since retiring in 2005, he and Marilyn are thankful to God for there ability to enjoy traveling and spending time with their twelve grandchildren

Nat B. Dellavalle

Nat Dellavalle was raised on a farm in Madera, California and began his career in agriculture the day he was allowed to accompany his father to the farm. He was driving the farm tractor by the age of 12 and, along with the fun of driving the tractor; he was given the task of tractor maintenance. Nat remembers his father teaching him what to do and then being left with the responsibility of completing his own work. That link between freedom and responsibility has been an important part of Nat's work ethic and a hallmark of his career.

Throughout his secondary education Nat enjoyed math, science, physics, and chemistry. During his senior year in high school Sputnik was launched and inspired Nat to go into engineering. Nat enrolled in Cal Poly San Luis Obispo as an electrical engineering major. Nat had good grades in math and physics, but he flunked out of his electrical engineering laboratory classes, finding that he could not seem to get the color codes straight.

Nat's dorm manager at the time was a soil science major and he introduced Nat to the subject. Eighteen months after changing his major to soil science Nat was required to take a physical for a job and could not pass the color blindness test. He stayed with soil science. Four years, one wife, and a first child later, Nat graduated from Cal Poly with a degree in soils science.

Nat's first job after graduation was as an agronomist with Coit Ranch on the west side of Fresno County. His lists of duties were many: responsibility for fertilizer programs, pest control, cantaloupe pollination, soil and tissue analysis and field evaluation of varieties and cultural practices. Nat grew to understand the demands and constraints of production agriculture while working for Frank Coit. Nat still remembers a few of those early key lessons: Always know where your test plots are – stakes are handy for warming tacos.

Nat's career next took him to Brown & Bryant in Shafter California where he was asked to design, build and operate an analytical laboratory. This was in the fall of 1963 as his wife Ann was expecting the couple's 4th child. The position paid $400/month with the added benefits of acquiring an on-the-job post-graduate degree (diploma not included). In addition to running the laboratory, Nat was involved in on-farm soil and water science, plant nutrition, and provided technical services to growers. At Brown & Bryant, Nat was given a large amount of freedom in developing predictable nutrient responses to fertilizer applications with the goal of reducing over-fertilization while limiting the risk of decreased production. One of Nat's life-long motivations in production agriculture has been to make farmers money (increased productivity) while also reaping some of the benefits. Brown and Bryant gave him the opportunity to make that goal a reality. Many Brown & Bryant associates are still Dellavalle clients to this day.

In 1968 Nat approached Frank Morrow about starting a laboratory in Fresno County. Along with Sherman and Vernon Thomas T-M-T laboratory was started. Again Nat designed, built and managed an analytical laboratory and consulting service, providing service for soil, water, irrigation and plant nutrition management information for production agriculture.

In 1978 along with Phil Dodd, Hugh Rathbun and Keith Backman. Nat started Dellavalle Laboratory Inc. in Fresno, CA. Nat served as president of Dellavalle Laboratory for 29 years and in the spring of 2007 stepped down as president of Dellavalle Laboratory Inc. although he remains chairman of the board of directors. One of the things that Nat is most pleased by is the large number of clients and employees who have had long tenures with Dellavalle Laboratory Inc.

Nat's major contributions to California agriculture include:

- Serving on the forefront in the application of agronomic science to environmental management. Using agronomic and soil science in the management of municipal and food processing wastewater re-use.

- Helping to provide sound agronomic science to help shape policy at the California Regional Water Quality Control Board. Nat was one of the first non-engineers to be accepted to sign reports submitted to the RWQCB.
- Promoting high quality control standards for agricultural laboratories nation wide
- Developing agricultural advisory services independent of regulation.

Nat's Dellavalle's professional affiliations include:

American Society of Agronomy California Association of Agricultural Laboratories
Soil and Plant Analysis Council
Soil Conservation Society of America
Soil Science Society of America
California Certified Crop Advisors Board, 1999 to 2002,
California Chapter of the American Society of Agronomy
Fresno County & City Chamber of Commerce

Advisory Committees Nat Dellavalle has served on include:

California Irrigation Management Information Service (CIMIS), Dept of Water Resources 1982-85
Department of Land, Air and Water Resources, University of California, Davis, 1983-93
Office of Water Conservation, Department of Water Resources, State of California, since 1985
Dean, College of Agriculture and Environmental Sciences, University of California, Davis, 1987-90
Fresno-Clovis Metropolitan, Water Management Plan, 1991-95
Public Works Task Force, Little Hoover Commission, City of Fresno, 1991
Fresno County Agricultural PM-10 Advisory Committee, 1989-1991
Citizens Advisory Group of Industries (Formerly Agricultural PM-10 Advisory Committee), 1991-95
California State University, Fresno, Department of Plant Science & Mechanized Agriculture, 1995
Fresno Fruit Fly Action Coalition Taskforce, Co-chair, 1995 - 1997
Western States Sample Exchange Advisory Committee, University of California, Davis, 1993-Present
North American Proficiency Testing Program for Agricultural Laboratories, Steering Committee, Soil and Plant Analysis Council, 1995 - Present
Western Regional Coordinating Committee, University of Idaho, Twin Falls, ID
Plant Science Department, California State University, Fresno, 1995 - Present
Soil Science Department, California Polytechnic University, San Luis Obispo, CA 1996 - Present
School of Natural Science, California State University, Fresno, 1996 – Present

Nat still remains quite involved in Dellavalle Laboratory Inc. but is taking more time to spend at home, travel with Ann, enjoy grandchildren and care for his mother. Nat and Ann also enjoy being involved with the Fresno Grand Opera and host many of the performers at their home. There is never a dull moment at the Dellavalle home.

2009 Scholarship Recipient and Essay

Essay question:

Who benefits from Biotechnology?

Scholarship Committee:

Suduan Gao

Ben Faber

Carol Frate

Ben Nydam

2008 Winning Scholarship Essay (first place)

Miguel Macias
California State Polytechnic University, Pomona

The Benefits of Biotechnology

Biotechnology is considered as "any technique that uses living organisms or part of organisms, to make or modify products, to improve plants or animals or to develop microorganisms for specific uses" (1 pg.5). I think that everyone can benefit from improved organisms since they have so many applications and help us produce more efficiently and get better products. In this essay I will mention some types of biotechnology such as micro propagation and genetic engineering and how it benefits humanity.

Micro propagation is the propagation of plants from tissue culture. This type of propagation can offer more benefits than traditional propagation because it's possible to create a larger amount of clonal propagules from a small amount of plant material with desire traits and disease free (1 pg.20); this is useful in pest management (2). Biotechnology has also made it possible to sequence, map, and mark specific DNA strands or molecules of desired traits (3). This has been very helpful in genetic engineering which makes it possible to isolate specific genes from one organism and implement them in another organism or to strengthen or suppress genes (4). This has lead to the creation of transgenic organisms that have made farming more efficient, created more nutritious food and produced important foreign products in plants or animals.

The benefit of biotechnology comes from its fruits. Plants have been modified to resist herbicides which reduce the labor cost, soil erosion and compaction and possibly air quality by reducing field operations (5). Plants have been modified to be pest resistant which reduce Pesticide applications and increase yields, plants could be modified to resist disease, be drought tolerant, resist cold temperature or to perform better in poor soils. Plants have also been modified to improve their nutritional value for example golden rice which can decrease malnutrition and blindness in developing countries (6). It is also possible to produce pharmaceutical products in plant and animals, an anti clotting agent ATryn has been produced from goat's milk which is much cheaper than the cell-cultured process and can be produced in larger quantities (7). It is possible to produce vaccines in plants in a much cheaper fashion such as the vaccine for hepatitis B. Biodegradable plastics can also be produced from plants this could lead to a better environment in the future (1 pg.255-257).

It's clear that biotechnology can benefit everyone because it basically allows us to produce more food in the same amount of land and with a higher nutritional value which is a big concern with the growing population. It can also offer a cleaner environment due to less application of pesticides, emissions, and replacement of more harmful industrial products such as plastics. Biotechnology can also make it cheaper to produce pharmaceuticals and in larger quantities making it cheaper to the public. Through correct regulation humanity can benefit much more from biotechnology because it can improve the quality of life especially in developing countries.

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2008 Winning Scholarship Essay (second place)

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Who Benefits from Biotechnology?

Biotechnology is becoming an increasingly important topic as we look for new forms of clean fuel for transportation and new ways to feed our world's growing population. Some positive progress is being made to replace energy inefficient corn starch ethanol, but when it comes to genetically modified foods, I believe there are still too many unanswered questions.

New biotechnology in the form of cellulosic biofules is vastly improved over current corn starch biofules. According to the U.S. Department of Energy's Center for Transportation Research, E85 fuel (85% ethanol blend) made from cellulosic biomass produces a 64% reduction of per-mile greenhouse gas emissions compared to other biofuel options. Recent studies show that ethanol derived from cellulosic biomass provides almost ten times more energy than the ethanol derived from corn per unit of fossil energy used. In addition, these high energy grasses need little or no herbicides or pesticides because they choke out weeds and have very few natural pests or diseases. They are also more water efficient due to deep root systems which also prevents erosion. This new biofuel technology will also help reduce the United States' dependence on foreign oil.

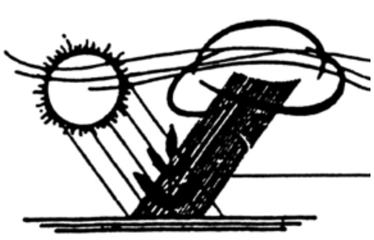
Biotechnology also has the potential to improve crop nutrition and create plants that are easier to grow, but are they a safe? I think more research needs to be done before genetically engineered food crops are deemed safe for human consumption. There are still too many unanswered questions to address before these foods are released into the market. Do genetically engineered crops cause more food allergies? Can they make bacteria more antibiotic resistant? Do they transmit their genes to other plant species? Can plants injected with pesticides kill non targeted insects? Another major concern I have is that there is no label information required on food packaging making it difficult for consumers to make informed choices. I believe biotechnology will be necessary to meet the needs of future generations, but a lot more regulated testing needs to be done, similar to the way the FDA regulates prescription drugs, to make sure these crops are safe to consume.

General Session

Biotechnology in California

Session Chair:

Tom Babb, CA Department of Pesticide Regulation,
Chapter President



Biotechnology 101: (some of) What You Need to Know in a Few Minutes

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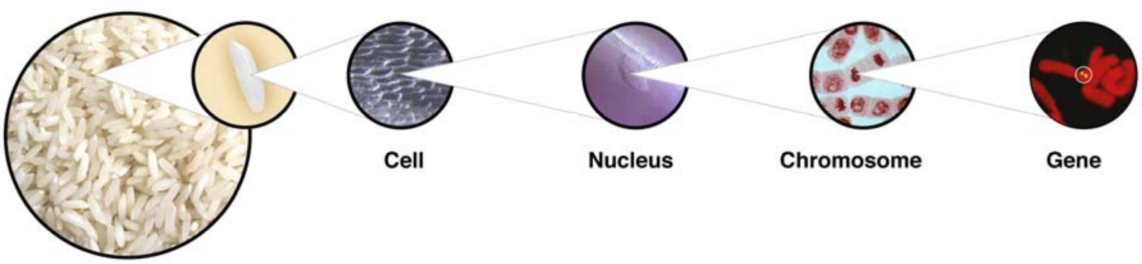
Introduction

Genetic modification of plants and animals by sexual crossing has been taking place for thousands of years. It began when humans decided to be less nomadic, staying in one place rather than moving from place to place in search of food. To increase the food available they began to choose plants with improved traits to breed for the next generation. For example, they might have crossed one plant with higher yields to another plant that had increased pest resistance and screen in the next generation for plants with both higher yield and better pest tolerance. Selection of natural or induced mutations has also been used to find plants with improved traits. Virtually every food today has been modified in these ways, and, as a result, most foods eaten today look little like their ancient relatives. With the advent of genomics and molecular biology, market assisted selection and genetic engineering have also been used to modify plants.

What happens when two plants cross sexually?

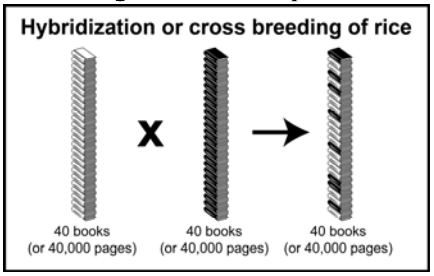
Living organisms are made up of large numbers of individual cells that contain the genetic information specifying what traits the organism will have, such as purple or red fruit, tolerance or susceptibility to disease, height, number of seeds. That information, contained in a small compartment of the cell called the nucleus, is in discrete packets called chromosomes, which are made up of long strings of DNA. The genetic information in DNA is made of individual chemical units organized in small packets, called genes that are responsible for specific traits.



The entire collection of genes in an organism, contained in all of its chromosomes, is like a collection of books with entries on many topic areas. The entries describe exactly what features the organism will have. Each plant species (plants that can interbreed) has its own set of related books and its own features. For a given plant, such as rice, the collection of books is called a genome and contains many topic areas. The entire collection is contained in its DNA, which is written in the same language for all organisms. Many entries in the books in that collection are similar, but some are different. If an alphabetic letter is used to represent each chemical unit in the DNA of rice, it requires a collection of approximately 40 books, each with 1,000 pages, to contain all of the information for a rice cell. In 2005, the complete genome sequence of rice was determined and found to contain approximately 37,500 genes, more than were identified in the human genome! The complete sorghum and the model plant, Arabidopsis, genomes have also been fully sequenced with similar numbers of genes.

How is classical breeding and mutation used to create new crop varieties?

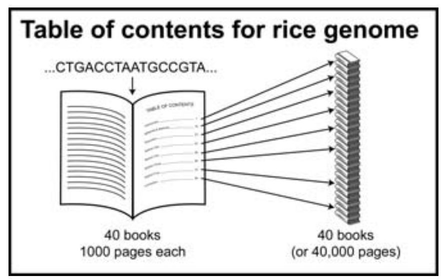
What happens to the genetic information in a cell when we cross two rice plants? Does the next generation of plants end up with 80 books in the set? No. Genetic rules state that the next generation plants can only have the same number as the parent, 40 for rice. So, about half of the information or genes from each parent are kept and about half are lost, yielding a plant with new characteristics. Historically, the person doing the breeding has little direct control over which genes are kept and which are lost. For example, a breeder crosses the male cells (pollen) of one plant with the female cells (eggs) of another plant, observes the outcome, and chooses the plants with the desired traits for the next round of breeding. This process, called classical breeding, results in plants with modified genomes and new mixes of genes.



Mutations, which cause very small changes in DNA, like adding or removing "letters", can happen spontaneously when, for example, plants are exposed to sunlight, or they can be induced when exposed to certain chemicals. This can cause the plant to have new traits; some are beneficial, some are not. A number of foods consumers eat derived from mutations, like Calrose rice and seedless grapes.

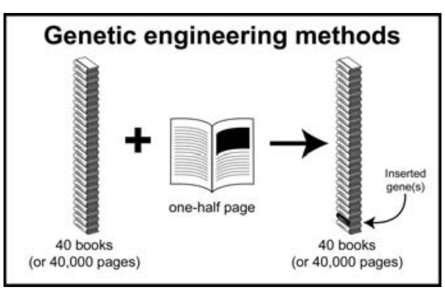
How is marker-assisted selection used to improve crop varieties?

There are two different ways that the new molecular tools can be used to change the genetic makeup of plants. In the first case, called marker-assisted selection (MAS), information in the genome of the plant is used to create a "table of contents" that can help breeders determine if a particular trait from one of the parents is in the next generation plant. It is like using the "find" command in a word processing system to find a particular series of words in a book. In breeding, the "find command" uses chemical tags to determine whether the desired genetic information is in a specific plant. If the chemical tag is found, it is likely the plant contains particular information. This process enables breeders to develop new varieties more efficiently than with the more "observational" classical breeding approach described above. For example, the USDA CSREES-sponsored Coordinated Agriculture Projects for barley, conifers, rice, solanaceae and wheat are developing maps for these crops to speed breeding efforts.



How is genetic engineering used to change crop varieties?

The second molecular method used to improve the genetic makeup of plants involves the direct use of recombinant DNA methods – in a process termed genetic engineering (GE). This approach allows researchers to modify genes in plants in a more directed way than with classical breeding. In this case, the "molecular breeder" finds a specific piece of genetic information, or gene (equivalent to a half of a page), from any living organism, cuts out the desired gene with chemical scissors and pastes it into the genetic material of the same organism or a different one.



How can the two methods, classical breeding and genetic engineering, be used to address an agricultural problem? To answer this question, let's look at two ways to increase sugar content of the commercial tomato, which is made possible because some wild tomato varieties, although quite different in looks and taste, have higher sugar content than others (Bennett et al. 1994).

In the classical breeding approach, breeders crossed the two varieties hoping to get a tomato with higher sugar content, but none of the undesirable characteristics of the wild tomato, like smaller size, bitter taste, and lower yield. After crossing the two varieties and many years of backcrossing to the commercial tomato, they got a higher-sugar tomato. In the analogy, they crossed the two collections of books. Because the genome is slightly larger than rice in the case of tomato, each collection contained 102 books, or 102,000 pages. The plants from the original cross were crossed back to the commercial variety to increase the amount of information from that variety. After many crosses back to the commercial tomato variety, most of the "information" or genes were from the commercial tomato. But the collection still contained about 100 to 200 pages from the wild species. In those 100 to 200 pages was the information for higher sugar, which they wanted, but also information for lower fertility, which they didn't want. This happened because they could not "read" and were unable to select against the other information in the remaining 100 to 200 pages.

They also used a genetic engineering approach. In this case researchers found a half page of information in the tomato that is responsible for breaking down sugar. This gene was cut from the tomato genome with chemical scissors and a reverse copy was inserted back into the tomato plant. The presence of the reverse copy made it difficult for the cell to break down the sugar, making the tomato sweeter. In this approach they changed only a half page of information and inserted only the specific information needed to change sugar content. Using this approach, the unwanted consequence of infertility seen with the classical breeding approach was avoided.

Are classical breeding and genetic engineering the same or different?

In some ways they are the same; in other ways they are different. In both approaches genetic information in a cell is changed or modified. And the exchange uses the same genetic machinery, either in the cell in classical breeding or in the laboratory with genetic engineering. But the two processes are different because with classical breeding gene transfer occurs largely through cross-pollination within a single species (by definition organisms that can interbreed), although examples of cross breeding between different genera has been accomplished, like triticale, a cross between wheat and rye.

Differences between the two include the fact that genetic engineering involves removing genes and manipulating them in the laboratory, before reintroducing them into the plant. Second, genetic engineering methods involve single or a few genes, whereas with classical breeding thousands of genes are exchanged and rearranged. Third, with genetic engineering it is possible to control precisely where and when the new product is made. For example, increasing sweetness in the tomato is only needed in the tomato fruit, not in the leaves or roots, and this can be controlled with precise on and off switches. Lastly, and perhaps most importantly to some, the half-page of information used in genetic engineering can be from any organism. It need not be closely related, as with classical methods, because all genetic information regardless of its source—plant, animal, or microbe—is written in the same language.

How is genetic engineering used to modify plants?

Creation of genetically engineered plants depends on a unique characteristic of plants, called totipotency. Cells can be taken from any part of a plant and, with appropriate "coaxing," made to multiply in an undifferentiated state until they are cued to reform an entire plant. This means that, if a new gene is introduced into the genome of an undifferentiated plant cell, that cell can multiply and ultimately yield an entire plant, each cell of which contains the new gene.

But exactly how is this done? A part of a plant, such as a leaf or a seed, is removed and a gene is then introduced into a small number of cells in that tissue, either by biological or physical methods (Federoff and Brown 2004). The biological method uses a microorganism, Agrobacterium, an inhabitant of the soil, which naturally inserts its DNA into the plant's genome to cue the plant to make sugars the bacterium needs for survival. Scientists put other genes into DNA that Agrobacterium transferred into the plant cell and then let Agrobacterium introduce the new gene into the plant cell. Another introduction method, termed the "gene gun", involves using microscopic DNA-coated "bullets" that are propelled at high speeds and end up inside the cell, where the DNA comes off the bullet and inserts itself into the plant's genome.

Once DNA is introduced, researchers must select for cells that received the DNA. This can be done through the introduction of a gene that gives a selective advantage to the engineered cell, like resistance to herbicides or antibiotics, or genes that allow cells to grow under nutritional conditions that the nonengineered cell cannot. After transformed cells are selected, the next challenge is to "coax" them to reform a plant, through manipulating the hormones in the growth medium. Once completed, a plant grows, each cell of which contains the new gene.

What GE crops are out there?

Some engineered products have already been commercialized, including insect-resistant varieties of cotton and corn, herbicide-tolerant soybean, corn, and canola, some varieties of these crops with both herbicide- and insect-tolerant traits, and virus-resistant papaya and squash. In 2007, 282.4 million acres of crops were grown commercially in 23 countries worldwide and, while the U.S. accounts for 50% of the acreage, the number of small and resource-poor farmers benefiting from biotech crops in developing countries exceeded 10 million. Other crops and traits are still in development in university and private laboratories that include plants with better drought and salt tolerance, higher yields, decreased allergens, increased antioxidants and micronutrients like folic acid and iron, and plants that serve as alternative sources of industrial oils and fuels and can remediate metal and organic pollutants from soils and water.

PERSPECTIVE

As with other technologies developed in the past, such as plant domestication, agricultural mechanization, chemical fertilizers, pesticides, the use of molecular tools brings questions about risks and benefits. While few, if any, activities in today's technologically complex world involve zero risk, attempts are made to minimize human and environmental risk. End-users and consumers must be knowledgeable about new technologies and their use and participate in informed debate about how they will be used.

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Benefits and Trends of Insecticide Use in California Crops

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California ranks first in grower expenditures on insecticides accounting for 20% of the US total for all crops and states. An examination of the historical record documents the importance of insecticides in California in preventing crop losses to destructive insect and mite species. Trends in the uses of insecticides are documented in the Department of Pesticide Regulation's full use reports for 1990-2007. Ten fruit, nut and vegetable crops have been selected for the initial insecticide benefits and use trends study: artichokes, asparagus, avocados, dates, nectarines, olives, peaches, pears, pistachios, and walnuts. For five of the crops, more than 90% of the acres receive insecticide treatments each year: (artichokes, dates, olives, peaches, pears) while 60-80% of the acreage of the other five crops is typically treated (asparagus, avocados, nectarines, pistachios, walnuts).

- In the early 1950s, *artichoke* losses due to plume moth damage reached major proportions often as high as 50-70%. [1] Insecticides came into common use in the 1960s following research showing reduced infestations of plume moth from 80% to 2%.[2] In recent years, use of older insecticides (methidathion, esfenvalerate) have declined while newer ones (diflubenzuron, deltamethrin,) have increased.
- Historically, the production of *avocados* in California required little usage of insecticides. Avocado pests were generally kept under commercially acceptable control by beneficial organisms. This situation changed in 1996 with the arrival of avocado thrips. Some growers had 80-90% of their fruit downgraded. [3] Insecticide acre-treatments in avocados increased from 500 to 97000.
- Frequent use of sulfur to control mites in *dates* was effective until the 1980s. [4] Beginning then, growers reported that sulfur was no longer effective and yield losses due to mites were as high as 35%. Following research that showed 99% control of mites, hexythiazox was registered for use by date growers. The use of hexythiazox is credited with preventing the demise of the California date industry. [5] The overall number of treatments has been reduced by 90% because of the increased effectiveness of hexythiazox.
- The production of *nectarines* in California was relatively small until the early 1960s. One of the major factors accounting for the rapid growth was the development of insecticides for control of western flower thrips. [6] Early reports on nectarine growing in California refer to sections of the state where thrips were so serious that production was practically impossible. Without thrips control, the nectarine industry in California would not exist today. [7] In recent years, use of older insecticides (formetanate, methomyl) has declined while newer active ingredients (spinosad) have increased.
- Traditionally, California *olive* orchards were infrequently treated with insecticides. The most significant pests were under good biological control. That changed in 1998 with the arrival of the olive fruit fly, the most serious insect pest of olives in the world. Olive processors enforce a zero tolerance of olive fruit fly. To guarantee that fruit will be free of olive fruit fly, insecticide sprays are necessary. [8] Insecticide acre-treatments in olives increased from 4000 to 80000.

- In 1984 the *asparagus* aphid was first found in California. Natural enemies that provide sufficient control in the eastern US and Europe did not control the pest in California. A serious aphid infestation in Riverside County destroyed 85% of the county's crop. [10] Without an effective insecticide for asparagus aphid control, a total collapse of the California asparagus industry would occur within one to two years. [11] In recent years, there has been a decline of 67% in insecticide treatments for asparagus aphid due to the declining economic viability of the crop.
- California entered the world pistachio market in 1976 with its first commercial crop. Initially, pistachios were relatively free of insect infestations, but as more orchards came into bearing, reports of nut meat damage by navel orangeworm (NOW) larvae became common. [16] NOW-infested kernels account for 84% of the aflatoxins in pistachio nuts. [17] Research has shown that NOW infestations in pistachio orchards are reduced to 1% with insecticide sprays. [18] Insecticide treatments in pistachio orchards have increased five-fold in recent years as the value of the crop has doubled.
- *Pears* cannot be grown profitably on a commercial scale without adequate control of insects. Consumers do not accept fruit damaged by insect feeding or its byproducts. If damage exceeds 1%, sorting fruit prior to packing becomes very difficult. The presence of too many insects in fruit destined for the processing market is not acceptable due to the risk of contamination of processed products by insect parts and rot. [15] Codling moth has the potential to destroy a high proportion (50-80%) of the California pear crop each year if not controlled. Current control programs result in less than .25% codling moth infested fruit at harvest. Codling moth mating disruption products have been adopted on close to 90% of California's pear acres leading to a 50% decline in insecticide treatments.
- In 1887, a 50% loss of *peaches* in California due to peach twig borer was noted in some districts. [12] The loss of peaches in California in the 1920s was estimated as 20-60%. [13] The Oriental fruit moth reached California in 1942.Experiments with organophosphate insecticides controlled both Oriental fruit moth and peach twig borer reducing the percent wormy fruit to 2%. [14] Overall insecticide treatments have declined about 20% as peach growers have adopted mating disruption products for Oriental fruit moth on about 50% of the acres.
- The codling moth has been known to attack *walnuts* in California since the early 1900s. [9] Growers placed the infestation as high as 50% in some orchards. The early research demonstrated that there was but one thoroughly satisfactory method for control: insecticide sprays. By 1926, spraying was the commercial practice employed in all the codling moth infested groves. Insecticide treatments in walnuts have increased by about 50% in recent years. Much of the increase was to control codling moth. Walnut growers have used codling moth mating disruption products on less than 10% of the acres due to the large size of the trees which increases labor application costs. Another factor leading to increased insecticide use is the need to treat for walnut aphid which is increasingly escaping from biological control due to the emergence of a new form of the aphid and hyperparasitoids of the aphid parasite

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Session I

Cultural Practices that Affect Pest Management

Session Chairs:

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Mulch Effects on Trees

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There are several reasons to apply mulch. Mulches prevent weeds from germinating, reduce evaporative loss from soil surfaces, add organic matter to soils thereby increasing their mineral content and increase soil disease prevention, and finally as shown in some studies (but not others), increase the growth of trees planted under them. The most widely cited reasons for mulching are weed control and moisture conservation (Robinson, 1988). There are also several mulch associated problems. Mulches can exacerbate planting problems, increase root disease, increase frost injury, introduce pests and trash into orchards and are costly to apply and maintain at working depths.

Benefits of mulching

Many studies of mulched trees measure growth benefits. Gillman and Grabosky (2004) note that mulched oaks grew better not because mulch was present, but due to lack of competition from turfgrass. Indeed mulching was found not to affect tree physiological factors such as gas exchange or chlorophyll fluorescence by Ferini and others (2008). Increased growth of trees has been associated with organic mulches in several studies (Downer and Faber, 2005; Greenly and Rakow, 1995; Foshee et al., 1996…) There is some evidence that benefits of mulching are not entirely generated by organic substrates. Iles and Dosmann 1999, found various stone or mineral mulches had the same levels of growth promotion as bark and wood chip mulches suggesting that biological effects of mulches are less significant than temperature and moisture effects conferred by mulches in general.

Mulching increases the mineral content of underlying soils, and most all of the nutrients in plants (including toxic ions) tend to accumulate in fine textured soils under organic mulches (Downer, 1998). When soil minerals are not limiting to plant growth, organic mulches still stimulate growth increases (Foshee et. al., 1999) again suggesting that nutrient additions are less important to plant growth response than other possible mulch benefits. While Faber et al. (2000) found that nutrients accumulated in soils underlying yard waste-mulched avocado and citrus, their tissue nutrient contents were not increased. They associated growth increases with another known mulching phenomena, increased rooting and root development. Many horticulturists believe that application of fresh (not composted) mulches of high carbon nitrogen ratio to soils will deplete nitrogen from them. Borland made the point that this is not supported in the literature back in 1988. This is still not shown to be true by in any valid study. In my own studies (Downer, 1998, Downer and Hodel, 2001; Downer and Faber, 2005) use of freshly chopped eucalyptus tree branches did not cause any nitrogen draft from soils or symptoms of nutrient deficiency in trees growing under them.

Mulching with a coarse layer of stone or organic materials cuts evaporative loss from soils thus preventing loss of moisture to the atmosphere that roots could absorb. This source of moisture is especially useful to shallow rooted trees such as avocado. I have found in various studies that mulched trees can skip every other irrigation compared to non-mulched trees and maintain the same soil matric potential (Downer, 1998; Downer and Hodel, 2001; Downer and Faber, 2005). The caveat here is that the mulch must be coarser than the underlying soil. Mulches that are texturally finer than the soil underneath them can lead to increased moisture loss and drying (Svenson and Witte, 1989). Moisture savings by mulches would be best achieved when there is maximum exposure of soil to the sun before complete canopy cover occurs. As soils become shaded this effect should decrease.

Mulching has been associated with root rot disease control for many years and was notably documented by Broadbent and Baker in Australia back in 1974. They observed that mulched avocado orchards could become suppressive to the avocado root rot organism *Phytophthora cinnamomi*. Later work in California avocado orchards established that enzymes produced by fungi growing in mulches play a role in control of diseases caused by *Phytophthora cinnamomi* (Downer et al. 2001a&b).

Deleterious effects of mulch

Mulching can have negative effects on the plants growing under mulching conditions. Mulching does not allow observation of the soil surface and thus awareness of underlying soil moisture status is reduced. Mulch has been observed to interfere with moisture penetration to underlying soil layers. In landscapes with frequent light irrigations, much may be wetted and dry but underlying soils may not obtain enough water for plants growing on these mulched soils. Gilman and Grabosky (2004) found that mulching increased tree stress in lightly irrigated landscape trees. Mulches have also been observed to absorb considerable amounts of water (Shaw) and thus can hold irrigations that would ordinarily reach the soil.

Mulching can accentuate the ill effects of improper planting. Arnold and others (2007) showed that green ash planted with its root collars below grade were less likely to survive when mulched than when non-mulched.

Mulches change the way that radiation is absorbed and radiated around trees having potential positive or negative affects on trees growing around them. Mulched trees are generally cooler and have cooler stem temperatures (Downer and Faber, 2007). Organic mulches better insulate landscape soils from intense solar radiation than decomposed granite or soil (Singer and Martin, 2008). The insulation properties of mulch help plants resist intense soil heating in arid climates; however, these same properties reduce night time radiation from soil and tend to cool orchards at night, increasing the number of nights that trees are exposed to freezing temperatures during winter months in subtropical climates (Ben Faber personnel communication).

Mulching is an obvious way to spread pests and pathogens. The main concern is that diseased trees or parts of them when chipped and freshly applied may transfer disease propagues to soils or trees elsewhere. *Verticillium dahlieae* was found to survive several weeks outside in wood chips (Foreman and others, 2002). The canker fungus *Thyronectria austroamericana* remained viable outside in mulch for over two years after removal from an infected host (Koski and Jacobi, 2004).

Survival of pests and pathogens in chips does not imply that the infection process will continue, only that they can remain viable for a time. Jacobs (2005) showed that mulch infested with

Sphaeropteris sapinea caused blight in Austrian pine, yet mulches with *Armillaria gallica* and *Botrysphaeria ribis* failed to initiate disease from their presence in mulch. When mulches are composted before use it is generally accepted that most pests are destroyed. However, pathogens, weeds, and insect pests can escape the yardwaste processing systems used by municipalities and survive the holding process in stockpiles (Daugovish et al., 2006; Crohn et al, 2007; Downer et al., 2008). Yellow nutsedge was one of the most persistent weeds surviving up to eight weeks in stockpiles and the fungal pathogen *Sclerotinia sclerotiorum* survived for similar durations.

Mulches are useful tools for horticulturists but their best use is by informed and observant farmers, gardeners and landscapers that can monitor their plants, understand soil moisture relations, and are alert to the development of diseases and other pests. If used in an informed way, mulches can add benefits to plantings, retard diseases and other pests while stimulating growth.

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Cultural Practices for Reducing Pest and Disease Pressure in Vegetables

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Production Practices

Vegetable farms on the Central Coast region are generally intensive operations, with two and sometimes four crops being harvested off the same acreage each year. For each crop, cultural operations begin with land preparation. First, the soil is disced once or twice. After this initial discing, land is chiseled one or two times, followed by one or two additional discings. The number of passes for each operation depends on the amount of residue of the previous crop to be turned under as well as the tilth of the soil. It is critical that any residues or organic amendments are thoroughly incorporated to reduce root problems and insect damage from symphlans and springtails.

Crop Diversification and Rotation

Rotations are characterized by cropping sequences that alternate a variety of vegetable crops and often include a cover or green manure crop. Because of the importance of soil fertility and soil organic matter, organic vegetable growers are increasingly planting some acreage to cover crops. A crop rotation's purpose is to continually recycle nutrients, break pest cycles, and maintain a balance between soil organic matter accumulation and decomposition. Organic matter is particularly important for improving soil structure and water holding capacity, and for providing nitrogen and other nutrients for crop production.

Individual vegetable growers may have differing strategies for planting and rotating a variety of crops. Cropping history and grower experience will factor into the determination of each year's rotation. Other considerations include:

1. The ease of each crop's cultivation.

2. The compatibility of each crop in terms of labor, equipment, and seasonal timing.

3. The availability of nutrients. Crops with greater nutrient requirements may produce higher yields when following a cover crop or a crop with lower nutrient needs. Also, crops with different root growth patterns may be better able to utilize residual nutrients that a previous crop was unable to capture.

4. The existing pest complex including weeds, disease, and arthropods (insects, spiders and mites). Selection of a crop that competes well with weeds, or planting disease-resistant cultivars may help overcome some of these difficulties.

5. The crop value and access to markets.

Additionally, most growers will not plant related crop species on the same acreage in the same year. Often this rule is extended for longer periods of time depending on the specific vegetable crop and cropping history. However, when production land is high in value or when growers use limited rotations, some crops (most commonly lettuce) may be grown back-to-back on the same land.

Cover Crops

Cover crops can be beneficial for intensive vegetable production in a number of ways. Water penetration and infiltration can be improved by root growth of a cover crop and by returning organic matter to soils. Increased organic matter may improve the soil's ability to retain moisture. If leguminous cover crops are grown, soil nitrogen can be increased through nitrogen fixation. Grasses are particularly helpful in promoting soil structure and soil aggregate stability because of their fibrous root systems. Microbial activity, often stimulated by cover crop root exudates and organic matter additions to soils, has also been shown to promote aggregate stability. As microbes decompose organic matter, nutrients are released. Weed suppression for subsequent crops may be another benefit. Furthermore, cover crops can provide a favorable environment to attract and sustain beneficial arthropods.

Planting cover crops in intensive vegetable operations may result in some negative impacts. Cover crops may attract some arthropod pests to production areas. Fall planted cover crops prevent ground from being worked up to allow for spring planting flexibility. Cover crops also require additional inputs such as seed, irrigation water, and labor. In addition, revenue-producing vegetable crop acreage is reduced when a cover crop is grown. However, some growers view the cost of planting and maintaining a cover crop as the cost of producing nitrogen and/or improving soil quality for the long-term.

Selection of a particular cover crop species should take into account the growing needs of the cover crop itself as well as the previous and subsequent vegetable crops, the soil type, and any irrigation requirements. In this region commonly planted cover crops include, but are not limited to, legumes such as vetch and bell beans and certain annual grasses such as barley, rye, and oats. Growers may use a grass/legume mixture to obtain benefits that are unique to each cover crop type. Cover crops may be planted on a year-round basis depending upon how they fit into a grower's rotation scheme. Vegetable crops that follow a cover crop may not require a compost or manure application to supply nutrients for crop production. Growers in some areas may find that certain cover crop species and mixes are not suitable for their soils and conditions. Often, the most suitable cover crop in each situation is determined by observation and experimentation over a period of years.

Pest Management

Diseases. Important diseases that have occurred in vegetable production areas of the Central Coast include: *Pythium*, *Rhizoctonia* and *Fusarium* on onions and squash, viruses such as beet yellows on lettuce and cabbage, and fungal diseases such as downy mildew (*Peronospora* *destructor)* on onions and powdery mildew (*Leveillula taurica)* on peppers. Techniques to minimize the incidence of disease in vegetable crops include:

1. Planting high quality disease-resistant cultivars.
2. Avoid planting at certain times of the year because of severe disease incidence.
3. Improving field drainage and/or modifying irrigation methods. Moist and wet fields provide a favorable environment for disease. Sprinkler irrigation should be avoided on some crops such as onions and garlic.
4. Mechanical and hand cultivations to remove weeds that may harbor disease.
5. The control of disease-transmitting insects (aphids and beetles) by such means as insecticidal soap sprays and diversified plantings for biological control.
6. Sanitation of equipment when moving from field to field.
7. Crop rotations.

Weeds. Optimal weed control in vegetable systems on the Central Coast often results from the integration of a number of weed control techniques. If economically feasible, using transplants rather than direct seeding provides the most competition for weeds. In the case of lettuce, this is not usually economic. Before planting the crop, preirrigate and cultivate to germinate and destroy weed seedlings. If this is done close to planting time, weeds that germinate and are killed will be those that would have infested the lettuce crop. Have beds near final shape before preirrigation so that they can be prepared for planting with shallow cultivation. Cultivate very shallowly after preirrigation to avoid bringing up ungerminated weed seed from deeper soil layers. Cultivating implements that cut horizontally through the soil, such as harrows or lilliston cultivators, work better than discs, which cultivate vertically and miss many weeds. Preplant herbicides can be applied at this time.

With precision cultivation, fewer weeds remain and handweeding costs are reduced. Seeded crops are hand thinned about 3 to 4 weeks after planting and weeds in the seedlines are removed at this time. Typically, lettuce is cultivated two to three times during the growing season utilizing sweeps, disks, top-knives and side-knives that are mounted on a cultivator. Camera-guided cultivation systems allow for greater precision in cultivation operations. Post plant herbicides can be used for controlling small seedling annual and perennial grasses. Buried drip can be useful in reducing the amount of weeds.

Insects. Insect pests that are prevalent in production systems in the Central Coast include a number of different aphid species, flea beetles (*Epitrix* and *Phyllotreta* spp), the spotted cucumber beetle (*Diabrotica undecim-punctata undecimpunctata)*, corn ear-worm *(Heliothis zea)*, the cabbage looper (*Trichoplusia ni)*, and the imported cabbage worm (*Pieris rapae).* These insects attack a variety of vegetable crops, feeding on plant foliage, stems, flowers, and fruits. Economic damage is therefore caused by reduced plant growth, weakened and scarred plants and fruit, and ultimately, decreased yields.

There are a large number of pesiticides available for controlling these invertebrates and more and more of them fit well into an integrated pest management program.

Pheromone traps may be used by some growers to monitor pest populations. Pest management may also include the release of biological control agents to augment that which may already exist in the field. For example, release of beneficial wasps of the genus *Trichogramma* may help control corn earworm. Additionally, some growers maintain insectary plantings in or near fields to provide a habitat and food source for beneficial arthropods.

Cultural Practices to Reduce Pest and Disease in Avocado and Citrus

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In many ways our pest and disease management of fruit tree crops are exacerbated by our cultural practices. Avocado and citrus offer some very clear demonstrations of how we manage our trees can lead to reduced pesticide use. From the beginning, our selection of rootstock and scion can help lessen pest and disease problems. In both avocado and citrus we have good rootstocks which can handle problems, such as root rot more effectively than seedling rootstocks. So it is imperative that if you know that drainage will be a problem, starting off with the right, healthy rootstock helps. Also scion selection can have a major impact, as well. For example, 'Lamb' avocado is much less prone to persea mite than is 'Hass'. This pest can significantly impact a spray program and planting 'Lamb' could mean virtually no sprays for this pest. There are similar examples in citrus where one variety is more prone to a pest or disease than another.

Irrigation is probably the most important cultural factor in managing tree disease. Over, under and improperly timed irrigations are the conditions necessary for many root diseases. The *Phytophthora spp.* fungi are looking for distressed root systems brought on by waterlogging and other stressful situations. Other conditions, such as wetted trunks can also bring on some trunk diseases, like gummosis in citrus and crown rot in avocado. Simply preventing irrigation water on the trunks can limit these diseases. Other diseases, such as black streak, stem blight and bacterial canker in avocado are bought on by soil moisture stress.

Nutrients, especially nitrogen management, has been long known to affect levels of insects, such as scale, mealy bug and aphid. Encouraging lush growth helps sustain these insects, so reducing this growth tends to lower their numbers. Managing when canopy growth occurs can affect pest severity. Avocado thrips build their populations in the spring and moves easily from leaf to fruit causing significant scarring. By promoting leaf growth at flowering time with a nitrogen application, keeps the insect on the leaves and reduces fruit scarring. This also promotes growth that replaces leaves that have been damaged by persea mite. Likewise the incidence of citrus leaf miner damage can be reduced if spring pruning is avoided so that a flush of growth does not occur at the same time as the population is building. Timing of pruning is important in lemons to avoid wet periods of rain and fog to reduce the spread of hyphoderma wood rot fungus when its fruiting bodies are active.

Pruning can change pest pressure by changing the humidity in the canopy, introducing light and changing the climate supporting disease and pests. By making spray coverage more thorough, it also makes for a more effective application. Modified skirt pruning can have significant effects on mealy bug and scale control, fuller rose weevil incidence, ant colonization and snail damage. It's important that the trunk be protected as an avenue of movement for snail and ant control to get the best effects of this pruning. Skirt pruning also reduces problems with such weeds as bladder pod and the ladder effect of brown rot in citrus – fungal propagules splashed from the ground onto low-hanging fruit, which in turn is splashed to higher fruit.

Keeping a canopy clean of dust and fire ash also makes for more efficient biological control. Because predators are slowed in their search, they are less efficient. They also spend more time grooming their sensory organs, and this also slows them down. Parasites such as wasps are actually slowed by the physical abrasion to their tarsi. Dust also creates a drier environment, which is more hospitable to our pest mites. Watering picking rows, roads and even the trees themselves can lessen mite populations. Use of cover crops can also reduce dust and potentially provide pollen and nectar for predators and parasites. Of course cover crops create a whole new set of management issues, such as colder winter orchards and snails.

Finally harvest timing to avoid pest and disease is often overlooked. In avocado, fruit is often set in clusters. Greenhouse thrips love the microclimate created, and if in a size-pick the cluster is reduced, greenhouse thrips will often not be a problem. Harvest timing is also important in citrus. Fruit left too long on the tree can often develop septoria fungal spot. Picking in a timely manner reduces the incidence of this disease.

These are just a few examples of how cultural practice at the right time can reduce pest and disease problems.

Farming Without Fumigants: Myth or Reality?

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Introduction

Fumigants have been widely used in California to manage plant parasitic nematodes, pathogenic fungi, and weeds. This paper will deal only with the potential for managing nematodes in California without the use of fumigants. Plant parasitic nematodes are microscopic roundworms. They are less than one tenth of an inch long and are found in soil, or within plants. Nematodes are aquatic organisms. Within soil, they live and move within the film of water which lines soil pore spaces. They are small enough to move between individual soil particles. It is not uncommon for a single teaspoon of soil to contain 50 nematodes, or for a single inch of feeder root to contain 200. Nematodes possess a spear or stylet that is used to pierce and feed on plant tissues.

The nematode life cycle consists of an egg stage, four gradually enlarging juvenile stages, and an adult stage. Plant parasitic nematodes exhibit several different life history patterns. For ectoparasites, all stages of the life cycle are passed outside of roots in the soil. For migratory endoparasites, life cycle stages may be found within roots as well as in soil. The second stage juvenile of sedentary endoparasitic nematodes enters a root, takes up a permanent feeding site, and then develops to an immobile adult female within the root. The root cells around her head enlarge to form a gall or knot. Knowledge of these life history patterns can be helpful in planning a management program.

The Problem

Plant parasitic nematodes are a significant statewide problem. Working generally from north to south, examples of some of the most significant crop-nematode associations causing substantial economic losses to growers are: Easter lilies – lesion nematode (*Pratylenchus penetrans*); potatoes – root-knot nematode; strawberry nurseries – foliar and root-knot nematode; small grains – lesion and root-knot nematode; fruit and nut trees – ring, lesion (*P. vulnus*), root-knot and dagger nematode; grapes – dagger, root-knot, citrus and others; tree and vine nurseries – lesion, ring, root-knot and dagger; tomatoes – root-knot; alfalfa – root-knot, and stem and bulb; turfgrass – *Anguina*, root-knot, sting and others; cole crops – sugarbeet cyst; strawberries – lesion and root-knot; ornamentals – root-knot, lesion, foliar and others; cucurbits – root-knot; sweet potatoes – root-knot; dry beans – root-knot; peppers – root-knot; carrots – root-knot, needle, and stubby root; garlic and onions – stem and bulb; cotton – root-knot; citrus – citrus and sheath; and sugarbeets – root-knot and sugarbeet cyst.

There are no hard figures on losses caused by nematodes. Estimates made by the Society of Nematologists for the United States are six percent for field crops, 12 percent for fruits and nuts; 11 percent for vegetables, and 10 percent for ornamentals. Applying these estimates to California cash farm values indicate a yearly loss to growers exceeding one billion dollars. As for which crops have the most problems with nematodes, one can get an idea of this by looking at those with the highest usage of nematicides. For annual crops these include carrots, tomatoes, cotton, sweet potatoes, and potatoes on which root-knot nematode is the major problem. Additional crops that are mainly damaged by sugarbeet cyst nematode include broccoli, cauliflower, sugarbeets and Brussel sprouts.

Is This a New Idea?

It is useful to ask the question "Is farming without fumigants a new idea?" In 1961, Gerald Thorne wrote the following in his textbook 'Principles of Nematology': "It is fitting that a few words of commendation be given to the officials of the Shell Chemical Corporation and The Dow Chemical Company for their foresight in pioneering the field of soil fumigation. Their efficient, generous, cooperative, and persistent campaigns have carried the science of soil fumigation into almost every country. **Those of us who had spent many years attempting to control nematodes by crop-rotation and cultural methods, often with futile, discouraging results,** now realized the satisfaction of recommending D-D and EBD for the control of nematodes on certain moderate- and high-priced crops."

It seems then that we are either trying to reinvent the wheel, or perhaps we know something that Gerald Thorne did not. Today we have access to knowledge developed since the writing of Thorne. For example, molecular techniques have been developed to assist with identifying nematodes to species and to assess variability between populations of nematodes. We have a better understanding of nematode biology, particularly with respect to the effects of temperature on nematode reproduction. For some species we know how to use degree-day temperature information to predict population increases. Within California is a network of CIMIS weather stations from which soil temperature can be obtained online from which to make these predictions. In addition to traditional breeding which has provided us with some nematode resistant plant varieties, there is the potential to genetically engineer new resistant varieties. We also have computer databases available online to help select resistant varieties.

Another question worth considering is: "Should we expect something else to work as well as a fumigant?" The effectiveness of fumigants has been due in large part to the fact that they move themselves through the air in the soil pores a considerable distance from a point of injection. They then dissolve in the film of water lining soil pores to contact and kill nematodes. Non-fumigant products, on the other hand, need to be moved through soil with water and tillage, a task that is considerably more difficult. Unfortunately, what makes a fumigant work also makes it a volatile organic compound (VOC) and that is a major concern at the present time.

Non-fumigant Management Practices

There are a number of management practices to be considered when developing a program to manage nematodes without fumigants. Based on the information that has been developed, it is likely that replacing fumigants will require using a combination of techniques. These techniques include prevention of infestation of land not currently infested; the use of crop rotation including the use of resistant varieties, fallowing with weed control, cover crops, green manures, biofumigation, flooding, and trap crops; altering the dates of planting and harvest; the use of soil amendments and natural products; the use of non-fumigant chemicals; the use of seed treated with nematicides; and the use of heat such as for steam sterilization or solarization, or hot water treatments of planting stock.

Prior to developing a nematode management program, a sampling is needed to determine which nematodes are of interest. Nematodes are not typically uniformly distributed within a field, so it is common for a sample to be composed of multiple sub-samples. Nematode thresholds and damage levels have been developed for a number of crops. The variability of nematode distribution within a field, and variability in extraction techniques often makes if difficult to utilize such thresholds. The threshold for some nematode sensitive crops such as carrot, squash, sugarbeet and sweet potato is 0 nematodes in 250 cc of soil.

Successful use of crop rotation requires one to also know the genus and species of nematodes present in a field. Root-knot and lesion nematodes have been particularly difficult to identify to species. During the past few years, molecular techniques using PCR (polymerase chain reaction) have been developed for these two groups of nematodes. More recently, it has been demonstrated that the technique of real-time PCR can be used to quantify species of lesion nematodes, as well. Once one knows the nematodes present, nematode-host association databases available online at http://ucdnema.ucdavis.edu can be used to help with the selection of rotation crops.

The use of green manures and biofumigation with *Brassicas* has been successful in some field trials. These products contain compounds called glucosinolates that decompose into isothiocyanates which are nematicidal and similar to the active ingredient in the metam sodium nematicides. Trap cropping is a technique that has been successful with sedentary endoparasitic nematodes such as root-knot. A host crop is planted and grown for a short period of time, possibly only two to three weeks. Juvenile nematodes enter the roots and establish a feeding site. Once the immature females begin to develop, the nematode is no longer wormlike and is unable to leave the root. The trap crop is then destroyed before nematodes mature, leaving the nematodes trapped within. A commercial crop can then be planted after a portion of the infective juveniles have been killed within the trap crop.

The sensitivity of the nematode life cycle to soil temperature can be utilized to minimize crop damage. Each nematode will have a nematode activity threshold that is the lowest temperature at which it is able to enter a plant. If one can plant when soil is cooler than this threshold, a crop can get off to a healthy start prior to nematodes being able to enter the roots. Generally, the warmer the soil temperature, the more rapidly nematodes develop. This knowledge has been utilized in crops such as potato to calculate nematode degree-days and to determine how many generations a population will go through during a growing season. It has been shown that tuber blemishing from nematodes can be avoided by harvesting a few weeks early.

Several new products have achieved registration in California. Sodium tetrathiocarbonate (Enzone) is a liquid that needs to be applied in irrigation water and releases the fumigant carbon disulfide into the soil. DiTera is a toxin produced by the fungus *Myrothecium verrucaria.*

Imidacloprid (Admire Pro) was first marketed as an insecticide but has been found to suppress nematodes on several crops.

A large variety of soil amendments and natural products have been available for testing in recent years. Some of these products have demonstrated increases in plant growth and yield. In some cases products have reduced nematode populations and in other cases populations have increased following use of these products. According to the manufacturers, these products have multiple modes of action. Some products add beneficial microbials to the soil. Other products stimulate the production of nematophagous fungi. Still others may compete for the root surface preventing nematodes from attacking. Nematodes are plant stressors and some products reduce plant stress by improving soil structure, water retention, and plant nutrition, making the stress from nematode damage less evident. Still other products produce nematicidal products when they decompose in the soil.

Due to these multiple and complex modes of action, it is advisable to first test a new product in the field in which it will be used prior to large scale use. This can be done by treating several small areas randomly within the field, and observing differences between treated and untreated areas. Non-fumigant products do not always kill nematodes. Some may promote plant growth and nematode populations may actually increase because a healthier root system can support more nematodes than an unhealthy one. Possible uses for these products would be to combine two or more of them, or to use natural products and soil amendments in combination with another cultural method such as biofumigation, trap cropping, or date of planting and harvest.

Conclusion

In summary, nematodes are a significant, statewide problem. They are a chronic problem for many growers. Although progress has been made towards farming without fumigants and considerable research is being done in this area, we are not there yet.

Challenges in Weed Management without Methyl Bromide

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Methyl bromide (MeBr) has been used for several decades for pre-plant soil fumigation in high value agricultural and horticultural crops because it can provide broad-spectrum control of many soil-borne pests. In the U.S., several economically important production systems including annual fruits and vegetables, perennial crop orchards and vineyards, floriculture and ornamental nurseries, and fruit and nut plant nurseries depend on the broad-spectrum control of soil-borne disease pathogens, parasitic nematodes, and weeds provided by soil fumigants.

Most MeBr used in soil or commodity fumigation eventually escapes to the atmosphere where it can contribute to depletion of stratospheric ozone. This important fumigant is being phased out of general use following the terms of the Montreal Protocol, an international agreement which also regulates 95 other ozone depleting chemicals including chlorofluorocarbons (CFC), halons, chlorine solvents, and hydrochlorofluoorocarbons (HCFC). According to the phase out plans, compared to the 1991 base-year, MeBr use was to be reduced 25% by 1999, 50% by 2001, 70% by 2003, and be completely phased out in the developed countries by 2005. The phase out is scheduled to be completed by 2015 in developing countries. Although phased out of general use in the U.S., MeBr is still used to some extent in several crops where technically and economically feasible alternative pest control methods do not exist [Critical Use Exemptions (CUE)] or where quarantine regulations require fumigation prior to shipping products interstate or internationally [Quarantine/PreShipment (QPS)]. Since 2005, all uses of MeBr in the U.S. fall under either CUE or QPS criteria. CUEs are annually applied for by each affected agricultural sector and are subject to review and authorization by the U.S. government and the Parties to the Montreal Protocol, and have been slowly decreasing as viable alternatives are adopted (Fig. 1).

Preplant soil fumigation decisions are often driven primarily by soil borne disease and nematode pressure rather than weed control. However, the broad-spectrum biological activity of MeBr has allowed producers to effectively control many pests including weeds with one fumigation treatment and has given users high expectations for efficacy and reliability of chemical alternatives. Effective pest control with soil fumigation requires that the target (embryos or vegetative propagules in the case of weeds) be exposed to high enough doses of the chemical for a sufficient amount of time for mortality. Efficacy can be affected by environmental conditions such as soil moisture and temperature (fumigant dispersion and concentration), weed seed condition (unimbibed or hard seed coats), weed seed presence (wind blown seed invasion after fumigation), soil sealing technique (persistence of toxic condition) as well as the toxicity of the fumigant itself.

Alternatives to MeBr: Short- and intermediate-term MeBr alternatives research has focused on more effective use of existing fumigants or obtaining new labels for fumigants registered in different crops. To meet these objectives, already registered products such as 1,3-dichloropropene (1,3-D), chloropicrin, combinations of 1,3-D and chloropicrin (Telone™ products), and methyl isothiocyanate generators such as dazomet and metam sodium have been tested alone and in various combinations. Longer term research objectives have primarily targeted unregistered products that are known to have some biocidal activity with the hope of finding a “drop in” replacement for MeBr. One of the most promising chemicals at this time is iodomethane (or methyl iodide) which recently was registered in 47 states and may be available in California in the future. Other products have been tested in greenhouse and field tests including propargyl bromide, sodium azide, propylene oxide, acrolein, dimethyl disulfide, furfural, fosthiazate, and various combinations of alternative fumigants or alternative fumigants and herbicides. Additional promising areas of research on chemical alternatives to MeBr include fumigant application techniques and equipment and barrier film systems to reduce fumigant emissions, increase efficacy, and allow use of lower application rates.

Problem Weeds: Although specific weed problems vary greatly across cropping systems, regions, and seasons, a few specific weed issues warrant consideration. Many crops dependant upon preplant soil fumigation have a high value per acre and are grown in temperate regions with supplemental irrigation. Under these conditions, one of the most difficult groups of weeds to manage includes sedges such as yellow and purple nutsedge. Nutsedges can be difficult to control with currently labeled fumigants including MeBr and this problem likely will be even more difficult in the absence of MeBr. Several currently available fumigants can control nutsedges in some situations; however, control is often more variable than MeBr. Other weeds such as morningglory, cheeseweed mallow, burclover, knotweed, and bindweed, are occasionally mentioned as being difficult to control with MeBr alternatives in some situations.

Weed Biology: Differences in weed biology can impact the level of control with MeBr and alternative fumigants. For example, some weeds have very hard seed coats which can physically protect the embryo, especially if the fumigant does not diffuse as readily as currently available materials. Some weeds can emerge from fairly deep in the soil or can creep in from adjacent untreated areas (eg. nutsedges, field bindweed, Bermuda grass, purslane) which likely will present greater problems in shallow-fumigated, bed-fumigated, or site-specific applications compared to broadcast treatments. Weeds that enter the field following fumigation will not be controlled by preplant fumigation. For example, weeds with wind blown seed such as hairy fleabane, prickly lettuce, sowthistle, horseweed, and dandelion may quickly reinfest a field from surrounding areas after fumigation.

Herbicides: Applications of preplant or post-emergence herbicides in addition to preplant soil fumigation is already an important part of weed management in many cropping systems dependant upon MeBr fumigation. However, herbicide choices are limited in many of the crops currently reliant on preplant soil fumigation. Many of the fumigation-dependant industries in the USA are small acreage crops and have had less herbicide development and registration compared to large acreage crops. Additionally, very high crop values translate to high risk for herbicide companies considering registration of new materials in these crops. Some sectors such as cut flower and ornamental nurseries may consist of hundreds of crop species and thousands of cultivars grown on small plots and in short rotations which greatly complicates crop safety and plantback requirements with herbicides. Although reviewing herbicidal efficacy and phytotoxicity in specific crops is beyond the scope of this paper; herbicides are likely to become a more important component in weed management as MeBr alternative fumigants are adopted in high value agricultural sectors.

Non-Chemical Alternatives: A number of non-chemical weed management techniques are used in various cropping systems. Some techniques used for non-chemical weed management include: mechanical tillage, water management, mulches, hand weeding, soil solarization, cover crops, biofumigation, bioherbicides, and others. While in many cases these techniques are insufficient to stand alone for weed control, it is likely that, in the absence of MeBr, growers will need to go "back to the basics" and utilize a variety of techniques to manage weed populations.

Weed Shifts: Regardless of the control tactics used, weed populations can shift to a community dominated by species favored by current management practices. Such shifts occur in response to changes in management systems, for example, change in tillage practices, type of herbicide, or fumigants. When a management practice does not control a particular species or type of plant, the weed community in that field eventually will be dominated by those uncontrolled species. Although weed shifts are almost certain to occur as growers transition from MeBr, thus far, no studies have reported weed species shifts with discontinuation of MeBr or use of alternative fumigants. However, because MeBr has provided very effective control of weeds and other soil-borne pests for many years, pest populations in many fields have been continually suppressed and several cropping cycles may be needed before weed shifts are noticed. While alternative fumigants and control methods may provide acceptable control of weeds in the short-term, long-term monitoring is needed to determine if species shifts and population increases are occurring.

Conclusions: No single alternative chemical or management practice appears to have the same broad-spectrum efficacy and consistency on the necessary weed, nematode, and disease targets as MeBr. Because many alternative fumigants are more target specific than MeBr and weeds are often the most difficult target, weed control in many high value fruit, vegetable, and ornamental crops will become an even greater challenge in the absence of MeBr. Weed management requirements may differ greatly across regions and countries due to environmental and soil factors, weed species present, and specific crops and cropping systems used; thus development of a single alternative to MeBr is unlikely. Rather, development of an integrated pest management system tailored to specific crops and regions will be necessary to reduce inconsistency and market instability with any single approach. Such an integrated approach likely will include both chemical and non-chemical techniques and may require increasingly sophisticated management of soil, crop, and environmental components of the agroecosystem. Because of the disease and nematode pests concerns in many MeBr dependant industries, pest management likely will continue to include fumigation in the near future. Short term weed control research efforts should include increasing the efficacy of alternative fumigants through advanced application techniques and barrier film technology and rate refinement of MeBr alternatives. Herbicidal and cultural weed control practices should be integrated with the goal of reducing weed populations and weed seed bank in production fields and nearby areas. Long-term success in weed control will require an integrated approach because there is not likely to be a single strategy to replace MeBr and fumigation will be subject to increasingly stringent environmental regulations.

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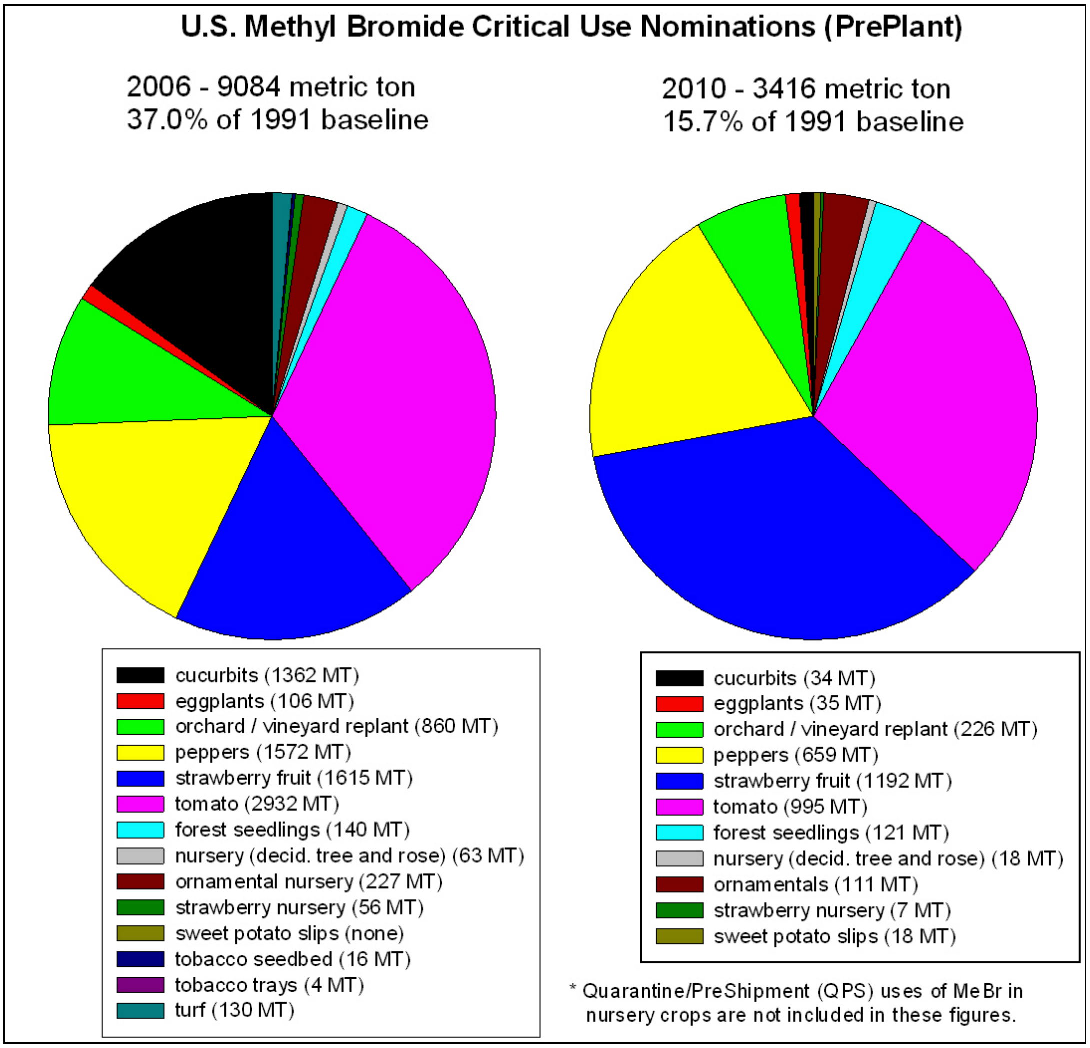

Figure 1. 2006 and 2020 U.S. methyl bromide critical use exemption nominations.

What to Consider when Emission Reduction is Required from Soil Fumigation

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Summary. Emission is one of the key factors affecting fumigant use in California due to regulations. Many commodities depend on pre-plant soil fumigation to achieve profitable yield and healthy crops. The phase-out of methyl bromide as a ***broad-spectrum*** soil fumigant in pest control has placed formidable challenges in searching alternatives. Most alternatives registered today are highly regulated because of their toxic properties and their nature as volatile organic compounds (VOCs). Minimizing emissions becomes essential to maintain the practical use of fumigants. This paper reviews and summarizes findings towards field practices to minimize emissions from soil fumigation. The effectiveness on emission reduction, impact on pest control and cost are important factors to consider in determining emission reduction technique. High-value cash crops (e.g. strawberry) can afford using highly effective, but costly low permeable plastic mulches whereas crops with lower profit margins (e.g. stone fruit orchards) may need to consider lower cost methods such as water treatments and/or target-area fumigation. More stringent regulations on fumigants are likely to develop in the future. Continuous research is necessary to develop good fumigation practices in various agronomic systems to sustain agricultural production while minimizing potentially detrimental impact.

Introduction. Soil fumigation with methyl bromide (MeBr) has been used to control a variety of soil-borne pests such as nematodes, diseases, and weeds in many agricultural systems. Major industries that rely on soil fumigation include high-value cash crops (e.g., strawberry), stone fruit/ornamental and grapevine nurseries and orchards, and some vegetables (carrot, pepper, tomato). Without fumigants, productions of these crops would suffer tremendous yield losses from diseases or replant disorders. Additionally, in California, tree and grapevine field nurseries must meet the nematode-free requirements of California Department of Food and Agriculture (CDFA) Nursery Nematode Control Program. Because of its role in depleting stratospheric ozone MeBr was phased-out in the US and other developed countries as of January 2005 under the provisions of the U.S. Clean Air Act and the Montreal Protocol (an international agreement). Some limited uses of MeBr are allowed under Critical Use Exemptions (CUE) and Quarantine/Preshipment (QPS) criteria. Although limited to the few registered compounds, alternative fumigants to MeBr such as 1,3-dichloropropene (Telone or 1,3-D), chloropicrin (CP) and methyl isothiocyanate (MITC) generators (e.g., metam sodium or dazomet) have been increasingly used (CDPR, 2005; Trout, 2006). These alternative fumigants, however, are VOCs and, when released to the atmosphere, can react with nitrogen oxides under sunlight to form harmful ground level ozone, an important air pollutant. Regulations (e.g., rate limits and buffer zones) have been used to minimize emissions. Stringent regulations are developed specifically on fumigant use to reduce air emissions especially in nonattainment area such as Ventura County and San Joaquin Valley of California (CDPR, 2008; Segawa, 2008).

We have been conducting research on emission reductions from soil fumigation for over four years. Our goal is to develop agricultural practices (effective, economic, and environmentally sound methods) to minimize fumigant emissions while achieving good efficacy.

Processes and factors affecting emissions. Soil fumigants are volatile compounds. The purpose of fumigation is to achieve maximum control of soil-borne pests, which requires sufficient fumigant concentration and uniform distribution in soil. A number of processes are involved in the fate of fumigant after application to soil (Figure 1). Fumigants are subject to partitioning to soil air, water and solid (most importantly organic matter), volatilization (emission), degradation, sorption and potential leaching. Emission loss is one of the major concerns related to fumigant effects on air quality. Containment of fumigant in the soil rooting zone is necessary for minimizing emissions as well as ensuring good efficacy.

Emissions from soil fumigation are affected by soil conditions (texture, moisture and organic matter content), weather, and surface barriers as well as fumigant properties. Generally speaking, lower emission are expected from soils with fine texture, high water content, high soil organic matter (SOM) content, and low temperature compared to soils with coarse texture, dry, low SOM content and high temperature conditions. Approaches to reduce fumigant emissions include management of application methods including equipment design/injection depth, physical barrier, irrigation, amendment with chemicals or organic materials, and target area treatment.

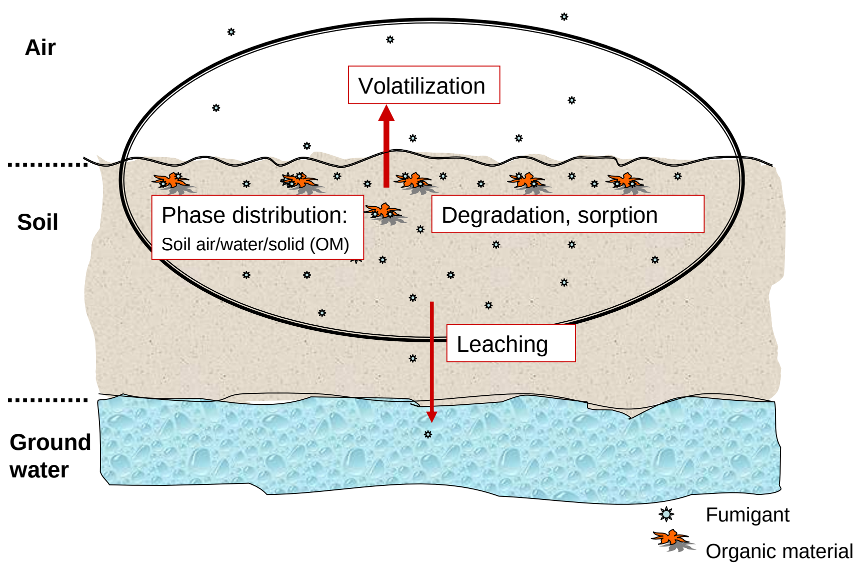

Figure 1. Illustration of processes affecting the fate of fumigants in soil.

Application method. Current fumigant applications include broadcast fumigation and chemigation. Standard broadcast fumigation refers to apply fumigants directly to a certain soil depth using conventional tractor-mounted shank-injection equipment. Chemigation refers to injecting fumigants into soil with irrigation water through sprinklers or drip-tape (drip-application). Application of fumigant to a deeper depth would lead to lower emissions than shallow depth applications. A general consensus is that emissions from drip application, especially subsurface drip application are lower than emissions from broadcast shank injections (e.g., Gao et al., 2008a; Wang et al., 2008). This is because increasing soil water content decreases air pore volume and increases the amount of fumigant partitioning in the aqueous phase. Fumigant diffusion rate in the liquid phase is much slower than through the gas phase.

Substantially high soil water content would reduce fumigant distribution in soils; thus it is only possible to ensure good efficacy when fumigant is applied with water (Ajwa and Trout, 2004). However, because of the high volatility of fumigants, drip-applied fumigants near soil surface without barrier may still lead to substantial high emission losses. To date, about half of strawberry acreage especially in the west coastal areas of California has adopted drip-application technique.

Plastic film. Plastic tarp (mulch) is the most commonly used practice for containment of fumigants in soil and to control fumigant emissions. The effectiveness of tarping on emission reductions depends largely on the chemical and tarp permeability and also soil conditions. Tarping with polyethylene (PE) film including both low density or high density (LDPE or HDPE) was found ineffective to control 1,3-D emissions in relatively dry soils. However, HDPE tarp applied over a moist soil profile from irrigation substantially reduced 1,3-D emissions due to water condensation under the film (Gao and Trout, 2007). Tarped treatment with HDPE in a pre-irrigated soil in summer may also benefit overall soil pest control. Shrestha et al. (2006) observed significant reductions in weed populations due to the high temperature under the tarp (up to 47^{o}C).

Use of low permeable films such as virtually impermeable film (VIF) showed great potential to reduce emissions in earlier laboratory or small plot tests. The VIF has much lower permeability to most fumigants than PE films (Papiernik and Yates, 2001). It is a three-layered film composed of barrier polymers such as nylon sandwiched between PE polymer layers (Villahoz et al., 2008). A number of studies have shown that the VIF can retain higher fumigant concentrations than HDPE thus reducing emissions while improving efficacy especially on weed control (e.g., Noling, 2002; Hanson et al., 2008). The effectiveness of VIF on emission reductions in large field applications had been uncertain because of the easy damage to the film and permeability change from field installation. Data obtained most recently confirmed that this type of film can effectively reduce emissions (Ajwa, 2008; Qin et al., 2008b; Yates, 2008). Although the tarp permeability increased after field installation, its permeability was still substantially lower than PE films.

A new type of film, the so called total impermeable film (TIF), has been shown to have easier installation and maintaining its low permeability property in field applications (Villahoz et al., 2008; Chow, 2008). This film has permeability to fumigants 10 times lower than VIF (Ajwa, 2008). It is a multi-layer (e.g., 5 layer) film incorporated with a thin layer of ethylene vinyl alcohol copolymer (EVOH) into a standard PE based film. Field testing on this film for emission reduction has been planned. The industry has been working towards the commercial availability of this film.

Irrigation. With proper management**,** water treatment can be used to minimize emissions. This includes post-fumigation water seal (applying water with sprinklers following fumigation) and pre-irrigation (irrigation prior to fumigant application). The latter is simply to achieve adequate soil moisture if soil is dry but to a level that will not inhibit fumigant distribution in soil profile. Water seal reduces fumigant emissions by forming a high water content layer at the soil surface to serve as a diffusion barrier. Some earlier studies showed that high water content in surface soil provided a more effective barrier to 1,3-D movement than HDPE tarp (e.g. Gan et al., 1998).

Intermittent water seals following fumigation have been recognized for effective emission reductions such as on MITC (Sullivan et al., 2004) and 1,3-D or chloropicrin (Gao and Trout, 2007). The effect is more profound on reducing emission peak flux (up to 80% reduction) following fumigant application (Gao et al., 2008b). When irrigation stops, however, emission flux tends to increase depending on fumigant concentrations in soil and, as a result, cumulative or total emission losses may not be reduced as substantially as the peak flux. Reducing the peak flux is important, however, because in addition to reducing the potential exposure risk to workers and bystanders during fumigation, buffer zone distance requirements are based on the peak flux. Although water seals were not found to reduce fumigant concentration and distribution in the soil profile, the high water content in the surface (0-15 cm) soil can decrease pest control at the soil surface (Hanson et al., 2008), thus, sequential treatment for the surface soil may be necessary.

Chemical amendment. Soil amendments with chemicals (e.g., ammonium or potassium thiosulfate (ATS or KTS), thiourea, or polysulfides) are extremely effective for reducing emissions. These chemicals can react with fumigants such as MeBr, 1,3-D, CP and methyl iodide to form non-volatile compounds by dehalogenation (Wang et al., 2000). Application of KTS with water to soil surface showed better control on weeds (Hanson et al., 2007). The practicality of using these chemicals as a field practice to reduce fumigant emissions is inconclusive at this time. Two field trials involving spraying KTS to soil surface following fumigation revealed that this chemical can reduce emissions of 1,3-D and CP significantly (Gao et al., 2008c). However, strong reactions between KTS and the fumigant in soil occurred resulting in a red-brownish soil and a very unpleasant smell that lasted for over a month in the vicinity. This was not observed in a strawberry field trial when KTS was applied to furrows of raised-beds (Qin et al., 2008ab). However, little fumigant emissions occurred from the furrows. Zheng et al. (2007) indicated that the smell may have been derived from further degradation of byproducts of thiosulfate and the fumigants.

Organic amendment. Soil amendment with organic materials such as composted manure has shown effectiveness in degrading fumigants and also reducing emissions in laboratory studies. Because of the strong incorporation of fumigants into organic matter (Xu et al., 2003), soil in high SOM content was reported to give lower emissions (Ashworth and Yates, 2007). However, there is insufficient field data at this time to conclude that organic amendments can effectively reduce fumigant emissions. Yates et al. (2008) reported that a field with incorporation of organic matter in previous year had much lower emissions than a field without the amendment but with water seals. In a field trial, manure incorporation at the rates of 12.4 and 24.8 Mg/ha (~5-10 tons/ac) did not reduce fumigant emissions (Gao et al., 2008c). Much higher manure application rates may be needed to achieve emission reduction from soil fumigation. Higher manure application rates, however, may not be economically feasible for some commodities because of the associated costs. This option may limit to those fields with access to free or low cost organic materials.

Target-area treatment. Fumigation to target areas such as tree rows or tree sites may be applicable for some orchards where pre-plant disease is the major concerns in preventing establishment of healthy crops. Shank application of fumigants in row-strip (shank-strip) or drip-application of fumigant in tree site (drip-spot) have been proposed and tested in field for efficacy of alternative fumigants (Browne et al., 2008). These target area treatment reduces emissions by reducing total treatment acreage to less than 50% (shank-strip) or 10% (drip-spot) of total field area.

Cost. Using low permeable plastic tarps appears the most promising technique in reducing emissions as well as achieving good efficacy. Costs of using HDPE tarp is about $2200/ha including: materials (tarp and glue: $1300/ha), application ($650/ha), and removal and disposal ($250/ha (Gao and Trout, 2006). Low permeability films (e.g., VIF or TIF) are expected to cost 1.5-2 times of PE films. In addition to the high cost, there are concerns on release of fumigants upon removal of the tarp or when planting holes are cut that increase the potential exposure risk to workers. Thus, longer waiting period of time between fumigation and tarp removal may be necessary to allow fumigant degradation in soils. If applicable, injection of thiosulfate under the tarp prior to tarp removal can effectively reduce this risk (Qin et al., 2007) although no field tests have been conducted. Commodities with low profit margin (e.g., stone fruit orchards and annual vegetables) may not be able to afford the costly plastic materials. Water seals, deep injection, drip application or incorporation of high rates of organic materials are the options in these crops. Using water costs much less than HDPE tarp and also offer some environmental benefits because no material disposal is required. The overall cost of using water at present is substantially lower than using plastic tarp. The cost for a 25-mm water application by sprinklers is in the range of $100–800/ha, depending on whether grower owns or rents the sprinkler system (Gao and Trout, 2006). Commercially available composted manure costs are in the range of $15-30/ton. Costs of higher rates than 25 ton/ha may not be feasible for these commodities.

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Session II

Nutrient Management

Session Chairs:

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Management of Mineral Nutrition in Table Grape Vineyards

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Introduction

An understanding of the seasonal uptake and partitioning of mineral nutrients of grapevines is essential in order to time fertilizer applications. Over the last three decades, several important studies were conducted to determine seasonal nutrition demands of field-grown grapevines and to quantify the partitioning of mineral nutrients (Christensen 1980, Conradie, 1981, Peacock, 1986, Peacock et al, 1989; 1991, Williams, 1987, Williams and Biscay, 1987). This paper aims to summarize what has been learned over the last few decades and highlight advances in grapevine mineral nutrition.

Nitrogen (N)

Nitrogen is the mineral element that grapevines require in the greatest amount. It serves as an important constituent of the protein makeup of all plant tissues and is a structural component of the chlorophyll molecule. When grapevines become deficient of N, vegetative growth slows and the foliage becomes chlorotic. In contrast, vines with an abundant supply of N have dark green foliage, growth is vigorous and canopies are dense, making canopy management difficult and may also contribute to other problems such as poor bud fruitfulness, poor coloration of red grapes, excessive shatter and increased levels of bunch rot and bunch stem necrosis (Christensen and Peacock, 2000).

The timing of N fertilizers, like other nutrients, should occur when demand is high and uptake is rapid. Nitrogen is needed most during the period of rapid vegetative growth, which occurs during the spring, from budbreak to early berry development. It is during this period that new growth may accumulate up to 50% of its annual N requirement (Conradie, 2005). Because active root growth and mineral uptake is generally minimal during the budbreak period, N demand is met primarily from reserves stored in the roots and other permanent woody structures (trunk, cordons, canes). The amount of N remobilized from permanent structures between budbreak and fruit set account for up to 40% of that needed by shoots, leaves and clusters (Conradie, 1980). Since the need for N is most critical in the spring and highly dependent on reserves, it can be inferred that the need for soil N is minimal very early in the season and that fertilizers should be applied when vines can best absorb and assimilate N as a part of the reserve while minimizing losses thorough leaching and denitrification (Conradie, 2005, Peacock et al, 1989).

Nitrogen absorption is most rapid between bloom and veraison, with the developing clusters being the largest sink for N during this time (Conradie, 2005, Peacock et al., 1989). Therefore, applications are best applied late in the spring, after the risk of frost, when uptake and demand is optimal (Christensen, 2008). A good timing for N fertilizer application is at fruit set (just after bloom), to correspond with rapid uptake and demand by developing clusters, and to a lesser extent by shoots and leaves. From bunch closure to veraison, when shoot growth slows, available N will also be allocated and incorporated into permanent vine structures for storage.

Another suggested timing for N fertilizer application is during the postharvest period. The postharvest period is an excellent time to provide N for uptake and storage to support new growth the following season. Studies using isotopically labeled N to measure seasonal uptake and partitioning of 'Thompson Seedless' grapevines, found that fertilizer applications made in July or late September (postharvest) resulted in the greatest concentration of labeled N in both storage tissues and in leaf tissue during the following spring and at bloom (Peacock et al., 1989). Furthermore, N absorbed during this period accounts for up to 60% of the total amount of N reserves available at the start of the next season (Conradie, 2005). When fertilizing during the postharvest period, the canopy should be healthy and functional to ensure adequate uptake—this application should be made before October in the San Joaquin Valley (Christensen et al., 1996). Furthermore, the postharvest window may be too short for late harvest varieties, like Crimson Seedless or Autumn King, for effective uptake to occur.

The N requirement of grapevines is considerably less compared to other agricultural crops (Mullins et al., 1992). A study conducted to determine the amount of N used by 'Thompson Seedless' grapevines grown for raisins in the San Joaquin Valley found that approximately 75 lb a^{-1} (84 kg ha^{-1}) was required to support annual growth of leaves, stems and clusters. Harvested fruit accounted for the greatest losses from the vine at approximately 31 lb a^{-1} (35 kg ha^{-1}), while other vine parts contributing to losses such as fallen leaves and prunings would be returned to the soil, recycled and remobilized within the vine (Williams, 1987). Based on this work and other studies, it has been estimated that a vineyard with an average yield of 10 ton a^{-1}, would require approximately 30 lb a^{-1}, or 3 lb per ton, of N in order to replenish the losses from the fruit at harvest (Christensen, 2008). Using this formula, a table grape vineyard with an average yield of 1000 (19-lb) boxes per acre, would require approximately 28.5 lb a^{-1} and the requirement would increase with larger yields. In general, vine yields and fruit quality can be sustained with 22.3 lb a^{-1} (25 kg ha^{-1}) to 44.6 lb a^{-1} (50 kg ha^{-1}) N applied annually (Peacock et al., 1996).

Determining the amount of nitrogen to apply to the vineyard depends on several factors. Nitrogen sources from irrigation water, crop residues/cover crops, and mineralization of soil organic matter and other factors such as the variety, rootstock, irrigation practices and canopy management practices should be taken into consideration when determining the nitrogen fertilizer requirements. In table grape vineyards, the goal of nitrogen fertilization is to meet the vine requirements in order to maximize yields and quality. Fertilization practices should be assessed and adjusted annually according to tissue analysis and observations of vine vigor and fruit quality.

Potassium (K)

Potassium is essential for grapevine growth and yield and serves an important purpose in several different plant functions. Potassium is readily translocated throughout the grapevine and may be involved in carbohydrate transport and metabolism. Potassium, a cation, is used as an osmotic agent in the opening and closing of stomata, an important mechanism of vine water relations. Potassium also neutralizes organic acids and plays a role in controlling acidity and pH of the fruit's juice (Mullins et al., 1992). Very little is known about the exact functions of K in grape berries, however it is known that K is vital for berry growth (Mpelasoka et al, 2003)

Potassium deficiency is generally not widespread in the vineyard and is often observed in areas with sandy soils with low native K fertility or where topsoil was removed for leveling. Compacted soils, poorly drained soils, water stress and vines with weak root systems due to damage by soils pests (phylloxera and nematodes) may also contribute to K deficiency due to poor K uptake (Christensen and Peacock, 2000). Vines deficient of K will exhibit chlorosis of the leaf margin and between the main veins by mid-summer and marginal burning and curling as symptoms progress. When K deficiency is severe, shoot growth is significantly reduced and vines may defoliate prematurely, especially if the crop is large. Vines may also have fewer, smaller clusters with poorly colored, small berries (Christensen and Peacock, 2000).

Like nitrogen, the demand of new growth for K in the spring exceeds root uptake during the period from budbreak to bloom. The need for K is most critical during berry development and ripening, and it is during this time that the fruit becomes the strongest sink for available K (Mpelasoka et al, 2003). This period also corresponds with the time at which root uptake for K is most rapid. Root uptake of soil K accounts for only about 50% or less of K accumulated in developing clusters and the remainder of the demand to support fruit growth is met from K reserves in the permanent vine structures (Conradie, 1981, Williams and Biscay, 1991).

Given that the developing fruit is such a strong sink for K, timing of K fertilizers should be applied during the early spring (a few weeks after budbreak) up to veraison. Potassium fertilizer efficiency is best when applied under drip irrigation, as much lower rates are required to correct deficiencies compared to banded applications in furrow irrigated vineyards. This is due to the fact that many soils in the San Joaquin Valley have a great capacity to fix (tie up) K. Efficiency under drip delivery is improved because high concentrations of K saturate the soil reaction sites in the area of greatest root density (Peacock, 1999). Previous work has demonstrated that a single application of K with drip is just as effective as multiple applications, given that the same amount is applied (Christensen and Peacock, 1986). However, it is often more practical to apply K in incremental units through the drip system on a weekly basis rather than all at once. Recommended K fertilization strategy for effective for K maintenance is 10 to 15 lb a^{-1} applied weekly over the course of 10 to 15 weeks (ending at veraison).

Magnesium (Mg)

Magnesium in grapevines plays two main roles. First, magnesium is an essential component of the chlorophyll molecule and is vital for photosynthesis. Magnesium also activates enzymes required for plant growth (Mullins et al., 1992). Because Mg is a constituent of chlorophyll, deficiency symptoms are observed as creamy-white chlorosis of the leaf. The chlorotic pattern is quite distinct with Mg deficiency, where fading begins near the leaf margin and progresses inward toward the primary and secondary veins. The pattern is generally described as a “Christmas tree” where areas surrounding the veins remain green. Magnesium is a mobile element and is readily translocated from older tissues to younger tissues. Because of this, older basal leaves show deficiency symptoms first, usually in mid- to late-summer (Christensen and Peacock, 2000).

Mild Mg deficiency, where a few basal leaves express symptoms, are commonly observed in table grape vineyards by late summer and are usually ignored. This generally does not contribute to negative effects on vine growth or yield because these basal leaves are well shaded during the summer and their contribution to the photosynthetic capacity of the vine is negligible. However, if 10-20% or more of the canopy is affected, correction is warranted, as 20% reduction in functional leaf area and thus photosynthetic capacity could present problems with respect to carbohydrate production, fruit ripening and overall vine growth (Peacock, 1999).

Magnesium is leachable in the soil and is often found in subsoils rather than in the upper portion of the profile where most of the root activity and uptake occurs. Because of this, young vines with shallow root systems and vines planted on older, highly weathered soils are more susceptible to Mg deficiency (Christensen and Peacock, 2000). It is important to note that severe and/or chronic Mg deficiency maybe caused by a preexisting soil condition or an interaction with other nutrients on the soil's (cation) exchange sites. Magnesium deficiency is more prevalent where soils have become acidic ($pH \leq 5.5$) after years of repeated use of urea and/or ammonical fertilizers. This can be corrected with the application and incorporation of lime, thus neutralizing the acid and adding calcium and Mg to the base exchange site (Peacock, 1996). Furthermore, calcium, potassium and Mg interact on the soil's exchange site and compete for entry into plants. It has been observed in vineyards under drip irrigation, that the application of calcium to improve water infiltration, or the application of potassium through the drip, has reduced Mg levels in vines (Peacock, 1996).

Seasonal uptake and partitioning of Mg within the grapevine begins at budbreak and from the period of budbreak to bloom, reserve Mg (mainly from roots) contributes 18% toward the requirement of new vine growth (Conradie, 2005). Leaves and shoots account for the greatest portion of total vine Mg throughout the season. The greatest amount of absorbed Mg partitioned to the permanent vine structures occurs about 4 weeks after harvest. Overall, the absorption pattern for Mg shows a steady accumulation for all measured vine organs (trunk, roots, shoots, leaves, bunches) from budbreak on and accumulation ceases just before the onset of leaf abscission in the fall (Conradie, 1981). Given that uptake and accumulation increase steadily from budbreak on, and if Mg fertilization is warranted, Mg applications can be delivered either through drip irrigation or foliar sprays anytime during the spring.

Zinc (Zn)

Zinc is the most common deficient micronutrient in vineyards (Christensen, 2005). Zinc is involved in the synthesis of plant hormone, indoleacetic acid (IAA) and in the formation of chloroplasts and the process of pollination (Mullins et al., 1992). Zinc deficiency in grapevines is observed on sandy soils of low Zn content and calcareous (high lime) soils where the high pH reduces Zn availability. Vines grafted to rootstocks of *Vitis champinii* parentage such as, 'Freedom' and 'Harmony' are also prone to Zn deficiency. Zinc deficiency in grapevines, depending on the severity, may affect both fruit and foliage. Fruit symptoms include reduced fruit set and the formation of shot berries. Severe deficiencies are expressed in the foliage, where shoot growth is stunted, with shortened internodes and many short lateral shoots, with abnormally small leaves. Leaves on main shoots also appear stunted with wide petiolar sinuses and interveinal chlorosis (Christensen and Peacock, 2000).

Most Zn deficiencies are corrected with foliar spray applications applied before bloom in order to improve fruit set and berry development. Studies to determine optimum timing of Zn and its effects on fruit set, berry size, cluster weight and petiole Zn levels demonstrated that the best timing is from two weeks prior to bloom to full bloom (Christensen, 1980). In addition, fall sprays were not effective in reducing Zn deficiency symptoms the following spring (Christensen, 1980).

Cultivar and Rootstock Effects on Mineral Nutrition

Cultivar and rootstock selection can have a strong influence on grapevine mineral nutrition. For example, when comparing the results of tissue analysis for N (NO_3-N) levels of different own-root table grape cultivars, it is consistently observed that healthy 'Flame Seedless' will tend to have relatively low (100-200 ppm) NO_3-N levels, while 'Thompson Seedless' grown on the same soils in the same location will have substantially higher levels (1,000-1,200 ppm NO_3-N). In addition, it is known that vines grafted to vigorous, nematode-resistant rootstocks 'Freedom' and 'Harmony' have larger, more explorative root systems compared to own-root vines, and as a result have higher N and K status and lower fertilizer requirements.

In conclusion, determining the nutrition requirement for table grape vineyards must take into account the following factors: soil type and chemistry, characteristics of the cultivar and rootstock, vine vigor and canopy management strategies, soil pests, fertilizer history, knowledge of nutrient inputs (other than synthetic fertilizers) and results of tissue analysis. Timing of fertilizer applications should be made when demand is high and uptake is rapid, while minimizing losses from the soil through leaching.

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Grapevine Nutrition- An Australian Perspective

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Summary

The physiological and metabolic processes involved with grapevine growth and production are influenced by key macro or micro-nutrients. Elements, such as nitrogen, phosphorous, potassium, magnesium, boron, zinc, manganese, iron and copper, play important roles in vine functioning, growth, yield and/or quality. Nutritional effects on wine quality have also been identified, thus giving even greater importance to nutritional management. In many viticultural regions, particularly in Australia, nutritional deficiencies of the key elements in soils have led to research into fertilizer requirements of grapevines. The ancient soils of Australia present specific challenges with a range of nutritional deficiency present across the continent in different viticultural regions. As our understanding of the nutritional needs of grapevines has evolved, we, as grape growers, are better equipped to develop effective fertilizer management programs for healthy and productive vine growth. Fertilizer programs should aim to address individual elemental deficiencies experienced by vines to ensure balanced growth between foliage and crop, rapid ripening of fruit and wood and promote wine quality.

This paper will review vine nutrition by evaluating the roles of the essential nutrients in the growth and productivity of grapevines and the physical symptoms expressed when individual elements are deficient or exceed vine requirements. Nutritional and fertilizer management will also be addressed, in terms of assessing vine and soil nutrient status and answering the important fertilizer application questions, including selection of fertilizers, how much to fertilize and timing of fertilizer application for healthy grapevine production.

Grapevine Nutrition

Nutrients involved in development of grapevines, photosynthetic functioning and metabolic pathways are required in certain quantities to ensure healthy growth and performance. Essential elements are classified and macro- or micronutrients dependant on the quantity of that element required by the plant. Macronutrients include nitrogen, phosphorous, potassium, calcium, magnesium and sulfur occur at high levels in plant tissue, 0.2 to 3% of dry weight. Micronutrients occur at lower levels in plant tissue; iron and manganese at 50 to 150 ppm dry weight and molybdenum, copper, zinc and boron at 0.5 to 40 ppm dry weight. If an element is not available in adequate amounts then vine performance is limited by the supply of that one element. In the case of micronutrients it is availability, rather than element concentration that is often the limitation when deficiencies are recorded. Deficiencies or toxicity of individual essential elements can result in characteristic foliar symptoms and restricted growth habit.

What are the roles of nutrients in growth and productivity of grapevines and their sources?

Macronutrients

Nitrogen

Nitrogen (N) is involved in almost every metabolic process occurring in the growth of grapevines, including the development of berries and consists of about 1-2% of the total dry mass of a grapevine. Nitrogen is an essential component of functioning proteins and chlorophyll in leaves and thus, photosynthesis. Vines low in nitrogen generally display low vigour and poor production, as a result of reduced protein synthesis and photosynthesis. Vines deficient in nitrogen will also display a yellowing of all leaves and green tissue (Fig. 1). This symptom is indicative of a lack of chlorophyll content in the leaves, which is evidence of reduced photosynthetic capacity. Yellowed leaves may defoliate mid-season, which can lead to delayed ripening and in extreme cases defoliation and loss of bunches. Nitrogen deficient vines may produce smaller bunches with fewer and smaller berries. Vines with high or excessive nitrogen can also have an adverse effect on productivity of the vine, due to vigorous growth of vegetative parts leading to shading and subsequent reduction in fruit set and poor bud fertility.

Nitrogen concentration of Australian soils is generally low and can originate from the following processes: fixation of atmospheric nitrogen by microbes, decomposition of plant and microbial residues containing nitrogen, and nitrogenous fertilizer inputs. It is available to plants as mineral nitrogen (nitrate and ammonium), organic nitrogen (biomass) and gaseous nitrogen (atmospheric nitrogen, nitrous oxide and ammonium) in the soil. The availability of soil nitrogen depends on the level of organic matter in the soil and with continual harvesting of fruit and removal of prunings, then nitrogen fertilization may be necessary.

Phosphorus

Phosphorus (P) is involved in the transfer of energy within plant cells that facilitate metabolism and is a constituent of the fatty portion of cell membranes and of compounds involved with assimilation and metabolism of carbohydrates. It constitutes approximately 0.1 to 0.3% of dry matter of the vine, equivalent to 1.3 lbs per ton of grapes (Robinson, 1988). Deficiency of phosphorus in vines can result in reduced vine vigor and yellowing of the interveinal area of basal leaves. In extreme cases, some red discoloration of the interveinal area of basal leaves may be observed (Fig. 2), followed by early defoliation of these leaves. These symptoms may be confused with leafroll virus but phosphorus symptoms occur earlier in the growing season (flowering). Poor bud initiation and fruit set may also be observed. Excessive phosphorus has not been shown to be a direct problem for grapevines; however it may limit the uptake of other essential elements, such as zinc.

Phosphorus is available from the breakdown of organic materials in the soil or as an applied fertilizer, which is common practice in Australia where the soils are inherently low in native concentrations of phosphorus.

Potassium

Potassium (K) constitutes up to 3% of the dry weight of a grapevine and is an important component of grape juice and thus wine. The role of potassium is to contribute to the regulation of water movement within the vine by providing an electrical balance for anions in the vacuole of plant cells and maintaining turgidity of cells. In red varieties, potassium is important for berry color development. Potassium deficiencies is expressed as marginal leaf yellowing in white varieties and marginal leaf reddening in red varieties, followed by marginal leaf burn, marginal leaf curling (Fig. 3) and defoliation of all varieties in severe cases. Potassium is readily mobilized in vines as symptoms move from basal leaves to younger leaves, as the vine grows. Other less common symptoms include reduced bunch weight, uneven berry ripening and blackening of leaves. Like phosphorus, high levels of potassium do not directly affect the vine or fruit but may limit calcium and magnesium uptake and increase grape juice pH levels.

Potassium is generally bound to negatively charged clay particles in the soil and many viticultural regions in Australia are based on clay mineral enriched soils, thus potassium availability is not a significant problem. However, potassium deficiency may occur in leached, acidic soils.

Other Macronutrients

Calcium (Ca), Magnesium (Mg) and Sulfur (S) are also found at high levels in grapevine tissue and contribute to the functioning and structure of the vine. Calcium plays a role in the structure of the vine and may be associated with bunch stem necrosis, but this has not been confirmed. Calcium can be applied to the soil in the form of lime or gypsum. Magnesium is a component of chlorophyll, thus contributes to carbohydrate production in leaves through photosynthesis. Magnesium symptoms appear in mid- to late season and include marginal leaf yellowing or reddening of basal leaves, which extends to the interveinal area, while the mid-vein region remains green. High magnesium levels may limit uptake of potassium by the vine. Sulfur (S) is present in proteins and chlorophyll and plays a role in energy metabolism. Sulfur deficiency symptoms are similar to nitrogen deficiency, yet are rare given the widely adopted use of sulfur-based sprays for fungicide management and sulfur containing fertilizers in Australia and around the world.

FIGURE 1: A nitrogen deficient leaf compared to a healthy leaf (sourced from Treeby *et. al*. 2004)

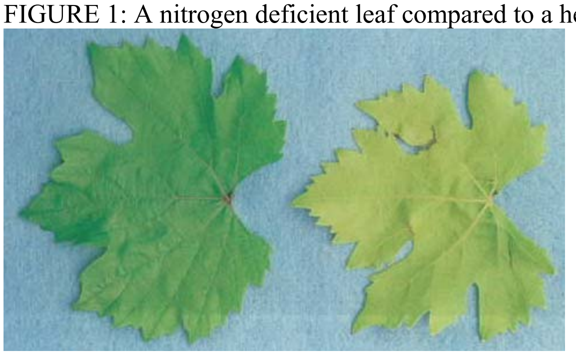
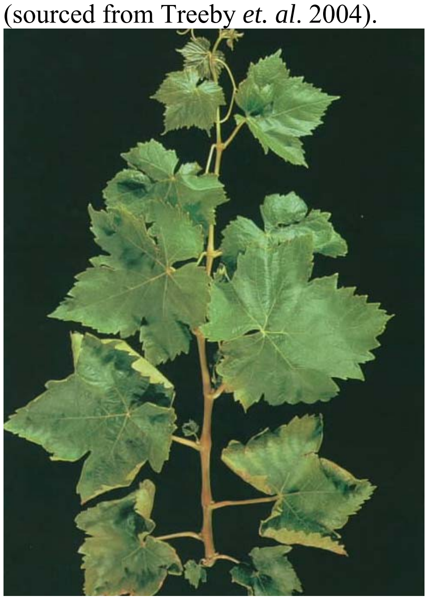


FIGURE 2: Severe leaf symptoms of phosphorus deficiency in a basal leaf of a red variety of grapevine (sourced from Treeby *et. al*. 2004)

FIGURE 3: Potassium deficiency expressed as leaf curling of the older leaves and subsequent leaf margin necrosis (sourced from Treeby *et. al*. 2004).



Micronutrients

Iron

Iron (Fe) is a micronutrient present in proteins for energy transfer in assimilation and respiration and is involved in chlorophyll formation. Deficiency of iron is observed as stunted growth and diffuse yellowing of young leaves and shoot tips (Fig. 4). In severe cases the whole leaf becomes chlorotic (bleached appearance), whereas leaf veins remain green with mild deficiency. Iron can be found in complexes with soil organic matter or in insoluble minerals and its availability is restricted by bicarbonate inhibition in compacted or waterlogged alkaline soils. To date iron toxicity is not known to occur in vineyards.

Manganese

Manganese (Mn) plays an important role in the synthesis of chlorophyll and nitrogen metabolism and is present in soil as exchangeable manganese or manganese oxide. Manganese deficiency is expressed as yellowing of the interveinal area of older leaves (Fig. 5) and may be mistaken for zinc or iron deficiency. These symptoms may be found in vines on sandy, calcareous soils or in areas of high rainfall. Toxicity of manganese is rare but can be seen as black spots on the leaves, shoots and bunch stems.

Molybdenum

Molybdenum (Mo) is involved in nitrogen metabolism and deficiency symptoms include stunted growth. Poor fruit set in Merlot has been linked to molybdenum deficiency and foliar Mo sprays have been use in southern Australia to successfully improve Merlot productivity and growth. Molybdenum is found in soil as molybdate and availability is greater in alkaline soils.

Copper

Copper (Cu) is a component of enzymes involved in oxidation and also chlorophyll synthesis. Deficiency symptoms are not common, probably due to the use of copper based fungicidal sprays but may be expressed as low vine vigor, poor production, shoots do not mature and bark appears rough. In areas of persistent copper fungicide use, toxicity has been reported and results in decreased levels of other essential elements (P, Fe and Zn) in plant tissue.

Zinc

Zinc (Zn) deficiency is common in Australian viticultural regions and is involved in protein synthesis, some plant hormone production and fruit set. Deficiency of zinc can result in stunted growth and development of small, undersized leaves with mottling between veins, clawed margins and widened petiolar sinus. Poor fruit set and “hen and chicken” bunches of variable sized berries may occur even when leaf symptoms are not observed. As a result, pre-flowering zinc foliar sprays are common practice in vineyards.

Boron

Boron (B) exists in the soil as the anion, borate and plays a role in the synthesis of growth regulating plant hormones and fruit set. Boron deficiency is observed as stunted growth with shorten internodes displaying a “zig-zag” pattern, death of shoot tips and interveinal chlorosis of older leaves. In cases of severe deficiency bunch and tendril abortion can occur and pollen tube growth is affected, resulting in poor fruit set. Boron toxicity symptoms include cupped leaves on young shoots, followed by brown necrotic spots on the leaf margin and yellow streaks between veins.

FIGURE 4: Shoot and leaf symptoms of iron deficiency (sourced from Treeby *et. al*. 2004).

FIGURE 5: Manganese deficiency expressed as interveinal chlorosis of basal and mid-shoot leaves (sourced from Treeby *et. al*. 2004).

Grapevine Nutrition Management

Managing the nutritional requirements of a vineyard requires visual assessment of vines and their growth habit for abnormalities and assessment of the nutrient status of plant tissue and/or the soil to develop an appropriate fertilizer program. Analysis of the nutrient content of petioles gives a good indication of the available nutrients to the plant, whereas soil tests reflect the nutrient content present in the soil and not necessarily available to the plant.

Grapevines generally require some supplementary fertilizer to ensure maximum production. Macronutrients are usually applied to the soil surface in dry form, ripped into the soil or applied via fertigation, whereas micronutrients are generally applied directly to the vegetative part of the vine via foliar sprays. Successful fertilizer management is dependent on selection of the correct fertilizer to address the specific deficit experienced in the vineyard, correct calculation of nutrient requirements, timing of the application of the fertilizer and cost-benefit comparison of available fertilizers.

Assessing vine nutrient status

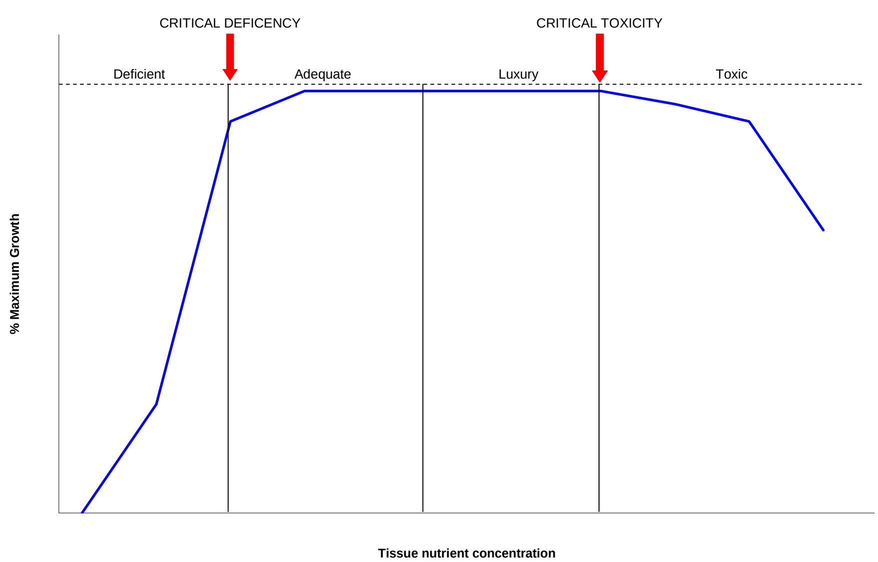
Soil Testing

Soil samples can be analyzed for nutritional composition; however this may not reflect what levels of nutrients are available for uptake by the grapevine. Soil physical properties, such as texture and structure may also be assessed, as they influence the availability of nutrients, especially nitrogen. Soils high in organic content generally have high levels of readily available nutrients. Whereas, sandy soils are likely to be leached of nutrients and high clay content soils will rapidly fix applied potassium fertilizers.

Petiole Testing

Petiole testing involves collection of a sample of approximately 100 leaf petioles taken from leaves opposite the basal bunch at 50% cap-fall (Treeby *et. al*., 2004). Samples should be collected from separate blocks, different varieties and rootstocks and from areas of apparent nutritional symptoms. Samples should be collected in the morning while wearing gloves, stored in a new paper bag and dispatched to the analytical laboratory immediately. Analytical results are expressed on a dry weight basis. Analyzed nutrient levels are compared to a range of nutrient concentrations standards representing deficient, adequate or high levels of specific elements based on plant performance. Deficient nutrient concentration limits vine performance and could be improved by nutritional supplement, adequate concentrations will not limit vine performance and high or excessive concentrations can be toxic and have an adverse effect on vine performance (Fig 6).

FIGURE 6: Schematic representation of the relationship between plant tissue nutrient concentration and vine performance.



Fertilizer Management

Developing an appropriate fertilizer program for a vineyard should involve answering 3 key questions: what fertilizer is the most appropriate for the job, how much nutrient is required based on petiole analysis and seasonal vine usage and when should the fertilizer be applied to maximise its benefit? Significant levels of nutrients are removed from the vineyard as grapes and pruning material each year. Further losses of nutrients can be attributed to volatilization, leaching and adsorption in the soil.

Fertilizer selection requires an understanding of the elements present in the fertilizer, the concentration of those elements and their availability to plants. This information is critical for evaluating the fertilizers effectiveness as a nutrient supplement and its value for money. Other considerations in fertilizer selection include other nutritional supplements the product supplies, ease of application, occupational health and safety requirement around handling and storage, certification for organic status and additional side effects (soil improvement, odor, spray drift etc).

Fertilizers

Nitrogen can be applied as a fertilizer in 3 forms: nitrate, ammonium and urea. Vine roots take up nitrogen in the nitrate form more readily than the ammonium form. Yet the choice of nitrogen fertilizer can be determined on cost (urea is cheapest per lbs of N) or physical property of the fertilizer (sulfate of ammonium is easy to handle but is most acidifying). Fertigation with calcium nitrate is popular in Australia, as calcium is also supplied in soluble form which can neutralize acidic soils.

Phosphorus fertilizers are classified as water soluble, citrate soluble and citrate insoluble. Water soluble forms are readily leached into the soil, thus fertilizers with high levels of this form are preferable. Superphosphate is produced by the reaction of rock phosphate with sulfuric acid. The majority of the phosphorus is in the water soluble form and this fertilizer also contains calcium, as gypsum, which helps maintain soil structure. Mono-ammonium and di-ammonium phosphates are also popular fertilizer choices in vineyards, as they have the advantage of being readily soluble and provide a source of both nitrogen and phosphorus. However, these fertilizers are not suitable for use on acidic soils.

Mixed fertilizers are generally a combination of nitrogen, phosphorus and potassium in various ratios. These fertilizers have the advantage of lowered application costs but a suitable ratio should be selected based on the vineyards specific nutrient requirements.

Organic fertilizers are gaining popularity, as they are often viewed as a soil amendment to improve soil structure and microbial activity in addition to providing nutritional benefits. The increased cost of synthetic fertilizers in recent time and industry shift to sustainable practices in the vineyard has also aided the shift to organic fertilizers.

Micronutrients are applied as foliar sprays, as they are more readily available to the grapevine via the vegetative portion of the plant. Also, micronutrients become immobilized if they come in contact with the soil due to the soil exchange capacity, thus have minimal chance of being leached into the rootzone.

Timing of fertilizer application

The timing of fertilizer application depends on vine age, phenology, availability of soil moisture, nutrient mobility and cation exchange capacity. Young vines require increased nitrogen inputs to ensure rapid root and vegetative growth compared to older, established vines. The phenological development of a grapevine dictates which nutrients are required based on the growth of vegetative or reproductive components of the vines. Nitrogen, molybdenum, potassium and phosphorus are important after budburst, when the vine is undergoing rapid vegetative growth. Whereas, magnesium, zinc, manganese, boron and iron are critical prior to flowering when compounds are required for good bud initiation for the following season and fruit set in the current season. After harvest, a flush of root growth and carbohydrate storage in the trunk requires addition nitrogen, phosphorus and calcium inputs. The movement of applied fertilizers through the soil into the rootzone is dependent on the soil moisture content, as provided by irrigation and /or rainfall and also, the concentration of the negative charge of the soil in the case of the cationic micronutrients.

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How to Develop a Nutrition Program for Nut Crops

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Introduction

Deciduous trees require 14 elements for normal growth and reproduction. These essential mineral elements are classified as either macronutrients (N, P, K, Ca, Mg, S) or micronutrients (Fe, Mn, Cl, B, Cu, Zn, Ni, Mo) based on the concentration normally present in plants. Each is essential for particular functions in the plant. Plant nutrients are also important in disease resistance and fruit quality, and the balance between the various elements can affect plant health and productivity. Amongst the essential nutrients, Cl and B, along with Na may be toxic to the tree if present at excessive levels in the soil or irrigation water. Optimization of nut crop productivity and quality requires an understanding of the nutrient requirements of the tree, the factors that influence nutrient availability and the methods used to diagnose and correct deficiencies. This paper will discuss important principles of plant nutrition that are the basis for developing a sound nutrition management program.

Factors Affecting the Nutrient Supply to the Plant

Although nutrients are taken up into the tree along with water, the absorption of these two essential plant requirements involve different physiological processes. Water uptake depends on physical forces in the soil and within the plant. Selective and active absorption of nutrients requires expenditure of respiratory energy and the existence of specialized cells and tissues found within the tips of roots. The efficiency and rate of nutrient absorption are greatest in the root tip region, but there is increasing evidence that other portions of the root are also capable of nutrient uptake. The fine, brown roots are also thought to contribute substantially to nutrient uptake because of their length and surface area.

Soil factors such as soil type and texture, soil moisture, pH and soil depth, as well as plant factors including root distribution, rootstock, fruit load and competition, all influence deciduous tree nutrition. Soil pH is a measure of the hydrogen ions present in the soil nutrient medium readily available for plant uptake. Its log scale ranges from 1 to 14, with 1 being highly acidic and 14 highly basic, or alkaline. A pH of 7 represents equal amounts of acid and base and is therefore neutral. Soil pH has a significant effect on nutrient availability. High pH (>7.5) greatly limits the solubility of many elements (i.e. Zn, Cu, Mn, Fe), while low soil pH can lead to deficiencies of P or Ca and toxicities of Al, Fe or Mn. Similarly, low soil temperature, poor aeration, or the presence of a hardpan can limit the plant's ability to obtain nutrients by limiting root growth and health.

Since all nutrients are supplied as dissolved ions in the water flow to roots, poor irrigation practices resulting in low soil water content reduce the availability of nutrients for plant uptake. Dry soil conditions also limit the concentration of nutrients (such as potassium) in soil water readily available for plant uptake. Under these circumstances, addition of more nutrients may not alleviate the deficiency; the solution lies instead in correction of the soil conditions that limit nutrient availability.

Amendments intended to change pH or improve soil structure can influence nutrient availability to the plant. However, it is essential that all aspects of the orchard and the production system be considered before deciding on such a course of action.

Environmental factors such as temperature, disease, salinity and the presence of high levels of specific elements may also influence plant nutrition. Each factor affects plant nutrition by influencing either the availability of nutrients to the root or the effectiveness of root uptake of the elements. Disease and salinity affect nutrient uptake by limiting root growth, and hence, volume.

DIAGNOSING ORCHARD NUTRIENT STATUS

Soil analysis

Soil analysis provides information on nutrient content and soil chemistry affecting its availability. Cation exchange capacity (CEC, the ability of a soil to retain cations for subsequent release into the soil solution), pH, and salinity all affect the availability of nutrients present in the soil. It is **CRITICAL** that adequate soil analyses be performed **PRIOR** to orchard establishment for accurate assessment of the site for nut crops. Correction of soil related problems is best and most effectively done before planting. Certain conditions, such as high pH combined with high soil lime (calcium carbonate) limit zinc, iron, manganese, and copper availability. High salinity must be corrected prior to planting to avoid poor orchard performance and tree loss. Pre-plant soil assessment may even reveal chemical conditions unsuitable for tree crops and save the investor from serious financial loss.

Established orchards benefit from soil analysis by assessing the impact of fertilization and irrigation management. It is also essential for a proper investigation into the cause for isolated poor tree performance. Soil analysis is most valuable when combined with a visual symptom assessment of the tree and tissue analysis. **Trees are complex, long-lived perennial plants whose nutritional status represents an integration of age and cultural practices in addition to soil nutrient availability!** Of greatest concern is the nutritional status of the tree-not the soil. Hence, soil analysis is usually recommended after a nutrient deficiency is suspected from the presence of foliar symptoms and tissue testing.

Collecting soil samples representative of the entire orchard is challenging and expensive. Deciduous tree roots spread through a large volume of soil, and soil type usually varies within the orchard. Soil chemistry also differs with depth from the surface. Surface soil chemistry and its nutritional status can be quite different from soil only one foot below it. Therefore, soil samples should be taken from the profile where roots are most active (typically the upper four feet of the profile). For a thorough analysis, soil samples should be taken in single-foot increments from five to ten different locations within the area of the orchard in question. The multiple samples taken from the same depth are then composited for submission to the laboratory. This process should then be repeated in other areas of the orchard, and compared to samples taken from the area of highest productivity. The number of areas sampled depends upon the different soil types occurring within the orchard. Nutrient deficiencies can be associated with soil differences (such as old creek beds), differences in topography, sand deposits, cuts or fills, or old coral and pasture sites.

When soil sampling, also consider the effect irrigation method has on root distribution and soil fertility within the root zone. Flood or basin irrigation applies water over a large area relatively uniformly and results in wider distribution of roots and area of nutrient uptake. Hence, sampling near the edge of the tree canopy but to one side of where fertilizer applications are made provides a reasonable assessment of soil nutrient status. With mini-sprinkler systems, sampling should be performed within the wetted pattern, but avoiding its edge where salts may accumulate. Orchards under drip irrigation require sampling approximately half-way between the emitter source and the edge of the wetted area. Due to the large difference in soil water content with distance from the emitter source, sampling too close to the emitter can lead to erroneously low soil nutrient assessment of some elements, particularly nitrogen because it exists as a leachable form in soil solution.

Interpretive guides for soils

The value of soil analysis as a guide to fertilization practices is limited by the inability to predict the relationship between soil chemical analysis and plant nutrient uptake. Soil analysis is best suited for assessment of pH, saturation percentage, CEC, and salinity. Diagnosis of nutrient deficiencies can be aided by knowing the soil pH, because it affects the availability (not the quantity!) of mineral nutrients. Nutrients may be abundant in the soil, but in order for them to be available for plant uptake, they must be in “the soil solution”. Soil solution is defined as the elements present in the water readily available for plant use. A low pH (<5.5) may result in deficiencies of Ca, Mg, P or Mo and perhaps excesses of Mn, Fe or Al. High pH (>7.5) may immobilize Mn, Zn, Fe or Cu, making them unavailable to the plant. High levels of calcium carbonate (lime) in the soil can induce deficiencies of Fe, Mn or Zn and may also make acidification of the soil difficult. The presence of any soil physical characteristic that limits root growth or water penetration is also likely to affect nutrient uptake.

Recent research on the effects of salinity in pistachio indicates it has significantly greater salt tolerance than other nut crops. No yield reduction was recorded using irrigation water with an EC_w (Electrical Conductivity) of 8.0 dS/m and soil with an EC_e (electrical conductivity of the saturation extract) of 9.4 dS/m (at 25^0 C). Soil chloride (Cl) and sodium (Na) in excess of 50 meq/liter were tolerated without negative effects. Experience in saline areas on the Westside of the San Joaquin Valley suggest pistachios tolerate 20-30 meq/l of Na and Cl and up to 4 ppm Boron (B) in the soil without adverse impacts on yield. Pistachios may be tolerant of exchangeable sodium percentages (ESP) as high as 15%. However, high exchangeable sodium levels in the surface soil can cause structural deterioration and subsequent water infiltration problems. Hence, water stress can be an indirect but significant effect of high soil sodium levels.

The soil conditions under which pistachios can be successfully grown are **NOT** those suitable for walnuts, almonds or pecans! Walnuts thrive on the best alluvial soils existent in the San Joaquin Valley. Soils with total salt levels (ECe) of 1.5 dS/m or less, sodium absorption ratio SAR) less than 5.0, chlorides less than 5.0 meq/L, and boron levels of 0.5 meq/l or less are chemically ideal for walnuts. Depending upon the rootstock selected, almonds can tolerate slightly higher salinity levels, but they should not be considered salt tolerant. Growing almonds in soils higher than optimal salinity presents significant problems associated with specific salt toxicity to plant tissues which limit productivity and longevity. Almonds grown on soils with elevated sodium or total salinity also experience major problems with soil water infiltration, resulting in sustained plant stress and reduced productivity. Prolonged soil surface wetness associated with low infiltration also greatly increases the risk of crown and root rot diseases.

Plant analysis

Leaf analysis is more useful in diagnosing mineral deficiencies and toxicities in tree crops than soil analysis. The mineral composition of a leaf is dependent on many factors, such as its stage of development, climatic conditions, availability of mineral elements in the soil, root distribution and activity, irrigation, etc. **Leaf samples integrate all these factors, and provide an estimate of which elements are being adequately absorbed by the roots**. The main limitation with leaf analysis is that it does not tell us **why** the nutrient is deficient. Leaf tissue can also vary significantly in nutrient content within individual trees, as well as between locations within a single orchard. To maximize the value of leaf analyses, one must therefore adhere to strict standardization of the sample procedure and locations sampled.

Sampling procedure

Concentrations of leaf nutrients vary with time, leaf age, position in canopy and the presence or absence of fruit. Trees within an orchard may also vary in their nutrient status as a result of differences in soil fertility, water availability or light exposure. Therefore, it is essential that sampling techniques be standardized if valid comparisons are to be made. Choice of sampling method also varies depending on the purpose of the survey. If the aim is only to identify the problem in an isolated tree or area, then sampling just a few poor and some good trees should suffice. If a determination of overall nutrient status in a large orchard is required, then more extensive sampling of trees from many sites will be required.

The correct leaf sampling procedure differs slightly by nut commodity. For pistachios, fully expanded sub-terminal leaflets (pistachios typically have five leaflets per compound leaf) are randomly collected from non-fruiting branches at about six feet from the ground. Four to ten leaves are typically collected per tree, and 10-20 trees are sampled in each orchard block. Leaves sprayed with micronutrients typically cannot be analyzed for that nutrient since the surface contamination cannot be removed. Hence, no leaves having received in-season nutrient sprays for the elements of interest should be sampled. Samples should be kept in labeled **paper** bags and submitted to the analytical service within 24 hours of collection. Leaves are living organs! Process them promptly! Pistachios are sampled from late July through August. The pistachio critical levels established through experimentation and observations (Table 1) are based on this timing. However the comparison of good trees against poor ones can be done at any time. Sampling at times other than from late July through August may have nutrient concentrations different than those recommended in the critical values tables and must be interpreted with care.

For walnuts, the least change in leaf nutrient concentration occurs between late June and early July. The sample date is different from pistachio due largely to the large boron requirement of pistachio, which continues to rise in the leaf tissue until nut maturity. Walnut nutrient studies performed over decades by UC researchers have examined leaves, petioles, hulls, nuts, stems, and even bark as the basis for critical level establishment. It was determined that fully expanded leaves from spurs were the most reliable. No designation is presently made between selection of fruiting over non-fruiting spurs, as in pistachio. Select spurs from as high as possible, but at least six feet off the orchard floor. Each sample should consist of about 50 leaves. Critical and adequate tissue levels for July can be found in table 2.

UC guidelines recommend tissue sampling almonds from July through mid-August. The critical values reported in table 3 are based on **nonfruiting** spurs sampled in July. Collect approximately 100 spur leaves at least six feet off the ground. Leaves within the sample must be from the same cultivar, on the same rootstock, and from trees of similar growth status. Sample different cultivars and trees of questionable condition separately to better assess orchard nutrient status. Label the samples so you can refer to their location later. Do not delay in delivery to the laboratory.

Pecans have multiple leaflets within a single leaf, and there are several leaves alternately opposed along a current season's shoot. **Sample two leaflets opposite one another mid-way on the leaf, and select a compound leaf that is mid-way along the shoot**. All four sides of the tree should be sampled, and a sample should represent about 60 leaves. July is the best time to sample in California. Table 4 provides the suggested nutrient levels typically used by California. Additional information is available at: http://cals.arizona.edu/pubs/diseases/az1410.pdf.

Table 1. Pistachio Critical and Suggested Levels for August Leaf Samples

Element	Critical Value	Suggested Range	Reference
Nitrogen (N)	1.8%	2.2 -2.5%	Weinbaum, et.al. 1988, 1995
Phosphorus (P)	0.14%	0.14-0.17%	
Potassium (K)	1.6%	1.8 - 2.0 %	Brown, et.al. 1999
Calcium (Ca)	1.3% (?)	1.3-4.0%	
Magnesium (Mg)	0.6% (?)	0.6-1.2%	
Sodium (Na)	(?)	(?)	
Chlorine (Cl)	(?)	0.1-0.3%	
Manganese (Mn)	30 ppm	30-80 ppm	
Boron (B)	90 ppm	150-250 ppm	Uriu,1984; Brown, et.al.,1993
Zinc (Zn)	7 ppm	10-15 ppm	Uriu and Pearson.1981, 1983,1984,1986
Copper (Cu)	4 ppm	6-10 ppm	Uriu, et.al. 1989

ppm = parts per million or milligrams/kilogram dry weight.

% = parts per hundred or grams/kilogram dry weight

Table 2. Walnut Critical and Suggested Levels for July Leaf Samples

Element	Critical Value	Suggested Range
Nitrogen (N)	2.1%	2.2 -3.2%
Phosphorus (P)	0.10%	0.14-0.3 %
Potassium (K)	1.0%	1.2 -1.7 %
Calcium (Ca)	0.9% (?)	>1.0%
Magnesium (Mg)	(?)	> 0.3%
Sodium (Na)	(?)	< 0.1%
Chlorine (Cl)	(?)	0.1-0.3%
Manganese (Mn)	(?)	> 20 ppm
Boron (B)	20 ppm	40-300 ppm
Zinc (Zn)	<18ppm	20-30 ppm
Copper (Cu)	4 ppm	6-10 ppm

Table 3. Almond Critical and Suggested Levels for August Leaf Samples

Element	Critical Value	Suggested Range
Nitrogen (N)	2.0%	2.2 -2.5%
Phosphorus (P)	< 0.1%	0.1-0.3%
Potassium (K)	1.0%	1.4–1.8 %
Calcium (Ca)	(?)	> 2.0%
Magnesium (Mg)	(?)	> 0.25%
Sodium (Na)	(?)	< 0.25%
Chlorine (Cl)	(?)	< 0.3%
Manganese (Mn)	(?)	> 20 ppm
Boron (B)	30 ppm	30-65 ppm
Zinc (Zn)	15 ppm	18-30 ppm
Copper (Cu)	4 ppm	6-10 ppm

Table 4. Suggested Levels for Pecan Leaf Tissue Sampled in July

Element	Suggested Range
Nitrogen (N)	2.7 -3.0%
Phosphorus (P)	0.18-0.30%
Potassium (K)	1.25 – 1.5 %
Calcium (Ca)	1.0-2.5%
Magnesium (Mg)	> 0.30%
Sodium (Na)	< 0.10%
Chlorine (Cl)	< 0.3%
Manganese (Mn)	80-300 ppm
Boron (B)	30-80 ppm
Zinc (Zn)	50-200 ppm
Copper (Cu)	> 4 ppm

Interpreting leaf analyses

Results of tissue analysis are reported as the concentration of a nutrient on a dry weight basis. For **macronutrients**, concentrations are reported on a percent basis (grams of nutrient per 100 g dry weight), while **micronutrients** are reported in parts per million (microgram nutrient per gram dry weight). For each element, the laboratory will usually identify the 'Critical Value' (CV), or the 'Adequate Range' to aid in interpretation of the results. 'Critical Value' or 'Critical Level' refers to the nutrient concentration at which plant yield is 95% of maximum, or at which distinct symptoms of deficiency are present. Tissue nutrient concentrations below this level will result in poor plant growth and reduced yields. The 'Adequate Range' refers to the nutrient concentration range at which growth is optimal. Above this nutrient concentration, plant growth may be inhibited by nutrient toxicity, or the soil concentration may be so high that plant uptake capacity is exceeded and the risk of leaching beyond the root zone exists. Nitrogen is the element of greatest concern, because of its potential to reach the groundwater. Critical values are crop specific. It is essential that the nutrient recommendations supplied by the testing laboratory reflect comparison to the adequate and critical values for the nut crop in question, since nutrient requirements differ significantly between crops. This is especially true for pistachio, since it has a much higher boron requirement than other deciduous tree crops and also tolerates more salinity.

Although valuable as a tool to assess orchard nutritional status, critical values are **not** absolute. They are based on general tree health and not yield or crop quality. Some nutrients, such as boron during bloom and potassium and nitrogen during pistachio kernel filling, may require supplementation for short periods to optimize production (Brown, 1993, 1999; Weinbaum, 1995). Ideally, fertilization would replace that amount consumed by the plant in growth and crop production. To achieve this objective, the total annual requirement of each nutrient must be determined, as well as the percentage removed from the orchard in the form of crop. Critical values for nitrogen, potassium, boron, zinc, and copper have been established from several research projects. Others remain estimates from field observation and levels acceptable in other deciduous crops. For several elements (nitrogen and boron and the toxic elements Na and Cl), it is equally important to ensure that nutrient concentrations do not exceed the optimum, as impaired plant growth may occur.

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Timing of Nutrient Applications – Stone Fruit

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Introduction

Many orchards suffer from poor nutrition and poor harvest quality due to errors in their fertility program. Frequently the orchardist has implemented a nutrient program for that deficiency, but applications are being made at the wrong time. These situations cause frustration for the growers who have made the effort of altering their fertilizer program but have not seen any improvement in their crop.

In this presentation I will address two of the most common nutrient timing problems, nitrogen timing and foliar micronutrient timing.

Nitrogen Timing

One of the main concepts in producing high quality stone fruit is to establish accurate nitrogen (N) control in the orchard. In most species of plants a high N level rapidly propels the plant through the season in a vegetative mode. Problems arise when there are no ways to bring the vegetative energy under control, to a point where the plant has a low enough N situation to properly mature a quality fruit at harvest.
Many characteristics of the plant are altered as N levels change.

High nitrogen levels in leaf tissue will promote the following:
extra wood production, extra leaf area production, increased shading, delayed fruit coloring, delayed ripening, increased disease pressure, potentially soft fruit.

Low nitrogen levels in leaf tissue will promote the following:
reduced wood production, reduced leaf area, reduced shading, earlier fruit coloring, earlier ripening, reduced disease pressure, firmer fruit at harvest.

With appropriate timing the above parameters can be used to control plant growth to fit variety and age specific production requirements. Most stone fruit need to start their season with a quick growth status (higher N) to produce the initial leaf area. Problems begin to occur when the tree needs to transition, later in the season, into a fruit sizing and ripening machine. At this point, the extra growth uses ("robs") more than its share of water and energy that would otherwise be directed into sizing the fruit. Additional shading and the high N status will delay the coloring and sugaring process. Though it is variety dependant, the result is often a poorly colored, bad tasting fruit that becomes soft before it reaches proper maturity. The real blame is often the grower's N program rather than the variety or the weather.

Variable harvest seasons of individual species and varieties add to the challenge of creating the perfect nitrogen program. An early harvest peach (May) often does best with the N applied in a split application in June & September. A late harvest peach (August) will often do best with split application applied in September & March. To treat them both the same will produce problematic and mediocre fruit. Obviously poor fruit is not the goal in the current poor marketing situation for stone fruit.

Nitrogen planning involves creating a relatively high N level in the spring to promote adequate growth in the early portion of the growing season and low N availability in the last month or two prior to harvest. This will trigger the plant to start consuming its N reserves and the ripening reaction need for optimum fruit quality. Small, carefully planned doses of fertilizer are used to create this scenario. Choice of fertilizer material, considering speed of availability, is important to control the N levels in the tree.

Sound complicated? Not really, but it becomes a bit more complicated when the N sources are a mix of manures, compost, foliar, ammonic fertilizer, nitrate fertilizer, N in the irrigation water, soil variations, etc. Pay attention to the nitrogen levels in the leaves as they change during the season, and the nitrogen history, to produce the desired results.

Minor Nutrient Timing

Controlling minor nutrient levels in orchards is simple, as long as you keep in mind the time of year when it is most needed and how much you are applying. First & foremost, remember that for most minor nutrient applications must be made using foliar sprays. In many cases soil applications can take years to make a deficient tree adequate.

Because one can spend years studying the intricacies of minor nutrient uptake I will focus on boron for this discussion. It’s deficiency is a very important problem experienced by many growers in Central California.

Bloom is the key time orchardists need to make sure boron is adequate in the plant. At this time it is important that adequate boron be distributed deep inside the blossom before it starts to bloom. Bloom sprays are a poor solution to correct this deficiency. These are applied just after the blossom has opened. The pollination process will have already started and your boron spray may not get to the deficient part of the orchard for a day or two. Trying to catch up after the fact is tough. Sure, a tissue sample taken mid-season will confirm you applied the boron but it does not tell anyone that it was applied too late to provide anything but marginal help.

Soil applications are effective with boron, but it can take many months to correct the deficiency depending on rates, irrigation system type, and soil type. Foliar applications applied in the late summer (August or September) will allow time for the minor nutrient to make the entire plant, including the fruiting buds, adequate before the move into dormancy. This timing will satisfy the trees’ requirement long in advance.

Application rates are another problem that the industry needs to address. Consider an orchardist that applies a “maintenance application” in the spring to an orchard that is deficient is zinc. If it is a true maintenance rate, it will be deficient again the next season at the same time, perpetuating the deficiency. Never use maintenance rates for a situation when you need corrective rates.

For a final thought, keep the dosages of the minor nutrients in the forefront of your decision. The number of applications depends on the dosage in each spray. Too many people making recommendations lose the concept of a nutrient application rate in their spray programs.

Example problematic zinc foliar program:
Apply Product-A (9% zinc) in 2007 at 1.5 qt. per acre.
Apply Product-B (0.9% zinc) in 2008 at 1.5 qt. per acre.

Obviously, the grower must apply 10 applications of Product-B to maintain a uniform program.

I have found that I can no longer ask my clients to apply a routine zinc spray. It has become more important to recommend dosages, such as a zinc spray program that provides "1 pound of actual zinc per acre". Unfortunately, when I ask most decision makers how many pounds of zinc was applied, they usually don't know. Also unfortunate, they have no idea how to make the calculation.

Concluding Statement

Appropriate nitrogen and minor nutrient programs have a moderate level of expertise required to develop the best program for a specific stone fruit block. Think of it like rebuilding a carburetor. Work with some one with experience for a while, select the right components, keep track of the order things go in, check yourself once in a while, finish making sure everything that was needed went in, and know your limitations. Being a good carburetor rebuilder is not rocket science but it is part of being a great mechanic!

Fertilization of Perennial Tree Crops: *Timing is everything!*

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Introduction

There are key stages in the phenology of every plant that have a greater demand for nutrients than others. For perennial tree crops, flowering, fruit set (with its associated period of early fruit drop) and June drop [the period of fruit drop (approx. June through July) that occurs when exponential fruit growth and vegetative shoot and root growth are simultaneous (Hamid et al., 1988)], are phenological stages of high nutrient demand. It is during these stages that the greatest gains in fruit number and retention, determinants of final yield, can be made. Moreover, events or treatments during these stages of phenology also impact fruit size, quality and storage life. The uptake of adequate amounts of nutrients during the period of flowering and fruit set can be compromised by cold, wet soil (Hamid et al., 1988), creating nutrient deficiencies that persist until the soil warms. A deficiency identified by visual symptoms or leaf analysis, even a transient or incipient deficiency, should be corrected quickly. The longer the tree's nutrient status remains at the low end or below the optimal range, especially during stages critical to yield, the greater the negative effects on yield, fruit size, quality and next year's bloom. Foliar fertilization can successfully supply essential nutrients more rapidly and more efficiently than soil fertilization. Application of zinc (Zn), manganese (Mn), boron (B) and molybdenum (Mo) to foliage was four to 30 times more efficient than soil application (PureGro, n.d.). Foliar fertilization has several additional advantages over traditional soil-applied fertilizer. Foliar fertilization can meet the tree's demand for a nutrient at times when soil conditions (low temperature, low soil moisture, poor drainage, pH, salinity) would render soil-applied fertilizers ineffective. Thus, foliar fertilization is an effective method for correcting soil deficiencies and overcoming the soil's inability to transfer nutrients to the plant. Nutrients, especially phosphate, potassium and trace elements can become fixed in the soil and unavailable to plants. Applying nutrients directly to leaves, the major organ for photosynthesis, ensures that the plant's metabolic machinery is not compromised by low availability of an essential nutrient. It is important to note that foliar-applied fertilizers of phloem mobile nutrients are translocated to all parts of the tree, including the smallest feeder roots. Moreover, foliar fertilizers reduce the potential for accumulation of nutrients in soil, run-off water, surface water (streams, lakes and oceans), and groundwater (drinking water supply), where they can contribute to salinity, eutrophication and nitrate contamination, all of which have serious consequences for the environment and humans. Replacing soil-applied fertilizer, at least in part, with foliar-applied fertilizer contributes to fertilizer best management practices (BMPs).

However, it must be noted that not all nutrients are taken up through the foliage of all plants and, even if taken up, some nutrients are not phloem mobile. *A priori* knowledge (research) is necessary to develop a foliar fertilization program for a crop. Whereas rates of foliar fertilizer are typically lower than soil-applied fertilizer, application of foliar fertilizer can be, in some instances, more expensive due to the need to use spray equipment. Thus, a goal of the author's research program has been to identify the role that the essential nutrient elements play in the physiology of a tree crop and then to apply the nutrient as a fertilizer to the foliage at the appropriate time in the phenology of the tree, i.e., a time when the demand for the nutrient is likely to be high, in order to stimulate a specific physiological process that increases yield, fruit (or nut) size or fruit (or nut) quality, such that the foliar application of the fertilizer results in a net increase in grower return even when the tree is not deficient in the nutrient by standard leaf (or petiole) analyses (Lovatt, 1999). The goal of the author's research is to obtain a plant growth regulator effect, yield benefit and net increase in grower income from a foliar-applied fertilizer by properly timing its application.

Due to the varying influences of edaphic and climatic factors, exactly when and how much soil-applied fertilizer the plant takes up remains largely speculative. Still timing is important. For example, to protect the groundwater from potential nitrate pollution, growers of the 'Hass' avocado (*Persea americana* Mill.) in California divide the total annual amount of nitrogen (N) into six small soil applications made from late January to early November. The lack of research data raised the question of whether 'Hass' avocado yield was being compromised by this fertilization practice. The author (Lovatt, 2001) addressed the question of whether yield of 'Hass' avocado could be increased by doubling the amount of N applied in one of the six applications if it was timed to meet the nutrient demands of a specific key stage of avocado tree phenology. The results of this research provided clear evidence that time of N fertilizer application to the soil was an important factor in determining final yield and fruit size, as well as yield the following year (Lovatt, 2001).

With the price of fertilizer continuing to increase, timing the application of foliar, and even soil-applied, fertilizers to stages of crop phenology with high nutrient demand makes sense. Not only will the crop utilize a greater amount of the nutrient applied, but also meeting the crop's nutrient demand will result in a yield benefit and an increase in net income to the grower. Use of foliar-applied fertilizers at key stages of crop phenology when soil conditions impede the uptake of soil-applied fertilizers is a judicious approach for enhancing yield and grower income.

Examples of Properly Timed Foliar-applied Fertilizers that Prove the Concept

Winter prebloom foliar applications of low-biuret urea or potassium phosphite (a form of P [HPO_3^{-2}] readily taken up by leaves and translocated through trees to the roots [Lovatt and Mikkelsen, 2006]) have been shown to increase total yield, yield of commercially valuable large size fruit and total soluble solids (TSS) of sweet oranges (*Citrus sinensis*) (Albrigo, 1999; Ali and Lovatt, 1992, 1994; Lovatt, 1999); when low-biuret urea and potassium phosphite were combined, the yield benefits were additive (Albrigo, 1999). When used as a winter prebloom foliar spray on navel oranges in California, low-biuret urea (46-0-0, ≤ 0.25% biuret) applied at 50 lb low-biuret urea (23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha) resulted in an average net increase in yield of 3 US tons per acre (7 metric tons per ha) annually for the 3 years of the experiment (Ali and Lovatt, 1992, 1994; Lovatt, 1999). Furthermore, as total yield increased per tree, the yield of commercially valuable large size fruit (transverse diameter 2.7-3.5 inches; 6.9-8.8 cm; packing carton sizes 88+72+56) also increased (Ali and Lovatt, 1994; Lovatt 1999). NOTE: Lower spray volumes can be used as long as tree coverage is good, but volumes of 500 to 700 gallons per acre (4,673-6,542 L/ha) showed greater incidence of tip burn due to pooling of the solution at the leaf tip.

The potassium phosphite formulation that has been used on perennial tree crops in all US research trials reported in the literature thus far is Nutri-Phite (Biagro Western Sales, Inc., Visalia, Calif.). Nutri-Phite (0-28-26) applied as a winter prebloom spray at 2.6 quarts (0.64 gallons) in 200 gallons water per acre (6 L Nutri-Phite in 1869 L/ha) to Valencia oranges in Florida resulted in an annual net increase in total yield of 3 US tons per acre (7 metric tons per ha), whereas the winter prebloom urea treatment resulted in a net increase of only 1.8 US tons per acre (4 metric tons per ha) (Albrigo, 1999). Both treatments significantly increased the total soluble solids concentration of the fruit. Use of urea and potassium phosphite in Clementine mandarin (*C. reticulata*) production in Morocco produced similar beneficial yield results (El-Otmani et al., 2003a, b).

To increase fruit size of navel oranges, potassium phosphite is applied to the foliage in May (during the cell division stage of fruit development) and again in July (at maximum peel thickness, which marks the end of the cell division stage of citrus fruit development) or a single application of low-biuret urea is made at maximum peel thickness in July. Potassium phosphite [Nutri-Phite, 0-28-26] is applied in two sprays at 2 quarts (0.49 gallons) in 200 gallons water per acre for each application (4.6 L Nutri-Phite in 1869 L/ha). The first application targets May 15 ± 7 days and the second targets July 15 ± 7 days. This treatment resulted in a 3-year cumulative net increase of commercially valuable large size fruit (transverse diameters 2.7-3.5 inches; 6.9-8.8 cm) of 4 US tons per acre (9 metric tons per ha) (Lovatt, 1999). When applied in the summer at maximum peel thickness, low biuret urea (46-0-0, ≤ 0.25% biuret) is applied as a single spray targeting July 15 ± 7 days at 50 lb low-biuret urea (23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha). This treatment resulted in a 3-year cumulative net increase of commercially valuable large size fruit (transverse diameters 2.7-3.5 inches; 6.9-8.8 cm) of 6.25 US tons per acre (14 metric tons per ha) (Lovatt, 1999). Additionally, the yield of commercially valuable large size 'Sunburst' tangerine (*C. reticulata* x *C. paradisi*) fruit was increased with three foliar applications of potassium nitrate (KNO_3) (25 lb KNO_3 in 250 gallons of water per acre per application (11 kg KNO_3 in 2336 L/ha) at dormancy (February), post-bloom (~April) and exponential fruit growth (July-August) (Boman, 2002). The treatment increased the number of commercially valuable large size fruit at the first pick by 30% and resulted in a 23% increase in commercially valuable large size fruit harvested over the season and an average annual net increase in grower return of $2,626 per acre.

Foliar application of potassium sulfate (K_2SO_4) at the post-shooting stage of banana (*Musa* spp.) increased yield, fruit quality and post-harvest shelf-life (Kumar and Kumar, 2007). Foliar-applied potassium during cantaloupe (*Cucumis melo*) fruit development and maturation improved fruit market quality by increasing firmness, sugar content, and nutritional value through increased beta-carotene, ascorbic acid and K concentrations in the edible flesh (Lester et al., 2007).

For avocado, canopy applications of B at 1.45 lb in 200 gallons of water per 110 trees per acre (1.63 kg B in 1869 L/ha) or urea-N at 50 lb (46-0-0, ≤ 0.25% biuret; 23 lb N) in 200 gallons water per acre (25.8 kg N in 1869 L/ha) just prior to avocado inflorescence expansion (cauliflower stage of inflorescence development), significantly increased the number of viable ovules and increased the number of pollen tubes that reached the ovules (Jaganath and Lovatt, 1998). These treatments resulted in a 3-year cumulative net increase of 5.4 and 5.0 US tons per acre (12.2 and 11 metric tons/ha) for boron and urea, respectively (Lovatt, 1999). Earlier (bud break) applications were not effective; later (full bloom) applications were intermediate in effect. B is also known to stimulate cell division and increase fruit set and fruit size of many crops, even seedless fruit, and even when leaf analyses indicate B is adequate. NOTE: B and urea-N should not be applied as a single spray to avocado as double pistils result. The effect of the combined treatment on other crops is not known.

Foliar-applied potassium phosphite [Nutri-Phite, 0-28-26; 2.6 quarts in 200 gallons water per acre (6 L Nutri-Phite in 1869 L/ha)] increased 'Hass' avocado total yield ($P = 0.0640$) and yield of fruit of packing carton sizes 60 (fruit weighing 6.3-7.5 oz; 178-212 g) ($P = 0.0534$) and 48 (fruit weighing 7.51-9.5 oz; 213-269 g) ($P = 0.0644$) and the combined pool of fruit of packing cartons sizes 60+48+40 (fruit weighing 6.3-11.5 oz; 178-325 g) ($P = 0.0595$) as both kg and number of fruit per tree in the off-crop year but had no significant effect in the on-crop years. As a result foliar-applied potassium phosphite significantly increased the 3-year cumulative yield of commercially valuable large size fruit in the combined pool of fruit of packing carton sizes 60+48+40 compared to trees receiving potassium phosphate to the canopy or to the roots. Based on a standard 240 trees per ha, foliar-applied potassium phosphite produced a 3-year cumulative net increase in commercially valuable large size fruit (packing carton sizes 60+48+40) of 3,769 or 3,364 lb per acre (4,224 or 3,770 kg/ha) compared to trees receiving foliar-applied potassium phosphate or control trees receiving soil-applied potassium phosphate, respectively. The net increase in yield of commercially valuable fruit produced a net increase in grower income, making the treatment cost-effective (Gonzalez et al., in press).

In the cases cited above, proper timing of the foliar fertilizer application was a factor in increasing commercial yield or improving fruit quality parameters, including increased fruit size. Moreover, these results were attained even though the crops were not nutrient deficient based on standard nutrient analysis for the crop.

An Example of Properly Timed Soil-applied Fertilizer that Supports the Concept

To protect the groundwater from potential nitrate pollution, growers of the ‘Hass’ avocado in California divide the total annual amount of N fertilizer into six small soil applications made during the period from late January to early November. This grower practice of annually applying N as NH_4NO_3 at 150 lb per acre (168 kg/ha; 168 trees/ha) in six small doses of N at 25 lb per acre (28 kg/ha) in January, February, April, June, July, and November served as the control in the following experiment, in which additional N as NH_4NO_3 at 25 lb per acre (28 kg/ha) was applied at one key stage of avocado tree phenology for a total annual N of 175 lb per acre) (196 kg/ha) (Lovatt, 2001). Two phenological stages were identified for which N application at 50 lb per acre (56 kg/ha) in a single application (double dose of N) significantly increased the 4-year cumulative yield (kilograms fruit per tree) 30% and 39%, respectively, compared to control trees ($P \leq 0.01$). In each case, more than 70% of the net increase in yield was commercially valuable large size fruit (fruit weighing 178-325 g). The two phenological stages were: (1) when shoot apical buds have four or more secondary axis inflorescence meristems present (mid-November) and (2) anthesis-early fruit set and initiation of the vegetative shoot flush at the apex of indeterminate floral shoots (approx. mid-April). Application of the double dose of N at flower initiation (January), during early gynoecium development (February), or during June drop had no significant effect on yield or fruit size compared to control trees.

Application of the double dose of N in April significantly reduced the severity of alternate bearing ($P \leq 0.05$). Yield was not significantly correlated with leaf N concentration. When the amounts of N applied were equal (175 lb/acre; 196 kg/ha), time of application was an important factor, affecting yield, fruit size and the severity of alternate bearing.

Conclusion

Time and rate of fertilizer application are factors that can be optimized to increase yield, fruit (or nut) size, and fruit (or nut) quality of perennial tree crops. Applying fertilizers to the soil, or foliage, at key stages of crop phenology when nutrient demand is high is fundamental to fertilizer best management practices because it improves fertilizer-use efficiency, is cost-effective and protects the environment. Moreover, incipient or transient nutrient deficiencies at phenological stages critical to yield, fruit (or nut) size or quality, reduce annual production and grower income in accordance with "Leibig's law of the minimum", i.e., crops can only yield to the level supported by the most limiting factor. The key to achieving a yield benefit and net increase in grower income is (1) to properly time soil-applied fertilizers when it is known that a specific essential nutrient is ineffective as a foliar fertilizer with a given crop and (2) to properly time foliar-applied fertilizer to specific stages of crop phenology when nutrient demand is likely to be high or when soil conditions are known to restrict nutrient uptake. For citrus and avocado tree crops, this approach is in contrast to the earlier standard application of foliar fertilizers at 2/3-leaf expansion to target foliage with a thin cuticle and large surface area to achieve yields equal to those attained with soil-applied fertilizer (Embleton and Jones, 1974; Labanauskas et al., 1969). With demonstration that properly timed foliar fertilization strategies can be used reliably to increase yield parameters of citrus, avocado and other crops and grower net income (Ali and Lovatt, 1992, 1994; Lovatt 1999), growers will increasingly replace soil-applied fertilizer, at least in part, with foliar-applied fertilizer, improving fertilizer efficiency and protecting the environment. As the cost of fertilizers continues to increase, the benefit of shifting from soil-applied fertilizer to properly timed foliar-applied fertilizers will also increase.

It is clear that the use of foliar fertilizers when uptake of nutrients from the soil is compromised and/or when nutrient demand is too high to quickly correct nutrient deficiencies—even ones that are transient or incipient—is a cost-effective means to reduce overall fertilizer use and obtain a yield benefit that results in a net increase in grower income even when trees are not deficient by standard analyses for the crop. Results presented herein provide strong evidence that when it comes to foliar fertilization, and even soil fertilization, timing is everything.

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Nutrient Management with Costly Fertilizer

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Introduction

Increased global consumption of fertilizer has resulted in increased fertilizer prices. Costly fertilizer coupled with drought conditions has growers concerned for the future of California agriculture. Improving nutrient management techniques is critical for maximizing nutrient uptake efficiency and optimizing economic return.

Water and Nutrient Management

The majority of high input agriculture in California takes place on irrigated lands. Water management is closely tied to nutrient management. Conversion of inefficient irrigation systems to micro-irrigation is helpful in reducing water losses and increasing fertilizer efficiency. Using one or more monitoring techniques, such as soil moisture monitoring, pressure bombs, weather stations, crop growth rates or newspaper forecasts will insure that crops receive water amounts that match crop demand and reduce water and nutrient losses.

Improper irrigation scheduling can waste fertilizer in several ways. Over-irrigation results in leaching losses of nitrate nitrogen, denitrification losses, reduction of metal micronutrients to insoluble forms and a change in the microbial community that hinders beneficial nutrient transforming species and favors crop damaging pathogens. Under-irrigation reduces mobility of plant nutrients, increases soil solution salinity, precipitates chemically incompatible nutrients, damages root systems and lowers or modifies the beneficial microbial community. Properly scheduled irrigation timing and amounts combined with split applications of liquid fertilizers applied to match crop water and nutrient demand results in optimum nutrient uptake efficiency.

Soil and plant tissue testing provides information necessary for applying amendments that increase availability of soil nutrient reserves. Soil tests aid in choosing appropriate forms of fertilizer that increase nutrient availability. Soil and tissue analyses can also highlight limiting factors and imbalances that may diminish crop performance and be corrected with fertilizers that can target these specific problems.

Grid soil sampling prior to establishment of perennial crops, geographic information system (GIS) analysis of grid sample results followed by variable rate applications of ‘stable’ soil nutrients such potassium, phosphorous and micronutrients can improve crop uniformity and early establishment vigor. Using variably applied soil amendments to correct influential soil parameters such as pH or base cation imbalances can improve the uniformity of nutrient availability of future fertilizer applications through highly uniform micro-fertigation.

Certain fertilizer application techniques increase nutrient uptake efficiency. Use of banded starter fertilizers aid with root establishment and setting yield potential. Broadcast dry fertilizer applications may appear to provide low cost nutrition but poor uptake efficiency can make the cost per unit of yield greater than split applications of banded or fertigated liquid fertilizers. Crops grown on soils with limited micronutrient availability may benefit from properly timed foliar fertilizer applications. The past practices of building soil nutrition with fertilizer applications beyond crop removal are not practical with costly fertilizer. The current recommendation is to farm the crop and not the soil.

Fertilizer is an Investment

The rapid rise of fertilizer prices during the 2008 season has caused some growers to consider reducing fertilizer inputs or searching for alternatives for the 2009 season. These same growers would not hesitate to apply a required pesticide if it was deemed necessary by a qualified pest control advisor. Skeptical growers should realize pesticides may prevent yield reductions but a balanced nutrient management program is likely to increase yield. Cutting back fertilizer to save money will result in lost yield and revenue.

The USDA stated that fertilize prices in 2007 are more than three times higher than in 1990. We know prices increased sharply in 2008 with some prices tripling in one year. In 2008, high fertilizer prices were met with high commodity prices so the economic impact was somewhat diminished. Lower commodity prices forecast for 2009 is causing alarm in the grower community, as fertilizer prices have not dropped as sharply as commodity prices.

Nevertheless, an article by The Mosaic Company cites data from Iowa University that shows fertilizer will remain a good investment, even when commodity prices soften and fertilizer remains costly. The data presented indicates that an estimated 25% of total yield of a dry land corn crop can be attributed to fertilizer inputs; a substantial component of yield. The article suggests that the return on investment for 2009 from fertilizer for grain corn will be about %155, which is similar to returns, experienced by growers in 2008 and 2005. In other words, for every dollar spent, a grower receives $1.55, a better return than many investments.

Fertilizer Additives and Alternatives

High priced fertilizer opens the market for additives promoted to aid fertilizer efficiency. Several products have years of replicated trial data and credibility and some fall into the category of "buyer beware". An overview of the benefits or questionable nature of these products may assist growers and their field persons decide on which products may be prove beneficial.

Many growers are applying organic materials or by-products as a portion of their total nutrient program. There is no doubt that addition of low carbon-to-nitrogen ratio organic amendments provide many soil health benefits. Properly composted organic matter improves soil tilth, water holding capacity, aeration and beneficial microbial activity, to name a few of many known benefits. However, lack of quality control of some materials that are sold as 'fertilizer' but are actually unregulated wastes can result in growers applying unbalanced nutrition along with potentially harmful elements. Excess salinity, heavy metals, weed seeds and other unwanted materials might be present in animal wastes and plant by-products. In addition, the low nutrient analyses of these organic materials and delayed availability may greatly reduce the economic benefits of these materials. The handling and application of these materials is very equipment and labor intensive. Surface applications of these amendments in perennial crops may end up acting only as mulch with little if any added nutrition. It is recommended that one request a full elemental analysis of organic material that will be applied in significant quantities to a field.

Organic extracts, polymers and microbial preparations are sold as fertilizer enhancements that will improve fertilizer efficiency. It is impossible to say, in general, if any one of these products will improve fertilizer uptake efficiency. However, there is evidence that certain products are able to cost effectively improve fertilizer availability. Long-chain, organic acid polymers with a high cation exchange capacity have been shown to economically increase uptake efficiency of phosphates by preventing reactions with calcium, magnesium and metal cations. Humic acids have been shown to provide similar benefits to polymers but the heterogeneity of these products makes it necessary to test humics on a case-by-case basis. The same holds true for microbial preparations. Field trials have shown enhanced performance from certain microbial products added to fertilizer. However, the complex nature of soil biology makes it difficult to make a blanket recommendation for all products in this category. Growers should perform field tests of these products before committing to apply them across their entire operation.

Slow and controlled release fertilizers as well as nitrification and urease inhibitors are products that are well understood and whose agronomic effectiveness has been proven over many years of research. The low cost of fertilizer in the past has prevented the widespread adoption of these materials. The current economic and environmental situation is creating an interest in re-examining these products. Controlled release nitrogen fertilizer prices have decreased with the advent of thinner coating materials. Controlled release nitrogen appears to perform best when combined with a soluble nitrogen fertilizer when there are no extenuating environmental factors. There is renewed interest in nitrification and urease inhibitors as growers attempt to extract as much nutrient value as possible from nitrogen applications by limiting losses.

Conclusion

Regardless of the direction fertilizer prices move in the future, one thing is for certain: an intelligently managed fertilizer program will always provide economic benefits to growers. Soil and tissue sampling, well managed irrigation, split applications, well placed, banded liquids, foliar and variable rate applications are all methods that, when combined, result in a best management practice that increases fertilizer uptake efficiency by increasing nutrient availability and reducing losses. The inclusion of fertilizer additives into a grower’s program may provide additional benefits but growers should test unknown products before applying them over every acre.

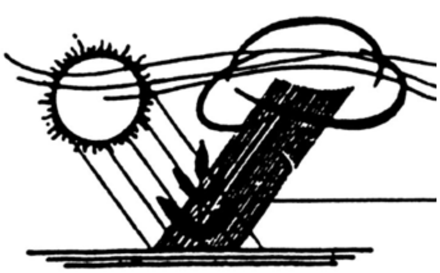
Session III

Nitrogen Management

Session Chairs:

Dave Gourahoo

Rob Mikkelsen



Process Based Models for Optimizing N Management in California Cropping Systems: Application of DNDC Model for nutrient management for organic broccoli production

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Background: Contemporary agriculture is in a transition from single-goal to multi-goal management systems. Optimum yield is not the sole criterion for assessing the success of agricultural production. Instead, concerns about the impacts of agricultural activities on soil fertility, water resources, and environmental safety are now included in assessments of best management practices (Tilman et al., 2002). A crucial task for implementing multi-goal management involves building the capacity to quantify the simultaneous impacts of any single or combined alternative practices on crop yield, soil carbon storage, nutrient leaching and greenhouse gas emissions. Most agro-ecosystems are complex systems, within which climatic, soil and management factors intricately interact. Field experiments play a key role in obtaining first-hand information about the effects of alternative management practices on crop yield and various carbon (C) or nitrogen (N) pools or fluxes in the concerned fields. However, most field experiments require extensive time and resources. To extrapolate the understandings gained at a limited number of field sites to regional scales, process-based models have been developed and adopted to the assist policy making process in agricultural studies (Ahuja et al., 2002). During the past decade, a number of agro-ecosystem models were developed that incorporate the complex interactions among climate, soil, plant growth and management practices. The modeling efforts have provided opportunities to assess the best management practice strategies in a range of scales from individual farms to watersheds and regions (Ahuja et al. 2000; Zhang et al., 2002; Li et al., 2006). Among these modeling efforts, the process-based, biogeochemical model, Denitrification-Decomposition or DNDC, was developed originally for estimating greenhouse gas emissions from U.S. agricultural lands (Li et al., 1992). This model was recently modified to enhance its capacity in predicting crop growth and yield, simulating discharge flow from tile-drained fields, and quantifying nitrate leaching while accounting for the soil buffering effect of ammonium (Li et al., 2006).

DNDC Model: The core of DNDC is a soil-biogeochemisty model which has been linked to vegetation models to simulate soil organic carbon (SOC) dynamics, nitrate leaching dynamics, emissions of nitrogen gases (N_2) and several trace gases including N_2O, NO, NH_3 and CH_4 from agricultural ecosystems. DNDC consists of the six sub-models for soil climate, crop growth, decomposition, nitrification, denitrification, and fermentation. The six interacting sub-models have included the fundamental factors and reactions, which integrate carbon and nitrogen cycles into a computing system (Li et al. 1992, Li 2000, Zhang et al. 2002). DNDC simulates N leaching by integrating soil N dynamics based on soil biogeochemical processes and water dynamics that are controlled by rainfall, irrigation, evapotranspiration and infiltration (Li et al., 2006; Farahbakhshazad et al., 2007).

Modifications of DNDC for the Organic Broccoli Production The Denitrification-Decomposition (DNDC) model was originally developed for simulating C and N biogeochemistry in agricultural lands. The model has been calibrated and validated against a number of croplands and pastures, most of which received synthetic fertilizers. DNDC is potentially able to track the turnover of farmyard manure in soils but lack of calibrations with other kinds of organic fertilizers (e.g., meat meal, blood meal). In addition, there was no accurate information about broccoli in the original library of DNDC. To make DNDC suitable to this case, we modified DNDC by adding broccoli as a new crop in the model library and calibrated the initial partitioning of soil organic carbon (SOC) fractions to reflect the long-term organic management.

Establishment of broccoli crop in DNDC To correctly simulate growth of the broccoli planted in the experimental site, a new crop, California-broccoli, was defined in DNDC based on observation data. The parameters of the California-broccoli are summarized as follows: Total biomass (3968 lbs C/acre), Floret fraction (0.27), Leaves+stems fraction (0.57), Root fraction (0.16), Floret C/N ratio (10.0), Leaves+stems C/N ratio (14.7), Root C/N ratio (53.3), Water requirement (330 lbs water for producing 2.2 lbs DM of crop), and Thermal degree days (TDD) for maturity (2912 °F). These parameters control growth of the California broccoli by precisely tracking its responses to temperature stress, water stress and/or N stress. The virtual crop was tested by running DNDC with the actual climate, soil and cropping management practices for the eight treatments. The modeled results showed that (1) the magnitudes of the modeled yields were in the same range of observations, (2) the modeled crop yields in 2005 systematically lower than that in 2006 due to the heat stress in 2005, (3) the modeled crop yields increased along with increase in the fertilizer application rates, and (4) the modeled phenology of the crop biomass was basically consistent with observations. The modeled yields were highly correlated with observations (R^2=0.90, see Figure 1). Since crop growth is one of the most important processes determining the soil water, C and N dynamics, correctly simulating growth of the broccoli was fundamental for further modeling the soil nutrient dynamics.

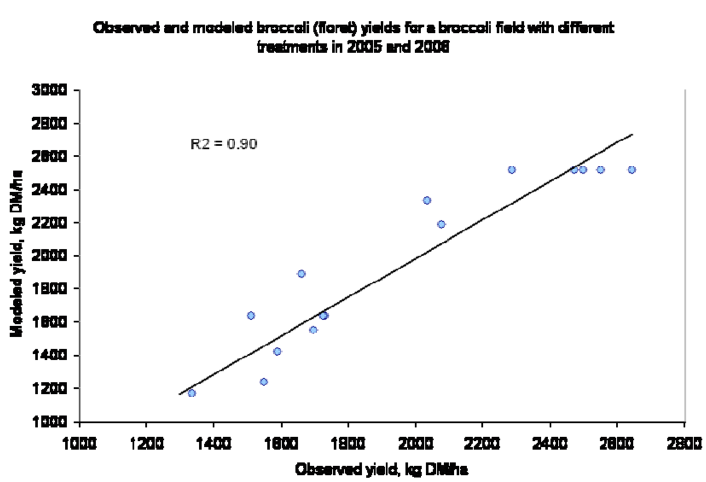

Figure 1. Comparison between observed and modeled annual floret yields for the eight treatments in the broccoli field in UCSC Organic Farm in 2005 and 2006. Source of data: Muramoto et al. 2008.

Initialization of soil organic matter pools: For most of upland, non-organically managed soils, the fraction of active humus is usually less than 10%. However, the tested field had been organically managed over 30 years (This farm was established in 1972). prior the experiment started in 2005. Usually, the soils with continuous incorporation of organic fertilizers have a relatively large portion of the soil organic carbon (SOC) partitioned into the active humus pool. Soils with large active humus pool have high mineralization rates although the total SOC content may not be necessarily high. That seams the case for this broccoli field. Based on field observations, this soil had a low SOC content (0.95%) but still moderately supported the broccoli growth at the plots with no fertilizer applied (Treatment 1 and 5) in 2005 and 2006. To reflect the boundary conditions for modeling, a series test simulations with varied fractions of the active humus pool were conducted. The tests indicated that when the active humus pool was set as 60% of total SOC, the soil could provide a certain amount of inorganic N through mineralization to support the observed broccoli yields for treatments 1 and 5. So the initial fractions for the SOC pools were set to be 60% and 40% for active humus and passive humus pools, respectively, with negligible litter. This setting allowed the soil to produce enough inorganic N to support the crop growth even without any fertilizer amendments during the two years of experimental observations.

Validation of DNDC against Observed Soil Moisture and N Dynamics: Data from Muramoto et al (2008) were used to test DNDC across a range of nutrient management treatments. The treatments varied based on the amount and type of organic fertilizers and use of cover crops (see Muramoto et al. 2008 for details). With the defined crop parameters and initial SOC partitions, we ran DNDC with all the eight management scenarios for two years, 2005 and 2006. Daily soil climate and N profiles were recorded and compared with observations.

DNDC simulates soil moisture with a one-dimension hydrological sub-model, which calculates the soil water inputs driven by precipitation and irrigation and the soil water outputs including transpiration, evaporation and water leaching loss at the bottom of the soil profile. The rate of water vertical movement in the soil profile is determined by the soil field capacity, wilting point, porosity and saturation hydrological conductivity, which are defined as library data linked to the soil texture. The soil in the experimental site is a sandy loam with light texture with relatively low field capacity and wilting point but high hydrological conductivity. The modeled daily soil moisture dynamics were basically in agreement with observations. The modeled results indicated that frequent irrigation events kept the soil moisture high during the broccoli growing season resulting in high water leaching losses.

DNDC calculates soil inorganic N (i.e., NH4 and NO3) content based on the inorganic N inputs (e.g., N mineralization, fertilization, atmospheric deposition etc.) and outputs (e.g., N uptake by plants, N gas losses, nitrate leaching loss etc.). In this study, the organically managed soil contained a high fraction of active humus and hence possessed high rates of decomposition. The intensive tillage to a depth of 30 cm further enhanced the decomposition rates. The mineralization-induced inorganic N constituted a non-negligible part of the soil available N to supply the crop, evidenced by the case for the plots with no fertilizer applied (Treatments 1 and 5). Driven by the high water leaching rates and high N mineralization rates, DNDC modeled high rates of nitrate leaching losses from the experimental plots. The modeled results indicated that (1) the NH4 and NO3 contents in the soil profiles were positively related to the fertilizer application rates, (2) the inorganic N contents increased in the early stage of the crop season driven by mineralization and fertilization, and decreased during the crop season due to crop uptake and nitrate leaching, and (3) the NH4 contents were constantly lower than the NO3 contents due to the high nitrification rates. The modeled daily NH4 and NO3 contents in the eight soil profiles were compared with observations. The magnitudes and patterns of the modeled inorganic N dynamics are well in agreement with observations.

Results from the validation tests for crop yields, soil climate and soil NH4 and NO3 dynamics indicated that DNDC, with the crop parameterization and soil initialization, is capable of simulating N biogeochemical cycling in the organically managed agroecosystem in the UCSC Organic Farm.

Environmental Impacts of Management Alternatives**:** Eight management practices with differed types and rates of organic fertilizer were applied for the broccoli field for two years (see table 1 and Muramoto et al. 2008). Field observations indicated that the different practices resulted in not only the crop yields but also NH4 and NO3 dynamics in the soil profiles. In fact, the impacts of the management alternatives on environment could be beyond the observed items. For example, nitrate leaching and N2O emission would inherently be affected by the fertilizer application alternatives. To extend our understanding beyond the observations, we conducted simulations for all the eight management scenarios but with a longer time period (20 years) to observe their long-term impacts on soil C sequestration, crop yield, nitrate leaching loss and N2O emissions.

Treatment #	2005 Compost		2006 Cover Crop		Organic fertilizer kg-N/ha	
	tons/ha	kg-N/ha	tons/ha	kg-N/ha	2005	2006
1	0	0	0	0	0	0
2	0	0	0	0	82	88
3	0	0	0	0	165	177
4	0	0	0	0	247	265
5	13.3	150	13.3	150	0	0
6	13.3	150	13.3	150	82	88
7	13.3	150	13.3	150	165	177
8	13.3	150	13.3	150	247	265
	Cover crop: 8.63 tons/ha (242 kg N/ha) was applied in 2005				Includes meat/bone blood and feather meal	

<u>Soil C sequestration:</u> The modeled results indicated that the total SOC content was clearly affected by the incorporation of the compost and the cover crop biomass. Under treatments 5, 6, 7 and 8, which provided 21 tons DM of compost and cover crop biomass to the soils every year, the SOC contents remained stable over the first 5 years and then continuously increased in the rest 15 years. In contrast, the SOC contents gradually decreased at the plots under treatments 1, 2, 3 and 4, which provided neither compost nor cover crop biomass to the soils. On a basis of the 20-year averages, treatments without cover cropping and compost amendments led to SOC losses while treatments with cover cropping and compost led to increases in SOC (see Figure 2).

<u>Crop yields:</u> As all of the plots were adequately irrigated, the broccoli yields were mainly determined by the soil N availability. The modeled results indicated that treatments 1, 2, 3 and 5 were not sustainable for the broccoli production. In the first simulated year, the broccoli at all the eight plots reached the maximum yields (about 1005 kg C/ha or 2510 kg DM/ha) due to sufficient availability of N (243 kg N/ha) from the soils, resulting from decomposition (or mineralization) of both the soil organic matter and/or applied organic fertilizers. However, for treatment 1 which had no organic fertilizer application, the crop yields started decreasing in the second year due to the consumption of the active humus in the soil, and continued to decrease annually along with the depletion of the active humus in the soil throughout the 20 year simulation. For treatments 2, 3 and 5 where some organic matter was amended to supplement the active humus in the soils, the crop yields decreased but not as much as treatment 1. For treatments 4, 6, 7 and 8, the higher crop yields were maintained throughout the 20 years simulation due to the adequate soil inorganic N induced from the high rates of organic matter addition through the incorporations of compost, cover crop biomass and/or the organic fertilizers (e.g., meat meal, blood meal or feather meal).

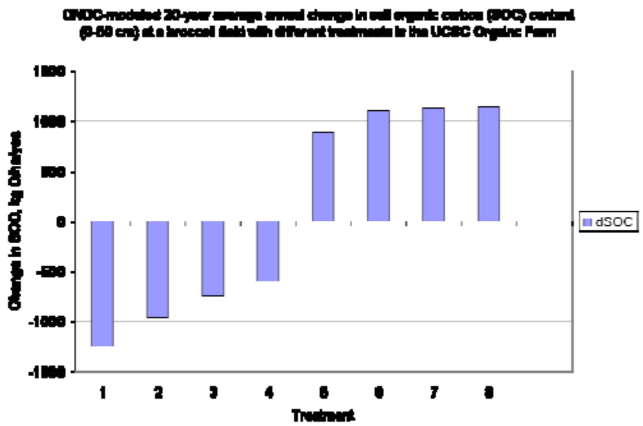

Figure 2. Impacts of different fertilizer treatments on soil C sequestration rates at a 20-year average basis for the broccoli field in UCSC Organic Farm.

<u>Nitrate leaching:</u> DNDC modeled high rates of nitrate leaching losses from the experimental plots. The field received annual precipitation of 882 mm (according to 2006 climate data) and irrigation water 679 mm; and the modeled annual transpiration, soil evaporation and water leaching loss were 364, 357 and 840 mm, respectively. In the soil with a light texture (sandy loam), the leaching water flow was a strong competitor for available N against the plant uptake for the soil. The modeled results indicated that the more organic fertilizer applied the more nitrate leached from the experimental plots. Started from the hypothesized soil initial conditions, the nitrate leaching rate in each plot was initially high and then gradually decreased to approach a stable level in 15-20 years driven by repartitioning of the soil SOC pools. At the 20-year average basis, treatments 1, 2, 3, 4, 5, 6, 7 and 8 resulted in nitrate leaching losses by 110, 130, 160, 200, 180, 210, 280 and 340 kg N/ha per year, respectively.

<u>N2O emissions:</u> The experimental field possessed conditions favorable to N2O production. The simulated data showed that the high contents of active humus in the soils resulted in high productivity of dissolved organic carbon (DOC), NH4 and NO3 which in turn supported high rates of both nitrification and denitrification. In addition, the high soil temperature and moisture, especially in the crop growing season, were generally favorable for the microbial activities. The modeled results indicated that N2O production was inherently related to the rates of organic fertilizer application. At the 20-year average basis, treatments 1, 2, 3, 4, 5, 6, 7 and 8 led to N2O emissions of 5.6, 10.9, 25.8, 40.6, 7.7, 18.8, 33.3 and 46.4 kg N/ha per year, respectively.

In comparison to impacts on crop yield, soil C sequestration, nitrate leaching and N2O emissions across the eight organic management scenarios, treatment 6 seams to be the best management practices which maintained the optimum crop yield, gained a high level of C sequestration, and had moderate nitrate leaching loss and N2O emissions (Table 2). However, the best practices would vary if the major concern for the field or region is redefined.

Table 2. DNDC-modeled 20-year average impacts of eight treatments on crop yield, soil C sequestration, nitrate leaching and N2O emissions for the broccoli field in UCSC Organic Farm

Treatment	1	2	3	4	5	6	7	8
Crop yield (kg C/ha/yr)	352	626	831	956	735	927	941	941
SOC change (kg C/ha/yr)	-1246	-965	-747	-600	883	1098	1128	1142
Nitrate leaching loss (kg N/ha/yr)	111	134	161	203	181	213	276	343
N2O emission (kg N/ha/yr)	5.6	10.9	25.8	40.6	7.7	18.8	33.3	46.4

Discussion: Organic farming is becoming more and more attractive across the world. Assessing impacts of organic management practices, which mainly mean replacing synthetic fertilizers with organic fertilizers, on crop yields as well environmental safety is crucial for implementing the new farming practices. The study described in this report represents an initial attempt in the direction. Detailed observations at the broccoli field in the UCSC Organic Farm provided a sound basis for calibrating and validating a process-based model, DNDC. By establishment of the broccoli parameters as well as the soil initial SOC partitioning, DNDC captured well the crop yields and the soil inorganic N profiles under eight different management scenarios. Through the simulations, the variations in the crop yield and the soil N dynamics across the eight treatments were interpreted with the mechanisms embedded in DNDC. After calibration and validation, DNDC was further applied to predict impacts of the management alternatives on more environmental issues including soil C sequestration, nitrate leaching and N2O emissions. The modeled results revealed a complex picture of how the organic management practices could affect the environmental concerns in different ways. Although there are difficulties to quantitatively assess the comprehensive impacts of the management alternatives on the various issues across crop production and diverse environmental concerns, we roughly determined treatment 6 could be the best option by accommodating all the concerns.

The study demonstrated that process-based model could be a powerful tool to assist field experiments by interpreting, integrating and extrapolating the field observations. To further develop the modeling tool, we will still need new efforts to eliminate the uncertainties related to the modeling approach. For example, decomposition rates of organic fertilizers is a critical issue directly related to their impacts on the soil C and N dynamics. There are a variety of organic fertilizers such as farmyard manure, fresh slurry, compost, meat/born/blood/feather meals, cover crop biomass, straw etc. although we have few data about their behaviors during the decomposition processes. DNDC characterizes the fertilizers simply based on their C/N ratio. While this simplification may not be entirely wrong, it is clearly inadequate. Further laboratory or field experiments are needed to fill the gaps in our understanding and in turn advance the model applications.

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Quantifying Nitrous Oxide Emissions from N fertilizer Management Practices

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Introduction

The effects of the anthropogenic increase in atmospheric greenhouse gas (GHG) concentrations on climate change are beyond dispute (IPCC, 2007), and agriculture does play a key role in this issue, both as a source and a potential sink for GHG (Cole *et al.,* 1993). Of the three biogenic GHGs (i.e., CO_2, CH_4, and N_2O) contributing to radiative forcing in agriculture, N_2O is the most important GHG to be considered, researched, and eventually controlled within intensive and alternative cropping systems. There are several reasons for the importance of N_2O. First, within an intensively cropped area, such as California, N_2O contributes the most of the three GHGs to agriculture's impact on global radiative forcing. It is estimated that N_2O accounts for up to 50% of all agricultural GHG emissions (CH_4 accounts for 37.5%, and CO_2 for 12.5%; CEC, 2005). Second, the uncertainty around N_2O emissions is the main source of uncertainty in the national inventory of GHG emissions from agriculture. In a comparison of five country-wide assessments of GHG emissions, Winiwarter and Rypdal (2001) reported coefficients of variation around N_2O fluxes from agricultural soils ranging from 100 to 900%. Third, in intensively managed agro-ecosystems, there is a great potential to mitigate GHG emissions through the reduction of N_2O emissions (IPCC, 2001).

The contribution of agricultural N_2O emissions to radiative forcing

In California, agriculture and forestry account for 8% of the total GHG emissions, of which 50% is accounted for by N_2O (CEC, 2005). With the recent approval of the Global Warming Solutions Act of 2006 (AB 32), the State has committed to reduce its GHG emissions to the 1990 level by 2020. Furthermore, the Executive Order signed by the Governor on June 1, 2005 (S-3-05) establishes a GHG emission target for California: an 80% reduction of the 1990 GHG emission levels by 2050. These are significant commitments with national and international implications; not only because of its size (California is the world's fifth largest supplier of food and agricultural commodities; CDFA, 2005), but also because of the pioneering role that California may play in this area for the U.S., and potentially the world. At a global scale, the atmospheric N_2O concentration increased from about 270 ppb in pre-industrial times to 319 ppb in 2005, primarily as the result of increased N input into agricultural soils (IPCC, 2007). Global annual emissions of N_2O from cropped soils are estimated at 3.3 Tg N_2O-N yr^{-1}, which is about 6% of the global anthropogenic fossil carbon emissions (Stehfest and Bouwman, 2006; IPCC, 2007).

However, N_2O is not only a very potent GHG responsible for most of the radiative forcing coming from agriculture in California (CEC, 2005), it also is characterized by the largest uncertainty (e.g. Six et al., 2004). Even after compiling data from over 1000 sites in a statistical model, Stehfest and Bouwman (2006), and Bouwman et al. (2002) reported coefficients of variations around annual N_2O fluxes of -40 to + 70%. The Intergovernmental Panel on Climate Change (IPCC) report stated an uncertainty range of -30 to +300% around the default emission factors for N_2O from managed soils (IPCC, 2006). Furthermore, it is important to note that N_2O

emissions are highly skewed towards high values. These great uncertainties illustrate the lack of data and understanding of annual N_2O emissions and budgets.

Mechanisms underlying N_2O emissions

The production of N_2O in soils is primarily controlled by two processes: nitrification and denitrification. During nitrification, ammonium (NH_4^+) is converted to nitrate (NO_3^-), and during denitrification, NO_3^- is reduced to nitrogen gas (N_2). The reduction of NO_3^- to N_2 occurs through a number of intermediate gaseous N forms, such as N_2O and NO, that can be emitted into the atmosphere before they are completely reduced to N_2. Nitrification is carried out by chemo-autotrophic bacteria. These organisms use the energy from oxidizing NH_4^+ to NO_3^-, using O_2 as an electron acceptor for maintenance and growth; CO_2 is used as a carbon source and N_2O is sometimes a byproduct of the reaction. Therefore, the primary drivers of nitrification are a high available ammonium concentration and a high redox potential (Parton *et al.,* 1998). Denitrification is carried out by heterotropic organisms. Conditions that stimulate denitrification are 1) high soil water content, leading to a low soil redox potential (anoxic conditions); 2) high availability of a C-substrate; and 3) high availability of nitrate (Weier *et al.,* 1993; Parton *et al.,* 1998). Under these conditions, heterotrophic bacteria cannot use oxygen as an electron acceptor for energy production. Instead, nitrate functions as an electron acceptor and is transformed to more reduced N forms; the most reduced and ultimate end form is N_2.

Driving factors of N_2O emissions

Since N_2O emissions through denitrification are linked to a simultaneous high soil water content (usually quantified as the water filled pore space, WFPS) and soil nitrate content, specific environmental and management conditions have been related to episodes of high N_2O emissions. Because of the erratic nature of soil water content (as influenced by rainfall and evapotranspiration) and C and N availability (as influenced by decomposition and fertilization), fluxes of N_2O are also very erratic. Nevertheless, there are certain management events that most often induce a peak in N_2O emissions. For example, sharp emission peaks follow fertilizer, tillage, or crop residue incorporation events. In an irrigated system, it is to be expected that there is a sharp N_2O emission peak after each irrigation event during the growing season. It is also to be expected that these peaks slowly attenuate as the mineral N content decreases upon further development of the crop. Furthermore, if the incorporation of residues coincides with a high soil water level, it will lead to a substantial amount of N_2O emissions (Kaiser *et al.,* 1998). Kaiser et al. (1998) found that the total N_2O loss during the fall and winter increased with the decreasing C:N ratio of the plant residues incorporated into the soil by tillage, a finding that was corroborated by Baggs *et al.* (2000). This effect of residue quality is especially important in vegetable production because not only are vegetables highly fertilized, the vegetable residues are also high in N. Typical C:N ratios for vegetable crop residues are between 10 and 15, while they are between 60 and 100 for grain crops. This low C:N ratio leads to both high NO_3^- leaching (De Neve and Hoffman, 1998) and high N_2O emissions after crop incorporation (Baggs *et al.,* 2000). Unfortunately, almost no data are available to accurately quantify the uncertainty around N_2O emission from vegetable production systems, even though they are likely to be very important in California conditions.

N_2O emissions and N input

It is well established that N_2O emissions increase with an increasing application rate of N fertilizers (see reviews by Eichner, 1990 and Cole *et al.,* 1996). Therefore, the current IPCC methodology calculates N_2O emissions from agricultural soils by assuming a fixed percentage of added mineral fertilizer is converted into N_2O (IPCC, 2006). These fixed conversion factors are based on a statistical analysis presented in a review by Bouwman *et al.* (2002). However, many authors noted that the amount of N_2O emissions increased exponentially with increasing N fertilizer — not linearly as the IPCC methodology assumes (e.g., Chantigny *et al.,* 1998). Many authors have reported that if fertilizer amounts exceed crop demand (e.g., about 130lbs N acre^{-1} for a corn crop), N_2O emissions increase drastically (Chantigny *et al.,* 1998; McSwiney and Robertson, 2005). Combining about 846 N_2O measurements in a statistical model, Bouwman *et al.* (2002) found that N_2O emissions increased little with N fertilizer at low application rates, but increased sharply at application rates greater than 100 lbs N acre^{-1}. Similar results were reported in a model study by Grant *et al.* (2006): where mineral N availability exceeded crop demand, N_2O emissions rose non-linearly.

Nitrogen often limits both plant growth and N_2O production in terrestrial ecosystems. Hence, where plants are competing with microbes for soil N, N_2O production will be suppressed until plant N demands have been fully satisfied. However, fertilizer-yield response curves show a plateau at higher additions rates of fertilizer. Consequently, over-fertilization will lead to an accelerated increase in N_2O emissions because of the N surplus available for microbial transformation to N_2O. Namely, when the crop does not take up the surplus N, the amount of unused mineral N increases rapidly, which causes a rapid increase in N_2O emissions when there is enough water and C substrate present in the soil. Sehy et al. (2003) found that a 15% reduction of fertilizer (relative to conventional practices) in a low-yielding part of the field led to a 34% reduction in N_2O emissions and no decrease in yield. In contrast, supplying 15% more N fertilizer in higher yielding parts of a field led to no increase in N_2O emissions. These results illustrate that it is not as much the N input that controls N_2O emissions, but rather the balance between N input and N uptake determining the mineral N content. In a modeling study under California conditions, it was calculated that N_2O emissions could be reduced by 13 to 38% — by fertilizing 25% less than conventional practices — with minimal effect on yields (<5%) (De Gryze *et al.,* 2008).

Simulation models for N_2O budget estimates

Simulation models have been used successfully to better understand C and N cycling in soils and to predict changes in soil C and trace gas fluxes at the plot and landscape scale (Paustian *et al.,* 1997). However, the success of these models is strongly dependent on whether they were calibrated for the local conditions of the studied ecosystem. In a comparative study of nine different ecosystem models using validation data from seven long-term field sites, Smith *et al.* (1997) concluded that performance of the models is strongly dependent upon 1) if the models were developed for soils and conditions similar to the tested field sites, and 2) how well the models were calibrated for the site. In addition, Campbell *et al.* (2001) concluded that both EPIC and CENTURY, two commonly used ecosystem models, were unable to satisfactorily predict long-term soil organic C changes due to management practices in southern Saskatchewan conditions, for which these models were not calibrated.

For some previous modeling work (De Gryze et al., 2008), an extensive search was conducted in the published and grey literature for experimental data on crop growth, yields, management data, soil C, and N_2O emission data under California conditions. It was concluded that for a substantial number of important California ecosystems (e.g., vineyards, orchards, vegetable crop systems, etc.), the experimental data on N_2O emissions, needed to successfully calibrate and validate these models, is missing.

Conclusions

Given the scarcity of available N2O data for Californian agroecosystems and the resulting lack of quantification of the the accuracy or uncertainty around model predictions of N2O emissions from Californian agroecosystems, there is an urgent need to quantify and reduce not only the amount of N_2O emissions, but also the uncertainty around estimates of agricultural N_2O emissions at multiple spatial and temporal scales. This quantification requires accurate measurements of annual budgets of N_2O fluxes and, eventually, well-validated and calibrated biogeochemical simulation models that can estimate annual N_2O budgets for a range of representative cropping systems at the regional scale.

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Factors Affecting a Nitrogen Budget for California Cotton

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Introduction

The "Holy Grail" of modern agronomy is to achieve efficient, sustainable production of quality food and fibers. This goal is becoming a greater challenge to contemporary agronomist in light of environmental and economic constraints. The very definition of "Sustainability" incorporates concepts of **economic viability** – it must pay for its self or be profitable; **environmental acceptability** – impacts are environmentally benign; and provide **societal benefits** – producing renewable goods (i.e. foods and fibers). The recent spikes in fuel and energy put tremendous pressures on the economic leg of this three pronged definition that would have toppled the cart had not some commodity prices surged along with the rising fuel costs. The greatest challenge to the sustainable concept is addressing the social and agronomic demands for acceptable practices to prevent environmental pollution of air and groundwater resources. Tools to meet this challenge will include regulatory mechanisms controlling nutrient applications through best management approaches. An example is the Nutrient Management Plan of the Waste Discharge Requirements General Order for Existing Milk Cow Dairies (Order No. R5-2007-0035) taking effect on July 1, 2009. This regulation limits the application of N sources to a maximum of 1.4 times the total N removed from the harvested crop. Regulatory goals are management input targets determined with the aid of dynamic computer models designed to balance input/output ratios according to soil and plant interactions. Although this new regulation is targeting dairy waste applications, future regulatory restrictions will continue to place greater demands on balancing nutrient inputs with extractable outputs in sustainable agriculture systems. Any attempts to model N dynamics in cropping systems as a managed and balanced input will need accurate and realistic values of the multiple factors affecting the availability of this important plant nutrient.

Test Crop

This paper will review information pertinent to understanding the fate of applied N on a commonly planted row crop in the San Joaquin Valley.

Cotton, one of California's major field commodities has been criticized for its excessive requirements of water, pesticides and fertilizers. When in fact, implementation of irrigation practices developed during the drought years of 1986 to 1992 helped cotton become one of the most water thrifty field crops grown in California implementation of Integrated Pest Management practices has kept California's annual pesticide usage one of the lowest of any U.S. Cotton Belt state (Hake, et al. 1996, Leigh and Goodell, 1996). Finally, the high annual fertilizer tonnage reflected the acreage planted of this commodity which averaged over a million acres between 1979 and 1999. Actual applied N for cotton averages approximately 180 lbs per acre (Hutmacher et al., 2001, Weir et al., 1996, Taylor, 1995). Declining acreage over the past decade has removed cotton from its former status as a major fertilizer user, but lessons learned from the research on this commodity may serve in developing efficient nutrient management practices as critical components of Best Management Practices (BMP) for other crops.

The uptake and partitioning of nutrients by the cotton plant has been well studied (Bassett, Anderson, and Werkhoven. 1970). This information has contributed to the development of useful guidelines for cotton nutrition requirements and general recommendations across the cotton belt (Gerik, Oosterhuis, and Torbert, 1998, Weir et al. 1996). More recent work by Hutmacher et al (2001), reported findings of similar plant nutrient uptake levels in above ground biomass but different lint yield responses to applied soil N rates across San Joaquin Valley soil types. Clearly there is more to efficient crop nutrient management then simply achieving or exceeding a designed nutrient level through the season.

Nitrogen Budget

A complete crop N budget has to account for all inputs and losses of N from the cropping system. The usefulness of an N budget for the development of BMPs greatly increases if N dynamics within a cropping system are understood at a mechanistic level, and if control points and factors influencing the fates and pathways of N as it cycles through the system are known. Thus, both detailed understanding about role of N over the course of plant growth and development, and a clear understanding of soil N cycles are important. In part due to its perennial nature, cotton N management presents a set of unique challenges in an annual production system. However, much has been learned with regard to N fertilization, uptake, and partitioning dynamics in recent years (Fritschi et al., 2004a and b, Bassett, Anderson, and Werkhoven, 1970). Soil N, even in a cotton rotation is very complex and difficult to accurately define. Residue organic N is found in all forms and especially difficult to determine in the various soil organic matter fractions (Roberts, 2005, Roberts, Fritschi, and Hutmacher, 2005). Air quality issues are becoming major concerns in regards to application and plant physiological N losses to the environment (Beene et al, 2002, Roberts et al., 2002). Accuracy and applicability depend on specific rate constants and other soil factors are of critical concern in producing accurate accounting for a total N budget. Sources of potential errors occur in estimates of:

- N uptake efficiency
- Mineralization
- Denitrification
- Volatilization
- Leaching

Understanding the contribution of each pathway is necessary to develop an accurate estimate of a seasonal N budget. Then we can apply this information to better synchronize crop use of indigenous soil N for best management practices in a sustainable production system.

N Uptake Efficiency

Fritschi, et al., 2006, summarized the fate of applied ^{15}N-labled urea after three consecutive cotton crops grown on two distinctly different soil types – a Wasco sandy loam and a Panoche clay loam. They used ^{15}N isotope labeled fertilizer to estimate fertilizer N use efficiencies and recovery of applied fertilizer N in the crop and in the soil. Average N fertilizer use efficiency as estimated by ^{15}N dilution varied between 43% and 49% for both Acala and Pima (Pima values from the Panoche soil only). Fertilizer use efficiencies were not significantly different between N treatments of 50 and 150 lbs N acre^{-1}. There were, however significant interaction effects of N rates by location (soil type) that suggest soil-type dependent modulations in the N dynamics (Fritschi et al., 2006). Recovery of ^{15}N fertilizer in soil and plant combined averaged across all treatments was 89%. Even though both fields were furrow irrigated more than 75% of the ^{15}N-fertilizer was recovered in the top 32 inches (0.9-m) of the soil profile.

Observations made during the second and third cropping season following ^{15}N applications revealed that Acala cotton recovered only 5.8 and 3.3% of the initial labeled ^{15}N, respectively. From a residue substitution study, the authors concluded that the vast majority of ^{15}N recovered in following years was cycled through soil N pools rather than originating from labeled plant residue incorporated into the soil at the end of the first season. Two years after labeled residue were incorporated into non-fertilized soil, the traceable residue source ^{15}N was found in the surface 12 inches (0.3-m) (Fritschi et al., 2004a). This supports the author's assessment that leaching was not a factor in this study and the applied ^{15}N was stabilized into more recalcitrant soil N fractions (Fritschi et al., 2006), and that additional utilization of this N would be dependent on seasonal mineralization rates of each soil.

Mineralization Rates

Mineralization is the biological decomposition of organic matter to inorganic NH_4^+ and NO_3^-. In soils, N turnover is an ongoing process that includes mineralization of organic materials (plant and animal) and immobilization of mineral N forms in dynamic cycles (a process called mineralization immobilization turnover, MIT) (Jansson and Persson, 1982). Residual and mineralizable soil N are important buffers in meeting the seasonal N demands of rapidly growing plants. Stevenson (1982) proposed estimates that over 90% of total soil N is held in organic forms. Therefore, MIT contributes greatly to the productivity of managed agro-ecosystems. Since this is a biological process, MIT is affected by soil properties and conditions (i.e. soil texture, temperature, soil pH, carbon availability, microbial activity and tillage practices) (Roberts 2005, Torbert and Reeves 1994, and Torbert and Wood 1992).

In a three-year cotton N study conducted on two major soil types (a Panoche clay loam and a Wasco sandy loam) of the San Joaquin Valley, cotton yields were shown to be influenced by residual soil N and factors associated with decomposition of soil organic matter pools (Roberts 2005). At the clay loam site, lint yields in the low N treatment declined more over the three year period than lint yields in the low N treatment from the sandy loam site. In contrast, lint yields in the high N treatments from the two sites were not significantly different. Seasonal N recovery was similar from both sites (Fritschi et al. 2004) suggesting larger contributions from residual N from labile soil pools of the sandy loam soil. There was also greater response of lint yield to applied fertilizer N on the clay loam compared to sandy loam, indicating the influence of N mineralized and made available over the course of the season. Mineralization potentials were significantly different between the two soil types. Estimates of microbial biomass were similar for both soil types but the microbial community structures as determined from phospholipid fatty acid analysis (PLFA) were distinctly different. These are all significant factors involved in the

MIT dynamics of soil N and indicate the importance of information on each component would be critical in modeling crop response to added N on each soil.

N Models

There are numerous computer programs developed to "model" the dynamic of soils and plant interactions. These models utilize defined or sometimes "best estimate" algorithms to describe the complex processes involved in crop growth and N cycling.

The Root Zone Water Quality Model (RZWQM) is a USDA program being used in defining Best Management Practices for California's new regulations for dairy waste discharge requirements mentioned earlier. The nutrient process component of this model defines carbon and nitrogen transformation within the soil profile. It requires inputs of initial levels of soil humus, crop residues, other organics and nitrate and ammonium concentrations and then simulates mineralization, nitrification, immobilization, denitrification and volatilization of applied N (Ma, Shaffer, and Ahuja 2001, Ma et al., 2000). Specific mineralization rates for each organic matter fraction used in this model would improve the predictability of N use on different soils.

The University of New Hampshire has developed the DeNitrification-DeComposition (DNDC) model that simulates carbon and nitrogen biogeochemistry in agro-ecosystems. This model can be used for predicting crop growth, soil temperature and moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of major trace gases including: nitrous oxide, dinitrogen, ammonia, methane, and carbon dioxide (Liu et al., 2006).

Other cotton specific models that simulate N use, growth and development and lint yield using similar inputs were reviewed by Roberts et al. (2001). Earlier models were designed for agronomic applications where the recent models focus more on environmental studies of secondary products (i.e. trace gas emissions) and for carbon sequestration and nutrient cycling between soil organic pools.

Recommendations

The adoption of Best Management Practices, in all aspects of crop production, is essential for a socially acceptable sustainable agriculture. For N management specifically, better estimates of biological cycling of residue via MIT processes will lead to improvements in overall nutrient efficiency across soil types and crops. The importance of extensive site-specific soil and biological data cannot be over emphasized. With more specific data inputs, existing models will provide more accurate estimates of the soil-plant-environment interactions and provide realistic management approaches to efficient, sustainable nutrient management programs. Future challenges leading to a "sustainable" agriculture will include the implementation of BMP's by growers and continued education on the judicial use of mineral and organic fertilizers.

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Session IV

Commodity Boards

Session Chairs:

Lori Berger, CA Specialty Crops Council

Joe Fabry, Fabry Ag Consulting

Mitigating pesticides in sediments transported from irrigated agriculture

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Presentation Abstract

Recent studies of sediment in agricultural dominated drains and streams in the Central Valley have suggested that this toxicity may be due to high levels of pyrethroid and organophosphate insecticides. Pyrethroids are cost effective insecticides used on more than 150 California crops for control of worms, aphids and other leaf feeding insects. Pyrethroids are a group of man-made pesticides similar to the natural pesticide, pyrethrum, which is produced from chrysanthemum flowers. Synthetic pyrethroids are more stable in light and have higher insecticidal activity than products made from chrysanthemum flowers. Because of this efficacy, only small amounts of pyrethroids need be applied to control pests (about 100 grams/hectare).

Pesticides moderately or weakly bound to soil will be detected primarily in the water phase; pesticides strongly bound to soil (such as pyrethroids and certain organophosphates such as chlorpyrifos) will be present on the sediment or silt particles. Movement of pyrethroids and organophosphates from farm fields into waterways can be most effectively prevented through Best Management Practices (BMPs) including drift management and reducing sediment transport by irrigation tail water. Removal of sediment from runoff water also removes pesticides present on the sediment, such as pyrethroids. Elimination or containment of field runoff water will prevent pesticide movement to nearby surface water, although such practices may not be practical under some circumstances.

The Coaliton for Urban Rural Environmental Stewardship (CURES) has undertaken and is planning a number of studies in cooperation with various public and private entities to evaluate practices already in use or in development to mitigate pyrethroid and organophosphate movement into surface water. In orchard and row crops, the focus is on preventing sediment from moving off site and treatment of drainage water with vegetation or enzymes. Sediment transport is a particular focus since pyrethroids are not generally found in water due to their lack of solubility. They also have short persistence in water because they rapidly move into soil and sediment particles or onto plant surfaces. The management practices include:

- Reduce or eliminate sediment movement off the field site.
- Reduce or eliminate flows of runoff water carrying dissolved pesticides and nutrients.

Practices that can assist in managing runoff water to minimize or eliminate the impact of off-site movement of sediment include:

- Channeling field runoff water through a settling ponds or vegetated drainage ditches
- Use tailwater return systems to recirculate drainage water
- Use of polyacrylamides (PAM) in irrigation water to settle suspended silt.
- Enzyme treatment of pesticides in irrigation drainage water

The High Cost of Aflatoxins

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The High Cost of Aflatoxins

Aflatoxins are naturally occurring chemicals produced by certain molds, mainly *Aspergillus flavus* and *A. parasiticus.* The main health concern of aflatoxins is their potential carcinogenicity. Chronic exposure to aflatoxins can increase the risk of developing liver cancer.

Aflatoxin-producing molds are common in nature, affecting a number of crops, including almonds. The mold spores are found in the soil and in dust in the air. Contamination may spread from previously infested almonds (mummy nuts), and navel orangeworm (NOW) or other pests. Spores of the molds can be transferred by the NOW and grow on nutmeats which have been damaged. Favorable conditions for mold growth include high moisture content and high temperatures.

Because they are a potent carcinogen, tolerances for aflatoxins have been established to reduce risk of exposure. When almonds are tested in the lab for aflatoxin and are found to have levels above the allowable limits, the consignment will have to be reconditioned or rejected with significant monetary losses to the grower and handler.

Cost of Rejection

One of the largest markets for California almonds—the European Union (EU)—also has one of the lowest allowable limits for aflatoxin contamination on almonds.

Increased rejections of California almond consignments led to additional import monitoring in the EU.

For shipments after September 1, 2007, the EU implemented Special Measures, which called for mandatory testing of California almonds imported to EU member countries. When almonds are rejected, significant costs are involved; industry estimates suggest that each rejected consignment can cost as much as $10,000 for demurrage, warehousing, replacement shipments and other expenses. The costs climb higher if the almonds must be reprocessed to reduce the level of aflatoxins. It is also possible that the consignment will be destroyed, leading to significant economic impact on both the grower and the handler.

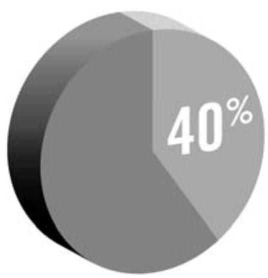
The California almond industry developed a voluntary aflatoxin sampling plan (VASP) comparable to the EU sampling procedures so that almonds can be uniformly tested before shipment to the EU. These procedures are considered to provide sufficient assurances such that almonds shipped with a VASP certificate are subject to approximately 5% testing on import in Europe, whereas without a VASP certificate almonds will be subject to 100% control.

Due to the random nature of aflatoxin contamination, it is unavoidable that some consignments of California almonds with a VASP certificate have continued to be rejected—although at a much lower rate than before implementation of the VASP program. As other countries become more concerned about food safety issues, stricter standards for aflatoxins in other markets could impact the California almond industry.

Loss of Markets

The European Union alone represents 55% of export shipments; in addition, the EU is expected to absorb an estimated 40% of the projected production increase anticipated by 2010. To preserve this and other valuable markets, the industry must be able to demonstrate the high quality of California almonds.

The EU represents 55% of export shipments



The EU is expected to absorb 40% of the projected production increase by 2010

Another sector at risk as a result of aflatoxin contamination is the almond by-product markets, including animal feed and oil. Inedible almonds, almond hulls, and press cake, the meal leftover after pressing almonds for oil, are used in animal feed as they provide a good source of fiber and sugars. These by-products are subject to scrutiny because aflatoxins can be concentrated in the inedible almonds and meal.

California has stricter feed requirements than any other state in the U.S. due to the importance of the dairy industry; in fact feed tolerances are equivalent to tolerances of products intended for human consumption at 20 parts per billion.

Preventing Aflatoxin

The almond industry needs to minimize aflatoxins at every stage of production—not only depending on testing, sampling, and processing, but focusing on the orchard environment where aflatoxin contamination begins and where it must be stopped.

Growers can reduce the potential for aflatoxin growth by minimizing navel orangeworm damage. NOW prevention can be accomplished by:

- **Winter sanitation.** The removal of mummy nuts—those that remain on the tree after harvest—before budswell, on or by February 1. They are a prime harborage of overwintering NOW and their removal is the most effective control method. After removal, they should be destroyed by March 15.
- **Early harvest.** Secondly, when nuts are harvested as soon as possible after they mature and promptly removed from the orchard, a third generation of egg-laying is avoided.
- **In-season treatment.** If winter sanitation and early-harvest guidelines are followed, an in-season treatment for NOW may not be necessary. A harvest sample can help determine if treatments are required.

Mummy nuts that remain on the tree after harvest are a prime harborage of overwintering navel orangeworm. Poling mummies and then destroying them once they are on the ground is the most effective control method for NOW. Photo: Jack Kelly Clark, courtesy UC IPM Statwide Program.

Complete NOW management guidelines, including treatment options, can be found on the Web at the UC IPM site: www.ipm.ucdavis.edu under Year-Round IPM Program for Almonds.

In choosing a treatment option, take into consideration both the product's international maximum residue limit (MRL) and potential environmental impact.

With NOW damage to kernels minimized in the orchard and increased surveillance for aflatoxins by handlers, the California almond industry can continue to provide high quality product that meets stringent tolerances for aflatoxin contamination in the U.S. and key export markets. For more information visit www.almondboard.com.

Agriculture Air Quality in the San Joaquin Valley: Successes and Challenges

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Presentation Summary:

The San Joaquin Valley of California is one of the most fertile and productive agriculture regions. With over 250 major and minor crops produced on more than 3.2 million irrigated acres under cultivation it is easy to see why its collective agricultural commodity value accounts well over $15,000,000,000,000 (billion). However, along with this monumental achievement come many challenges to the industry and citizens located not only in the valley, but state and nationwide. Particulate Matter, Ozone precursors and GHG potentials are only part of the issues valley farmers and ranchers are currently contending with.

In 2004 the California Senate passed a series of bills known as the S.B.700 series covering agricultures permitting exemptions, cogen plants and the disposal of residential construction waste. While not all of the bills in the series passed, the most onerous of regulation to agriculture did. The valley air district summarily commenced rule development to meet the new statutory requirements. Growers in the air basin proceeded to complete the required permits, following a strict regimen of Particulate Matter mitigating practices for both production and animal livestock facilities. The permitting process produced over 34 tons per day of emissions reductions from the valleys inventory. In 2007, livestock feeding operations were required to complete plans to mitigate their Volatile Organic Compound emissions and there seems to be no end in sight.

The Natural Resource Conservation Service is pleased to have an active role in helping landowners meet their regulatory requirements and voluntary conservation efforts of the natural resources not only in California, but throughout the nation.

Management Practices and Water Quality: Conflict, Compromise and Considerations

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Introduction:
Water quality impairments resulting from agricultural production practices have been documented throughout the U.S., California and the Central Coast of California. The State and Regional Water Quality Control Boards have responded by imposing Conditional Agricultural Waivers to Discharges from Irrigated Lands. These Ag Waivers "waive" the requirement that each grower must obtain a permit to allow water to leave his farming operation. The Ag Waiver regulatory requirements vary between Water Board Regions and on the Central Coast of California, the Ag Waiver focuses on management practice education, documentation, tracking, and implementation in the hope that water quality improved as better water quality protections are instituted by all growers. Conceptually, this is a reasonable approach; however, implementations of water quality practices may be restricted by lack of grower education and awareness or by institutional barriers such as permitting issues or by conflicting policies and regulations among single resource regulatory agencies. These single resources may pit food safety requirements against water quality improvements or endangered species protections. This presentation presents an overview of water quality regulation, a review of types of management practices that growers may implement, examines barriers to management practice implementation and discusses the role of The Central Coast Water Quality Coalition and what is needed to overcome institutional and practical obstacles to water quality protections. The Central Coast Water Quality Coalition is most familiar with regulation and conditions on the Central Coast and therefore, for the purposes of this presentation, will concentrate its discussion of conditions in this area.

Brief Water Quality History:
In California, in order to place today's agricultural water quality issues in context, it is important to understand the trail of regulations that have lead to this point. In the early stages of water regulations, point sources were targeted by the 1969 – Porter Cologne Water Quality Control Act ratified in California; 1972 Clean Water Act (CWA), National Pollutant Discharge Elimination System Program. Then, in 1987, CWA directed states to develop plans to deal with Non Point Sources (NPS) which included agriculture. The State Water Resource Control Board (SWRCB) became active in NPS regulation in 1988 with the first SWRCB NPS plan. In 1999, The SWRCB was legislatively required to develop guidance for NPS, impose fees for Waste Discharge Requirements (WDR's) and impose a 5 year term on all Waivers of WDRs. In 2004, The California NPS Implementation Policy established the three regulatory vehicles for NPS regulation: WDRs, Waivers and Prohibitions. The first Conditional Ag Waivers for Discharges to Irrigated Lands was adopted in 2001 in the Central and Sacramento Valleys. This was followed several years later by adoption in the Central Coast Region in 2004 and the Los Angeles/Ventura Region in 2005. Currently, the San Diego Regional Water Quality Control Board is drafting an Ag Waiver.

It is important to note that the Conditional Ag Waivers do not "waive" regulation; but rather waiver the requirement for a Farm Specific Discharge Permit. All Ag Waivers require: 1) standards at Farm Level; 2) implementation of Management Practices until standards are met Waivers, 3) individual, group or watershed-based monitoring and 4) compliance. They must be in the public interest and are conditional in nature.

The Central Coast Conditional Ag Waiver has five requirements. Four of these are administrative: 1) Enrollment with the Central Coast Regional Water Quality Control Board (RWQCB), 2) Attend 15 continuing education hours of RWQCB approved courses, 3) Complete and implement a farm-specific Farm Water Quality Plan that stays on the farm, and 4) Monitor – either as an individual or as part of the Cooperative Monitoring Program. The fifth requirement is action oriented in that growers are required to implement Management Practices of pesticides, fertilizer, irrigation and sediment management as outlined in their own Farm Plans. It is critical to note that every aspect of this regulation is about management practices documenting, tracking, planning, implementing and monitoring to determine effectiveness.

Management Practices (MPs)

Management Practices may be sorted into two broad categories: source controls and pollution prevention practices. Source controls concentrate efforts at the pollution source. These are practices which impact pesticide, fertility and irrigation uses. Pollution prevention practices tend to ameliorate agriculture constituents that could potentially discharge from an agricultural operation. Often, these will manage sediment. Examples of pollution prevention practices are catchment basins, filter strips, grassy waterways, and riparian corridors. In general, agency personnel or natural resource professionals tend to approach water quality from a pollution prevention perspective. Growers tend to focus on source controls as they have much more control over these practices. Grower adoption for source controls is documented by the Central Coast RWQCB Conditional Ag Waiver Enrollment Checklist and is discussed below.

Pesticide MPs are widely adopted. Greater than 88% of growers document that they utilize IPM practices such as scouting and use of pest thresholds. They consider run-off when selecting pesticides. They calibrate and participate in early pesticide training. MP adoption varies across crop type in design of pesticide storage, mixing/loading facilities and wells protections. And the least adopted Management Practice was the use of bio control agents.

Fertility MPs also have a fairly high rate of adoption. Over 75% of all acres on the Central Coast know and budget crop nutrient requirements, test soil and irrigation water for N and consider the analysis in calculating N budgets, calibrated and maintain application equipment, and mixing and loading is done more than 100 feet from well heads. Growers exhibit a variable rate of adoption across crop type for tissue testing,

Irrigation MPs possess a lower level of adoption. The reason for this lower level of adoption is not known (but should be investigated). Nevertheless, when one considers demographics in which a large percent of growers have less than 50 acres, then, the conjecture is that financial limitations may impact grower decisions regarding irrigation MPs. Grape and vegetable growers are more likely to use irrigation mobile lab services. The least adopted MPs are: the use of published evapo-transpiration data used to determine crop water use, knowledge about soil water-holding capacity, and record keeping,

Sediment Management MPs execution varies widely across crop types:
– 36% of all acres use hedgerows while 25% say it is not applicable.
– 91% of acres have graded roads to minimize erosion.
– 50% of all growers said the water and sediment basins are not applicable.
– About 42% of acres utilize vegetative buffers between cropped areas, along the lower edge of the farm and along roadways.
– >53% of all growers said that riparian buffers are not applicable.
– >60% of all grower plan to evaluate their MPs for effectiveness thru photo-monitoring or water quality testing.

What Impacts Management Practice Implementation in California?
Four different types of barriers impact grower decisions regarding MP implementation. The first is Grower Awareness and Education regarding impacts to Water Quality and Management Practice Implementation. The second is the limited amount of available financial capital needed for major MP improvements. The third barrier is Institutional Barriers such as permitting requirements. And the fourth is conflicting regulatory programs and policies such as Food Safety/Water Quality, Endangered Species Act/FIFRA, and Food Safety/Water Quality/Aquatic Species Protection. In order to effectuate water quality improvements, each barrier must be adequately understood and each must be separately addressed.

1. Grower Awareness and Education
While there seems to be a growing belief among organizations and granting agencies that outreach does not, in and of itself, lead to water quality improvements, The Central Coast Ag Water Quality Coalition finds different results. The Coalition conducted a survey of a randomized subset of over 400 growers with whom the Coalition had interacted during a four year period. These were growers who had initiated a call for assistance with Conditional Ag Waiver compliance or Farm Plans or MP implementation. In summary, 81% of survey respondents made changes to their farming practices to respond to water quality issues and over 63% plan to make additional changes to protect water quality. Likewise, The Coalition has found that education has a positive impact on grower behavior and attitude modifications relative to water quality. The Coalition teamed with the University of California Cooperative Extension (UCCE) to further survey the impact of formal Farm Water Quality Planning education. Survey respondents that had attended the Farm Water Quality Planning Short Courses found: It easier to obtain information regarding Ag Waiver compliance or management practice implementation (69% as compared to 52% of non-participants); that education was useful in determining what water quality management practices to implement (72% vs. 55% non-participants); and that The Ag Waiver successfully promoted water quality (63% vs. 53% non-participants).

2. Limitations on available financial capital
As discussed above, limits on operating capital have the capacity of small or marginally profitable growers to upgrade irrigation equipment or implement expensive pollution prevention or habitat restoration practices.

3. Institutional Barriers to Management Practice Implementation

Permitting issues are problematic on the Central Coast if a grower wants to do habitat restoration or implement any construction related activities. Growers often are required to obtain numerous permits. These can take several years and several thousand dollars to obtain. Currently, there are efforts to obtain coordinated permits in which one agency or organization will "hold" a pre-approved and conditioned permit on behalf of all permitting agencies.These coordinated permits have had variable degrees of success which is largely determined by the willingness of local agency personnel to view the full benefits to resources and society outside of their single resource authority.

4. Conflicting Single Resource Policies or Regulations

During the last four years, it has become apparent that conflicts between single-resource issues, policies and regulations are probably the biggest deterrent to grower implementation of management practices. For example, Water Quality Protections have an inherent conflict with over-zealous Food Safety Requirements. Another example is that court interpretations of the Endangered Species Act may result in restrictions to pesticides registrations which may eliminate single existing pest control technologies for many minor crops. The newest example of conflicts among single resources is that water quality efforts to reduce irrigation water and food safety efforts to remove wildlife habitat could potentially create hazards to certain rare coastal plant and endangered animal species.

Example 1. Conflict between Water Quality Protections and Food Safety

The 2006 Spinach E. coli 0157:h7 outbreak investigations resulted in thousands of environmental samples being taken from fields in question. As a result, one farming operation had E. coli 0157:h7 DNA matches of victims' feces, spinach found in the victims' homes, cattle feces from cattle near the farming operation, pig intestines from pigs found on the ranch, and surface water near the field. Consequently, while no one has been able to "connect the dots" as to how the E. coli moved through the natural system, wildlife and domestic cattle were implicated.

The produce industry and California Department of Food and Agriculture (CDFA) responded rapidly by forming a CDFA approved Leafy Green Marketing Agreement (LGMA) which establishes metrics that produce handlers and growers must meet in order to protect food safety. The metrics are measurable and quantifiable and establish a minimum standard of care. The conflict that exists between Water Quality and Food Safety occurs when produce buyers impose a more rigid set of metrics that eliminates nearby vegetation, catchment basins or riparian buffers that might harbor pathogen vectoring wildlife, amphibians or birds. Often, growers or produce buyers employ the services of third party food safety auditors that may or may not consider impacts to water quality when they impose a zero-risk approach to food safety. In this case, growers must make choices between selling a crop and protecting water quality.

Unfortunately, early attempts to find ways to Co-manage Water Quality and Food Safety protections are becoming mired in polarized dogma and political turfiness. While there will eventually be some resolution of these issues as basic research is conducted on pathogen environmental fates; the changes will be long in coming and water quality may be negatively impacted for some time to come.

Example 2. Endangered Species Act/FIFRA
Since 2004, The Center for Biological Diversity (CBD) has filed a series of lawsuits under the premise that all federal agencies were required to consider impacts to endangered species when they take any action. In the case of these lawsuits the CBD argued that the EPA did not adequately consider impacts to salmon (in the case of the 2004 Washington Toxics Case), Red legged frogs (in the case of the 2006 RLF Stipulated Injunction) and eleven Endangered Species in the San Francisco Bay case. In the Washington Toxics and Red legged frog cases, the EPA lost the lawsuit and was/is required to do "effects determination" of the impacts to the respective endangered species. The long-term ramifications are that many pesticide chemistries may be (justifiably) restricted to the point that they can not be used. Unfortunate for coastal agriculture, past EPA registration policies favored registrations for large commodities crops, and consequently there are often no replacement or substitute pest management tools or technologies for older pest control tools used in minor crops. Endangered species and water quality may or may not benefit as cropping patterns shift from loss of pest controls. The unanswered question is whether growers will shift to less lucrative crops on high value coastal land or will attempts be made to develop this highly expensive land.

<u>What is The Central Coast Water Quality Coalition and What is it Doing?</u>

The Coalition is a for-public benefit, non-profit with a 503(c) 3 status that is directed by growers with geographic or commodity interests. It is dedicated to working on water quality issues or issues with a water quality nexus on the Central Coast and has the mission to provide education, outreach, coordination and facilitation. Over the last 10 years, The Coalition has participated Farm Water Quality Planning Short Courses, participated in Rangeland Water Quality Planning Short Courses, assisted more than growers with writing Farm Water Quality Plans, assisted growers Conditional Ag Waiver compliance, hosted technology transfer meetings, facilitated Watershed Working Group Meetings in multiple watersheds, created and mailed mailers with water quality and management practice information, education schedules, and regulatory compliance information were provided, and participated in advisory committee meetings related to water quality education, outreach and research. The Coalition has also teamed with multiple partners to organize tailgates, demonstrations, seminars, and conferences on a number of issues related to water quality.

The Coalition's goal has been to use its mission of education, outreach, coordination and facilitation to move growers along a behavior change continuum from traditional attitudes to a proactive approach. Currently, The Coalition is at a crossroads. There are many forces at work that will impact how well growers continue to move along this Continuum. Single resource regulatory agencies are quickly changing their focus towards implementation and are abandoning efforts at education and outreach. This is impacting the availability of grant funds to support The Coalition's mission. Quite honestly, these rapid shifts in regulatory agencies policies are leaving growers very confused and alarmed and we see growers becoming regressive rather than progressive. Other changes are that environmental activist organizations are turning from regulatory mechanisms to legal actions. The result is that one well-educated legal professional is making environmental and business decisions that could potentially have a profound impact on local economies. As we all know, economic times are squeezing growers with increased cost of inputs and reduced available operating credit and capital. Likewise, reduced grant budgets are reducing the availability of grant funds that will keep organizations such as The Coalition afloat.

The question of how to address barriers to agricultural management practice implementation is complicated and will require coordinated and multi-pronged approach. Times are changing, however, and it appears that as a society, there is an abandonment of a collaborative, coordinated approach. Economics and accelerated regulatory efforts are compressing time-frames to the point that dialog between perspectives can not adequately occur. The result is that positions are becoming polarized and beneficially useful compromises are becoming more difficult to obtain.

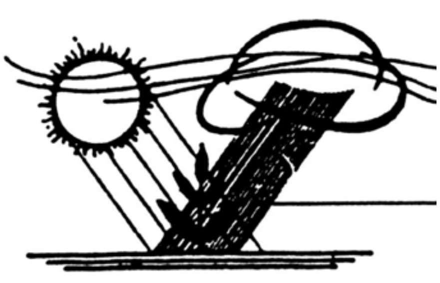
Session V

Plant & Soil Nutrition

Session Chairs:

Larry Schwankl, UC Davis

Blake Sannden, UCCE



Irrigating Alfalfa with Limited Water Supplies

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Introduction

Alfalfa is California's single largest agricultural water user due to the amount grown, typically about 1 million acres, and its long growing season. Seasonal alfalfa water applications generally range from 4,000,000 to 5,500,000 acre-feet. However, because of drought conditions, water supplies for irrigation may be limited, thus forcing alfalfa irrigators to apply less water than that needed for fully-irrigated alfalfa.

One option for coping with limited water supplies is to reduce the irrigated acreage. The amount of reduction depends on the amount of water. The reduced acreage is fully irrigated according to normal irrigation practices that would occur under adequate water supply conditions. No irrigations are applied to the remaining acres. Under this option, the yield per acre will remain unchanged for the fully irrigated part of the field; however, the total yield of the field will decrease.

Another option is to irrigate the entire field throughout the normal crop season by applying water for the full crop season at a rate smaller than that needed for full irrigation. This means decreasing the number of irrigations between harvests, decreasing the amount applied per irrigation, or some combination of both. The amount applied per irrigation or number of irrigation will depend on the amount of available irrigation water. Both yield per acre and total yield will decrease. One disadvantage with this strategy is that distributing the irrigation water throughout the crop season may result in very small yields that may be uneconomical to harvest, depending on the amount of available irrigation water. Also, applying small amounts of water may not be practical using flood irrigation.

A third option is to distribute the limited water supply such that the alfalfa is fully irrigated during the early harvests and then deficit irrigated (no terminate irrigations) thereafter. This approach is referred to as the full/deficit option. The number of fully-irrigated harvests will depend on the amount of available water. This strategy maintains the relatively high yields of the first part of the year and eliminates irrigations during the summer when yields are small and quality usually is poor.

During the past several years, a study on mid-summer deficit irrigation (no irrigations during July, August, and September) of alfalfa was conducted... The study investigated the seasonal ET requirements of fully-irrigated alfalfa and the effect of midsummer deficit irrigation on yield and evapotranspiration in commercial alfalfa fields at various locations in California. Results of this study were used to evaluate the reduced acreage and full/deficit irrigation options.

Methods and Materials

Alfalfa evapotranspiration (ET) was determined at Tulelake (Klamath Basin), Scott Valley (near Yreka in the intermountain area of northern California), Sacramento Valley (near Davis), Kern County (near Buttonwillow), and the Imperial Valley (near Holtville). All sites were commercial fields except for the Tulelake site, located at the University of California Intermountain Research and Extension Center. These sites reflect mid-summer climate conditions ranging from warm summer temperatures in the Intermountain areas (Scott Valley, Tulelake) to very hot summer temperatures (Imperial Valley). Border (flood) irrigation was used at the Sacramento Valley, Kern County, and Imperial Valley sites, while sprinkle irrigation was used at the Scott Valley and Tulelake sites, reflecting the irrigation practices of each area. Most of each field was fully irrigated; a section of each field was deficit irrigated during the mid-summer. The fully-irrigated alfalfa was irrigated according to the irrigators' normal practices. Measurements of ET, yield, and soil moisture tension were made at the Davis site from 2005 to 2008, and at the other sites in 2007 and 2008.

Results and Discussion

Fully-irrigated Alfalfa Evapotranspiration (ET)

Daily ET values are shown in Figure 1 for Scott Valley, Sacramento Valley, and Imperial Valley. Seasonal evapotranspiration ranged from 33 inches (Scott Valley 2008) to 63 inches (Imperial Valley 2008) (Table 1). Measured seasonal ET values of all sites except Imperial Valley were greater than the historical ET commonly used for crop water use. The seasonal ET of the Imperial Valley was smaller than the historical value, possibly due to the heat stress during August through September.

Mid-summer Deficit Irrigation

Mid-summer deficit irrigation reduced the ET, but the amount of reduction varied considerably between the experimental sites. ET differences between fully-and deficit-irrigated alfalfa during the periods of mid-summer deficit irrigation ranged from 0.2 (Tulelake 2007) to 9.4 inches (Sacramento Valley 2005). The 2007 value for Tulelake reflects the influence of shallow groundwater, which contributed to the ET of the deficit irrigated alfalfa.

Table 1. Measured seasonal ET of the fully-irrigated alfalfa and historical ET for the experimental sites.

Site		Seasonal ET (inches)	Historical ET (inches)
Imperial Valley	(2007)	58	76
	(Dec. 3, 2008)	63	
Kern County	(2007)	56	49
Sacramento Valley	(2005)	50	
	(2006)	54	49
	(2007)	55	
Scott Valley	(2007)	39	33
	(2008)	33	
Tulelake	(2007)	41	33
	(2008)	35	

Yield

Actual yield differences between fully–and deficit-irrigated alfalfa during the period of deficit irrigation ranged from 0.4 (Tulelake 2007) to 3.74 tons per acre (Sacramento Valley 2007). The small Tulelake difference reflects the shallow ground water contribution. The practical yield reduction ranged from 0.4 (Tulelake 2007) to 4.59 (Sacramento Valley 2007). Yields smaller than 0.5 tons per acre were excluded in the practical yield differences, since experience has shown that those yield levels are not economical to harvest.

Which Option is the Best Water Management Practice under Limited Water Supplies?

ET and yield data from this study were used to evaluate the reduced acres and full/deficit irrigation options previously discussed. The second option (reduced applications per irrigation) was not evaluated because it is not practical for flood-irrigated fields and the information needed to evaluate this method is not available. The procedure consisted of calculating the total yield obtained for each option for different seasonal amounts of evapotranspiration using yield and ET data obtained from the Imperial Valley, Kern County, and the Sacramento Valley sites of the alfalfa ET study. For the full/deficit option, it was assumed that no economical yields occurred during the periods of deficit irrigation, based on the field study results.

Results using the Kern County data showed that total yields were slightly higher for the full/deficit irrigation option compared to the reduced acres option (Table 2). A relationship between cumulative yield and cumulative ET was developed for this evaluation (figure 2). The results of the three sites showed no consistent trend between options, indicating site specific responses of the options. However, differences in total yield between the options were small at all sites, suggesting that either option is a reasonable approach.

Table 2. Results of the comparison between the reduced acreage and full/deficit irrigation options for Kern County. Assumptions include a maximum yield of 9.56 tons per acre, seasonal ET up to the last harvest of 50.8 inches, and field acreage of 160 acres.

Full/deficit option (160 acres)		
% of maximum ET	yield (tons per acre)	Total yield (tons)
30 (2 cuttings)	3.21	513
45 (3 cuttings)	4.67	747
61 (4 cuttings)	6.05	968
77 (5 cuttings)	7.51	1201
Reduced fully-irrigated acres option (9.56 tons per acre)		
% of maximum ET	Acres irrigated	Total yield (tons)
30	48	461
45	73	695
61	98	940
77	123	1179

Conclusions

These ET measurements generally showed seasonal ET values that are higher than the historical seasonal ET values. The exception was Imperial Valley where the 2007 and 2008 seasonal values were considerably smaller than the historical value. Mid-summer deficit irrigation reduced the ET during the period of deficit irrigation, but the differences in ET between fully-irrigated and deficit-irrigated alfalfa were site specific. Yields were also reduced by deficit irrigation.

Which option is the best? No trend was found between the options. The best option may be site specific, reflecting the site specific responses found in this study. Thus, the options of reduced acreage and full/deficit irrigations should be considered.

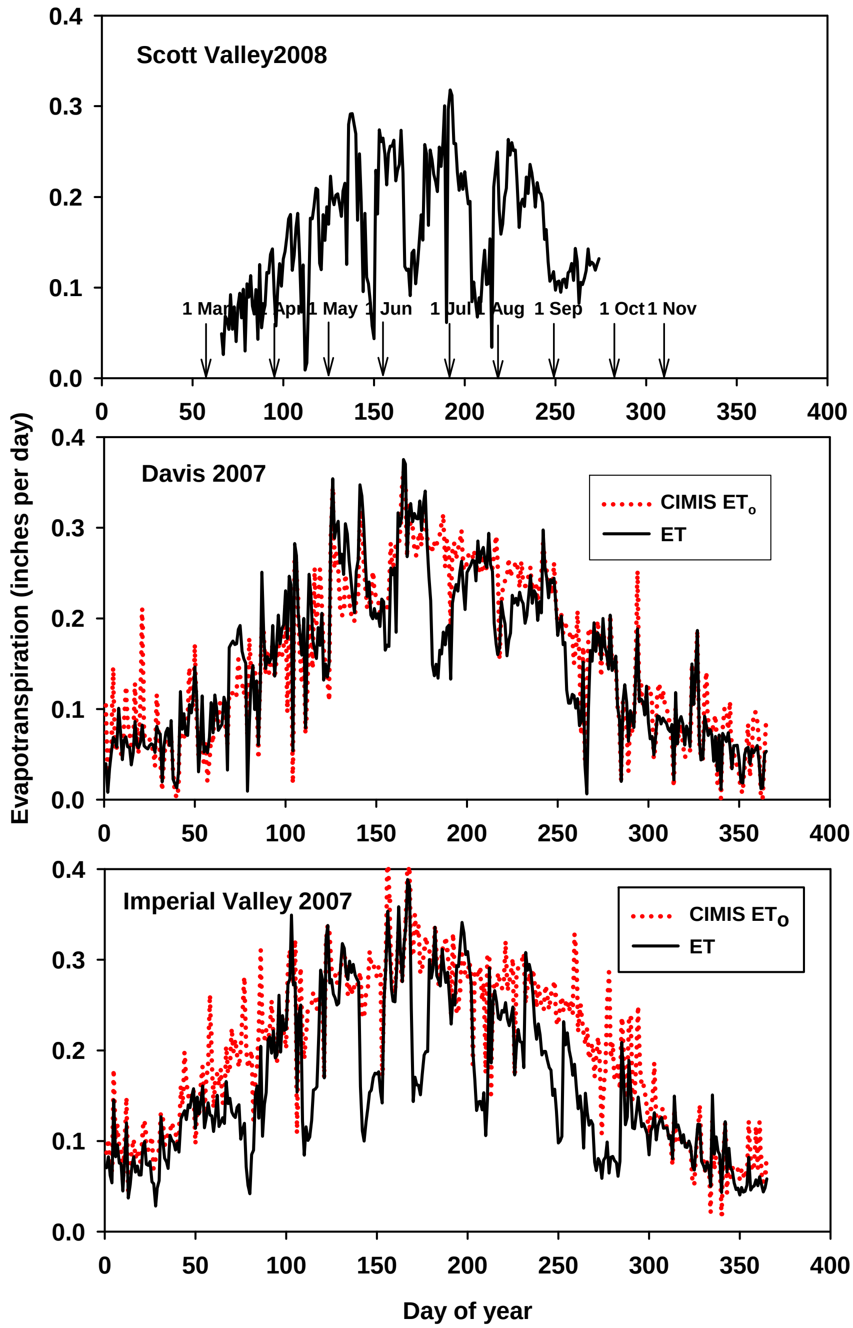

Figure 1. Daily evapotranspiration of alfalfa for Scott Valley (2008), Sacramento Valley (2007), and Imperial Valley (2007). CIMIS ET$_o$ is the California Irrigation Management Information System (CIMIS) reference crop ET, defined as the ET of a well-watered grass. CIMIS ET$_o$ is obtained from the California Department of Water Resources.

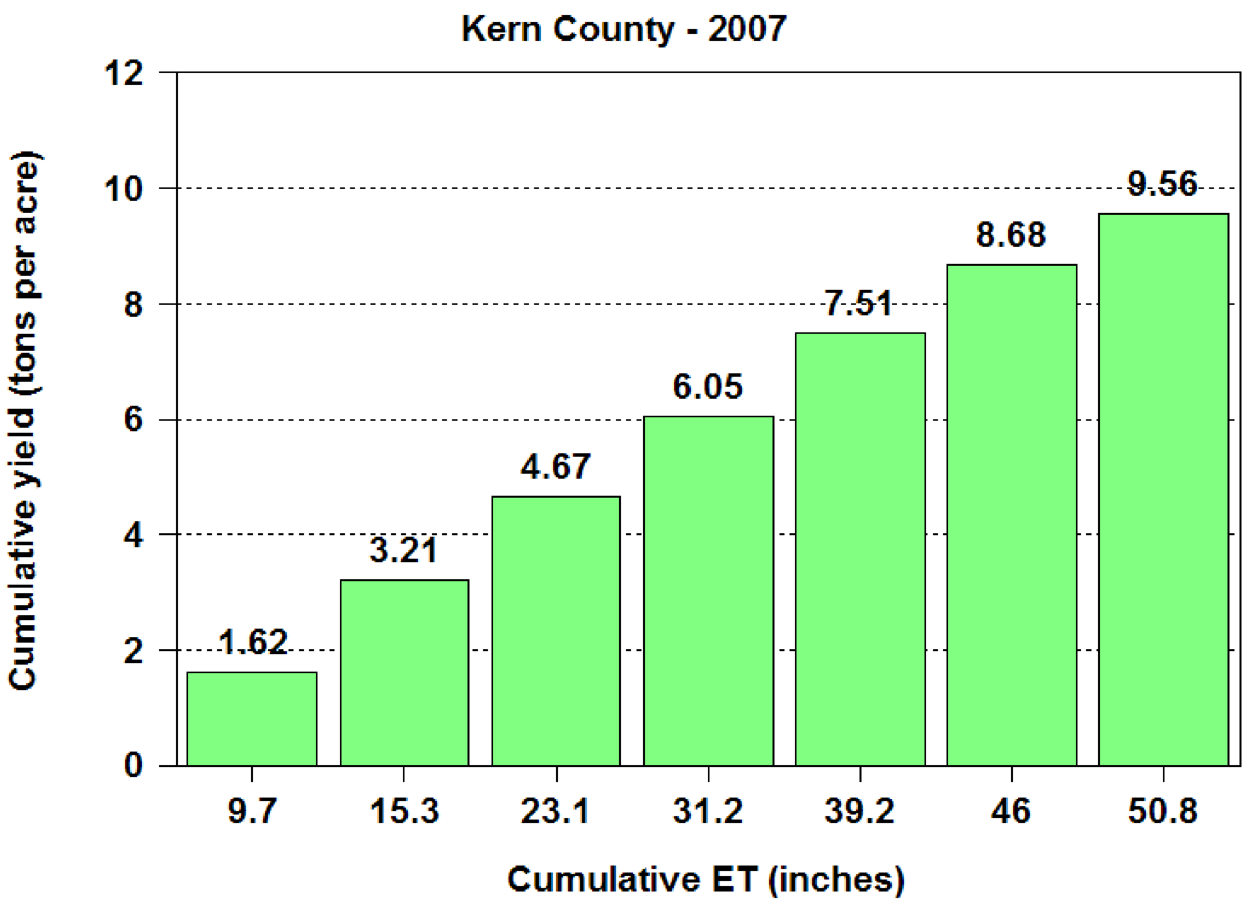

Figure 2. Relationship between cumulative ET and cumulative yield for Kern County.

Irrigating Stone Fruit with Limited Water Supplies

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Irrigating fresh fruit orchards with less than 100% evapotranspiration (ET) can lead to problems with fruit quality and tree health. Nevertheless, research has shown that certain stages of growth are less sensitive to water stress than other stages. Therefore, there are periods during the season when reduced irrigation will generally be less harmful. With hundreds of different varieties, many soil types and numerous irrigation systems, it is difficult to develop generalized drought strategies to fit every situation. However, the following guidelines should help an orchard manager design a program for his/her particular situation.

Fresh market stone fruit varieties are harvested anywhere from early May to October in California, with the majority coming off in June, July and August. For the purposes of irrigation management, those picked in May and June will be referred to as early varieties. Those harvested in July and later will be termed late varieties. The fruit of all varieties grow rapidly in early spring (Stage I). Early varieties continue to enlarge steadily until harvest. However, late varieties have a period of slow enlargement (Stage II) right after pit hardening (generally early May). They then enlarge rapidly again for the last 4 to 6 weeks before harvest (Stage III).

Early Varieties

It is not recommended to stress trees before harvest in early varieties. First, ET tends to be relatively low early in the season, so not much irrigation water is needed. Second, large fruit size is critical in the early market (Lopez et al., 2007) and any water stress will reduce fruit growth. Instead, the period after harvest offers the potential for saving substantial amounts of irrigation water.

In a deep soil under flood irrigation, peach trees have been shown to survive and remain productive for four consecutive years with no irrigation between June and October (Larson et al., 1988; Johnson et al., 1992). However, in many situations this would be too extreme of an approach and problems such as defoliation, scaffold sunburn, gumming and increased mite damage would likely occur. If water is available, a better strategy would be to cut back to 40 to 80% ET for the remainder of the season (Johnson & Phene, 2008). Some of the problems mentioned above may still develop so trees should be monitored regularly. The pressure chamber (Shackel et al., 1997) is a useful tool to help with this monitoring. Research in California and in Israel (Naor et al., 2005) has suggested serious problems can be avoided if the stem water potential (as measured with a pressure chamber) is kept above (less negative) than a threshold of -20 bars.

Water stress in late summer also interferes with flower bud development and can cause fruit defects the following year. Fruit doubles, deep sutures, split pits and smaller fruit size can all result from water stress (Handley & Johnson, 2000; Johnson & Phene, 2008). The critical timing for minimizing these disorders appears to be late August to early September when carpels (fruit) are forming in the flower buds. Therefore, a drought strategy of extra irrigations from early August through early September, even at the expense of reduced irrigations during June and July, might be advisable for some varieties (Johnson et al., 1992; Johnson & Phene, 2008). Different varieties differ greatly in their propensity to succumb to these disorders. Fruit doubles and deep sutures are seldom a problem in plum varieties (Johnson et al., 1994a).

Late Varieties

After harvest of late varieties, irrigation can be reduced substantially or even eliminated in some cases without major detrimental effects. Late varieties don't generally have as many problems with double fruit and deep sutures the year after the trees have been water stressed. The trees should still be monitored regularly during the rest of the season as it is possible to have mite flare-ups, defoliation, gumming, shoot dieback and scaffold sunburn. As with early varieties, the pressure chamber (Shackel et al., 1997) is a valuable tool to help monitor the degree of stress, and a "danger" threshold of -20 bars should still hold for most situations.

In a more severe drought situation it may be necessary to reduce irrigation with fruit on the tree. This is a more challenging problem. First, fruit size will invariably be reduced with any reduced irrigation strategy (Johnson et al., 1994b). Fruit soluble solids content will often be increased (Crisosto et al., 1994), but always at the expense of fruit size. Research has shown that fruit size is more sensitive to stress during Stage III than during Stage II of fruit growth. Therefore, to minimize the detrimental effects of stress, the recommended drought strategy is to reduce applied water during Stage II but restore full irrigation during the final 4 to 6 week period before harvest. In many California soils this strategy can be difficult to implement as water infiltration is greatly reduced after a period of soil drying (Girona et al., 1993).

Severe Drought

If little or no irrigation water is allocated to the orchard, the goal may be to just keep the trees alive until more abundant water is available. A severe treatment of cutting the scaffolds back almost to the trunk (dehorning) has been shown to work in Washington (Proebsting & Middleton, 1980) and California. We were able to keep trees alive with no irrigations during the season with this strategy. Winter rains provided some initial soil moisture and the trees put on several feet of new growth. After a year or two of normal irrigation dehorned trees can be reformed into standard looking trees.

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Drought Irrigation Strategies for Citrus, Almond, and Pistachio

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Introduction

Limited availability of water requires fundamental changes in irrigation management for California orchards. Growers without wells must get through the season with substantially less water than their trees have the potential to use. Water becomes a precious commodity and knowledge of how trees respond to water deficits is of paramount importance. It's no longer a question of irrigating to prevent plant water deficits as in normal years; the presumption is that the trees will be deprived of water at certain times during the season. Under these conditions, irrigators must make decisions based on conserving (minimizing the waste of) water and knowing when the water deprivation will have the least effect on current season yield and quality and on subsequent seasons' tree performance.

Herbaceous versus Tree Crops

There are important differences in the relationship between yield of marketable product and consumptive use between herbaceous and tree crops. The water production function, the relationship between yield and evapotranspiration (ETc), for herbaceous crops can accurately be described with a first order mathematical (straight line) expression with a one to one ratio between production and ETc. Additionally, marketable yield (lb/ac) and gross revenue ($/ac) have the same pattern relative to consumptive use. Thus, there is no “good” time to stress these crops.

Whereas crop plants have vegetative and reproductive growth occurring simultaneously over most of the season, this is not the case for tree crops. There are periods of the season where vegetative growth is high and reproductive growth is low and vice versa. This fact led to the initial research on what would be eventually be known as regulated deficit irrigation (RDI). The goal of this initial work was to limit unwanted reproductive growth of vigorous late harvest peach trees (Chalmers et al., 1981). The season was divided into stages based on the double sigmoid pattern of reproductive growth rates—early season rapid growth (Stage 1), followed by the lag phase (Stage 2), and finally the rapid fruit growth prior to harvest (Stage 3). They found that deficit irrigation in Stage 2 reduced vegetative growth without negatively impacting the yield of marketable product. Although not the original focus of this work, the water stress in Stage 2 also reduced consumptive use, and thus, increased WP.

The initial RDI work in Australia and New Zealand spawned additional work worldwide and it became clear that certain stages of tree crop development are more sensitive to water stress than others in terms of impact on productivity in most tree species. That is the key to optimizing drought irrigation strategies—to limit stress as much as possible during critical stages of the season. Unfortunately, different tree species and even cultivars within a given specie react much differently to stress timing and magnitude in terms of crop productivity. In other words, there is no universally applicable RDI regime that can be recommended for tree crops; they are species, and in some cases, cultivar specific.

Pistachio

While pistachio trees are very drought tolerant in terms of being able to survive with limited applied water, their potential ETc rates are very high (Goldhamer et al., 1985). In view of the fact that the pioneering work of Chalmers et al. (1981) was predicated on having a double sigmoid fruit development pattern, we theorized that pistachio would be a good RDI candidate due to its fruit growth characteristics. There is rapid growth of the hull and shell early in the season; full size is attained by about mid May in the southern San Joaquin Valley (Stage 1). Growth of the kernel (Stage 3) does not begin until early July. During the approximate six week period between full shell size and rapid kernel growth, the only growth in the fruit is some thickening of the shell (Stage 2).

Concomittant with our initial work investigating the effects of stress during Stage 2, we also studied by impact of water deprivation during each growth stage and postharvest (Goldhamer and Beede, 2004). We found that Stage 1 stress has relatively little negative impact on production; only a modest reduction in fruit size. On the other hand, Stage 1 stress can reduce the production on unslit (closed shell) nuts in favor of the more desirable split nuts. We confirmed that Stage 2 is also a relatively drought tolerant period and that Stage 3 is, by far, the most drought sensitive period of the season. This has been confirmed in numerous trials in the southern San Joaquin Valley. Stress during this time can reduce shell splitting, increase nut abortion and blanking, and cause more nuts be to be left in the tree after mechanical shaking. We found the postharvest period to be relatively drought tolerant. Using RDI regimes with Stage 2 and postharvest stress, the pistachio production function is not a one to one relationship between yield and applied water (Goldhamer and Beede, 2004). To the contrary, we found that that RDI yields were greater than would be predicted using the best fit linear expression between yield and applied water plus rainfall for both data from a sustained deficit irrigation study and the one to one ratio expected for herbaceous crops.

Citrus

In most cases, RDI can be used to reduce consumptive use while having minimal, if any, negative impact on crop production. However, there are cases where deficit irrigation can actually increase grower revenue beyond the savings associated with reduce water costs. One example of this "best of both worlds" achievement with RDI is with navel oranges. With ‘Frost Nucellar,’ a cultivar that is particularly sensitve to peel creasing, we’ve shown that stress imposed early in the season (mid May thru mid July) can reduce this peel disorder and thus, increase crop productivity while saving water (Goldhamer and Salinas, 2000). Peel creasing is apparently due to rapid cell expansion of the layers that comprise the peel when the fruit is small causing microscopic fissures between certain cells. These fissures manifest themselves as creases as the fruit approaches harvest. Stress early in the season slows fruit growth during the critical period and we believe limits the fissure development. Returning the trees to full irrigation following the deficit irrigation period results in accelerated fruit growth such that harvest fruit size is not affected. Over a three year period, we decreased creasing from 29.8 to 9.7% of the fruit load (full irrigation and RDI, respectively). This resulted in fancy fruit production increasing from 22.1 to 38.0% and juice fruit production decreasing from 20.0 to

12.0%. Applied water was reduced from 31.6 to 23.7 inches; a savings of 25.0%. Harvest fruit size, fruit load, and packable cartons were not affected.

Perhaps one of the most obvious situations to employ RDI involves late harvest citrus. Rather than a December to March harvest, the late harvest cultivars are not harvested until April through June. Market prices are normally higher for this later harvest fruit. However, fruit left on the tree for such a long period tend to be very large and market prices at this time favor smaller fruit. In fact, the super large size fruit are not marketable. Whereas reducing fruit size with water stress is normally a negative, it could be a positive in terms of gross revenue with late harvest citrus. We tested four RDI regimes; stress during the early, mid, and late periods of the season and an additional regime that imposed stress over the entire season. We achieved the desired reductions in fruit size with the stress late in the season; both in terms of individual fresh fruit weight and fruit size distribution (Goldhamer, 2003). Fruit load was not reduced by this RDI; in fact, it tended to be higher than the fully irrigated Control over a three year period. There were no statistically significantly differences in gross fruit yield. Gross revenue was $6560/ac for the late season stress regime compared with $3600/ac for the Control.

Almonds

Most of the RDI work to date in California that imposed preharvest stress also reduced harvest kernel size (Goldhamer and Viveros, 2000; Girona et al., 1993; Goldhamer et al., 2006). The magnitude of the size reductions was related to the magnitude of the stress. One study found that a uniform preharvest stress imposed by irrigation at 85% ETc caused no significant reduction in kernel size but preharvest stress levels high enough to reduce seasonal consumptive use by 45% decreased harvest kernel size by 15% (Goldhamer et al., 2006). Even with a short term, moderate stress imposed in the first two weeks of July that was found to significantly reduce hull rot, a fungal disease that can kill young shoots and spurs, consistent reductions in harvest kernel size occurred (Teviotdale, 2001). While these reductions of 3-5% usually were not statistically significant relative to fully irrigated trees, they occurred repeatedly. On the other hand, preharvest stress has been found to accelerate the rate of hull split, allowing for an earlier harvest (Goldhamer et al., 2003; Shackel, 2002). Processors usually pay a premium price for nuts delivered early in the season.

There is some disagreement on the impact of preharvest stress on fruit size. A study in northern California showed that stress imposed during the hull split period (from late July thru harvest) had no negative impact on nut (kernel+shell) size (Shackel, 2002). In Spain, Romero et al. (2004) found no influence of preharvest stress on fruit size and recommended a predawn leaf water potential value of -2.0 MPa as a threshold. These Spanish results may be related to differences in cultivar (hardshell) as well as climate.

Stress during harvest and in the six week period during and immediately after harvest is extremely detrimental to the following season's fruit load (Goldhamer and Viveros, 2000; Goldhamer and Smith, 1995). One school of thought is that stress during this time significantly reduces fruit set; the evolution of flowers into fruit (Goldhamer and Viveros, 2000). The hypothesis is that since reproductive bud differentiation in almond trees occurs late (Aug.-Sept.)

relative to other *Prunus* species (June-July), harvest and postharvest stress may structurally affect the developing flower, hampering either pollination or events subsequent to pollination in the flower that prevents fruit set. The other school of thought is that harvest and postharvest stress restricts vegetative growth required to establish new fruiting positions (Esparza et al., 2001; Klein et al., 2001).

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Managing Organophosphate Pesticide Residues Using Degradation Enzymes

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All growers farm under the requirement not to pollute surface and ground water. Water leaving the field, irrigation runoff or winter storm water, can contain residues of applied pesticides, sediment or nutrients. These surface discharges are regulated by the Central Valley Regional Water Quality Control Board under a program called the Irrigated Lands Program. In mid 2003, the Regional Board adopted conditional waivers for discharges from irrigated lands. The bulk of the irrigated lands comply with the conditional waiver through water quality coalitions. Today there are about ten coalition groups representing geographic areas or specific commodities.

Under the Irrigated Lands Program, the Water Quality Coalitions must:

- Monitor and comply through reporting all water quality exceedances as established in the Basin Plan
- Develop management plans in areas where water quality triggers are exceeded—called exceedances.
- Monitor watersheds to demonstrate compliance

Water quality monitoring was initiated in 2004 by the Central Valley Regional Water Quality Control Board. Residues of organophosphate (OP's) pesticide found in the water column are the most common pesticide residue found in water quality monitoring programs in California. Table 1 shows the pesticide exceedances during the 2007 irrigation and winter storm period for a single coalition area. Chlorpyrifos represents 31 percent of the pesticide exceedances. All the OP's exceedances sum to 46 percent of the pesticide exceedances. These water column exceedances do not include the pesticides found in the sediment samples.

Table 1.

Pesticide Exceedances 2007												
	Carbofuron	Chlorpyrifos	Cypermethrin	Diazinon	Dieldrin	Disulfoton	Diuron	Malathion	Methidathion	Simazine	Thiobencarb	Copper
Limits	0 µg/L	0.015 µg/L	0.002 µg/L	0.1 µg/L	0.00014 µg/L	0.05 µg/L	2 µg/L	0 µg/L	0.7 µg/L	4.0 µg/L	0 µg/L	variable trigger
April - Sept 6 Irrigation season Samples												
	1	9	1		1	1					2	18
Feburary 2 Storm Season Samples												
		7		5			2	1	2	2		
Percentage of Individual Pesticide Exceedances												
	2	31	2	10	2	2	4	2	4	4	4	35

Do Legal Pesticide Applications Cause Exceedances?
To address this issue a few selected measurements of runoff were measured after organophosphate pesticides were applied in different crops is offered.

Chlorpyrifos in furrow irrigated corn runoff waters.
In this study corn was planted into a dry bed and furrow irrigated soon after planting. Chlorpyrifos granules were applied with the seed to protect from wireworm and cutworm damage (Prichard 2008). Runoff samples were collected during the first irrigation after planting on 4/23/08 and the subsequent irrigation conducted on 6/01/08. Practices evaluated were treatment (Treatment) with 8 ounces per 1000 feet of row or 1.3 pounds active ingredient per acre chlorpyrifos applied with the seed at planting and an untreated control (UTC) where no insecticide was applied with the seed.

Results from first irrigation after planting.
Samples of runoff waters began as soon as sufficient depth of water in the furrow was available—10 minutes after runoff began. A second sample was taken near the peak runoff period which was mid-way or 290 minutes after the runoff began. The last sample was collected near the end of the runoff period—600 minutes after runoff began. The results indicate the concentration of chlorpyrifos residues found in the runoff water exceeded the standard of 0.015 ppb in all "treatment" samples. The concentration at runoff time 10 minutes was 1.2 ppb, increasing to 2.5 ppb at peak flow, followed by the least concentration of 0.93 ppb found in the last sampling—600 minutes after runoff began. No detectible chlorpyrifos residues were found in the untreated control runoff water at any sample times.

Results from second irrigation after planting.
Samples were collected from the same furrows on the second irrigation in the same fashion as the first irrigation. No sample was taken in the untreated control furrows as was done in the first irrigation since water from treated furrows mingled into the UTC furrows. Instead, inflow water was collected as to compare with the treated furrows. Inflow water was from a surface water source which contained drainage water from upstream farms. Chlorpyrifos levels were less than the 0.015 ppb water quality standard at each sampling of in flow water. However the initial sampling, at 0.011 ppb, was near the standard of 0.015 ppb indicating some residues were present in the irrigation water source. Water runoff samples collected art all three sampling times exceeded the water quality standard by a factor of 6 in the initial sampling to 2 in the final sampling time.

Chlorpyrifos in runoff waters from border-check irrigated alfalfa.
A border-check alfalfa field was treated with 1 pint per acre chlorpyrifos as Lorsban 4E at a spray volume of 35 gallons per acre 24 hours before the irrigation (Prichard, 2008). The alfalfa was about 10 inches in height at application. Samples were collected at the onset of runoff, (time 0) and at runoff time 15, 30 and 60 minutes in each treatment. The runoff water chlorpyrifos concentration remained relatively constant thought the irrigation averaging 8.1 ppb for the first 60 minutes of runoff. The water quality standard is 0.015 ppb. Since this was the last irrigation of the season no subsequent irrigation samples were collected.

Chlorpyrifos applied in alfalfa- Southern Sacramento Valley
A study conducted by Rachael Long et.al (2002) measured toxicity in irrigation runoff up to 62 days after chlorpyrifos application in alfalfa. Fourteen of the 16 tail-water samples collected caused 100% mortality to *C. dubia* within 24 hours. Moreover, mortality occurred in all the observed field sites 22 to 62 days after application under a range of application rates and field conditions.

Management Practices to Reduce Off-Site Movement of Pesticide Residues
Management practices to minimize off-site movement with irrigation runoff and winter storm generated runoff are many. They run the gamut of using integrated pest management approaches, safe and careful mixing and loading, and controlling or treating runoff waters. This paper focuses on the management practice of treating runoff waters with OP degradation enzymes, Landguard OP-A®, before they exit the farm and enter surface water sources.

Degradation Enzymes
Landguard OP-A® is an enzyme based product that results in the rapid hydrolysis of a wide range of organophosphate pesticides. Landguard OP-A® discovered by CSIRO, Australia, has been developed for use in a range of situations including the treatment of contaminated soil, irrigation run-off, effluent from agricultural processors, postharvest and stock dips, used pesticide containers and contaminated solutions arising from the washing of pesticide application equipment. Laboratory trials demonstrated that the application of Landguard OP-A® will consistently reduce organophosphate concentrations to very low levels within a short time period. For example, Landguard OP-A® will consistently reduce diazinon concentration in used stock dip from approximately 100,000 μg/L to approximately 1 μg/L within 3 hours. Landguard OP-A® was approved for sale in the United States of America during early 2006.

The OP-A enzyme acts as a catalyst for the rapid hydrolysis of the pesticide active, producing metabolites with lower toxicities. Mass spectra studies indicated the two diazinon breakdown products resulting from the hydrolysis of diazinon are diethyl thiophosphoric acid and 2-isopropyl-4-methyl-pyrimidin-6-ol (Figure 1). These two breakdown products have been confirmed in laboratory and Landguard OP-A® treated samples collected from field trials, in solutions with low and high pH.

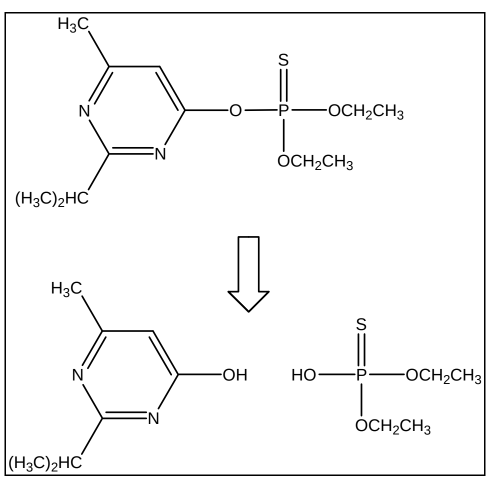


Figure 1. Hydrolysis of diazinon

The two diazinon hydrolysis metabolites were found to be unstable in situations with high biological activity. It was found that the concentration of metabolite 1 (2-isopropyl-6-methyl-4-pyrimidol) decreased from approximately 40,000 ug/kg to less than 3,000 ug/kg after one day in slurry and reduces further after one week to 1,000 ug/kg. The second metabolite, diethyl thiophosphoric acid was not detected in the slurry solution even after one day. Toxicity studies of runoff containing toxic OP residues which were fully treated with Landguard OP-A® were non-toxic to *C. dubia*.

A laboratory study demonstrated the effect of pesticide concentration on the efficacy of Landguard OP-A® (Table 2). Higher rates or longer treatment times are required for solutions contaminated with higher concentrations of pesticides. Study conducted by Analytical Consulting Services (Study Number T135). It is apparent from Table 2 the treatment rate of the enzyme and the contact times are both important in the assured degradation at a minimum material cost.

Table 2.Enzyme rate vs. time at various Diazinon concentration waters

Diazinon Concentration (µg/L)	Resulting diazinon concentration (µg/L) for several Landguard OP-A® application rates (g/100L) and treatment times (hours)							
	0.01 g/100L		0.1 g/100L		1.0 g/100L		5.0 g/100L	
	1 hour	48 hours	1 hour	48 hours	1 hour	48 hours	1 hour	48 hours
10	<0.05	<0.05	<0.05	<0.05	-	-	-	-
100	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-
1,000	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-
10,000	26	17	20	14	14	<0.05	-	-
100,000	37,000	51	870	<0.05	130	<0.05	19	<0.05

Methods of Enzyme Application to the Runoff

Landguard OP-A® must be applied at a minimum concentration for the enzyme to work in the expected amount of time. The key factor in determining the dosing rate (amount of material to the amount of runoff) in the tail ditch is the maximum rate of runoff water. Furthermore, the runoff rate is typically not constant over the time of an event. When using a single dosing rate based on the maximum estimated flow rate, over-dosing likely at the less than maximum flows which typically at the beginning and end of a runoff event. Dosing at the highest expected volume results in significant over dosing while dosing at too low a rate will result in not meeting the goal of the application—reduce the OP's concentration to below the water quality standard in the time required.

Early tests were performed at enzyme concentrations which were adequate at the highest estimated runoff flow rate by using manual valve-controlled orifices to control the discharge rate from a gravity flow reservoir directly into the runoff ditch. This practice accomplished the adequate OP's degradation but used more material than was required on the total runoff volume. In addition, runoff hydrographs from different sets in the same field were found to be significantly different since five alfalfa borders were run as a set at night while three were used in daytime sets using the same 2000 gpm inflow. The result was different runoff dynamics causing different peak flows and different durations of runoff (Figure 2). A comparison was made of the amount of enzyme required on single maximum rate dosing and a variable rate, dosed as required by flow rate—essentially keeping the dosing rate constant. A single rate setting to dose for the maximum volume for set 1 overdosed about 2.3 times when compared to the amount needed. Estimating the next set would be near the same runoff flow rate and using the same dosing rate, the second set required 6.6 times that of a correctly dosed variable system. Subsequently, a 29 step variable rate dispenser was developed for use up to 1000 gallons per minute of runoff. It relied on measurement of the runoff volume using a flume where head, measured by a linear voltage float and then was transformed a non-linear pulse generator output to account for the flume geometry. The pulse output was used to drive a solenoid attached to a constant head reservoir of enzyme stock solution. Experimental measurements found an average of +- 1% calculated to actual application (Figure3).

Figure 2.

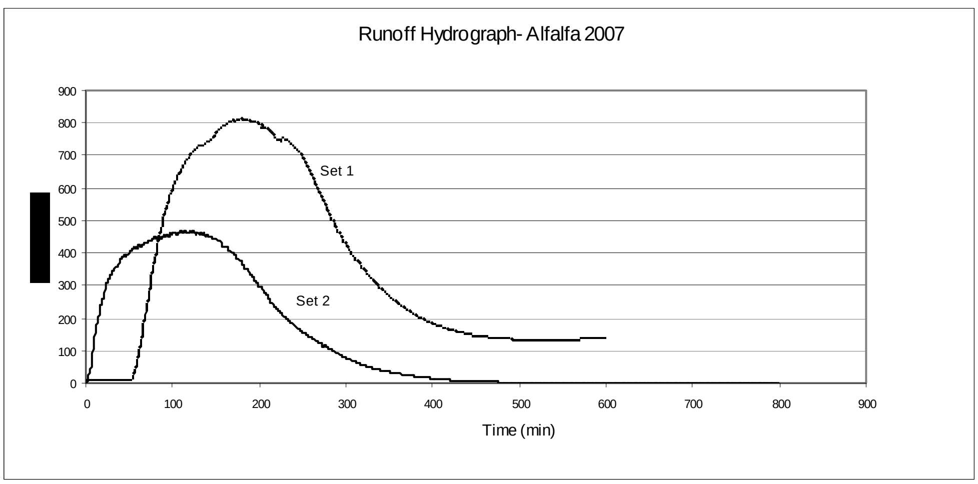
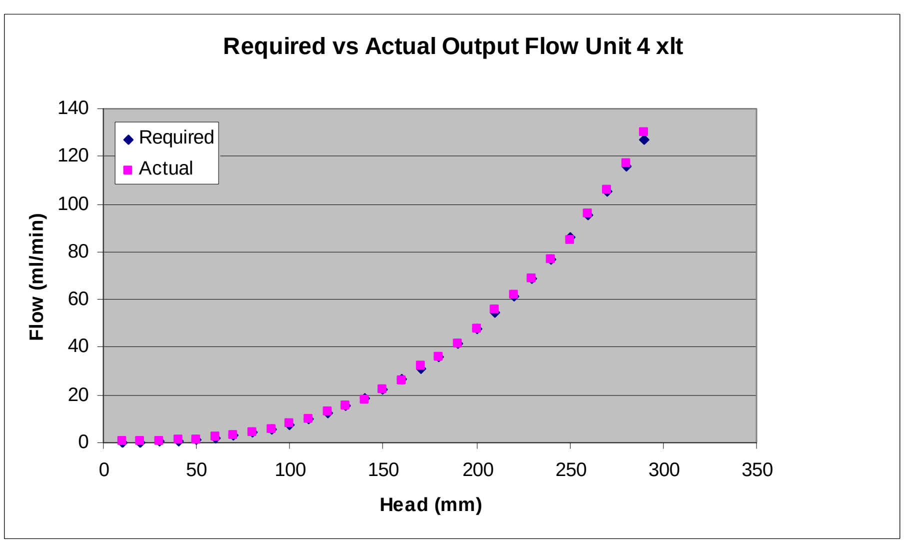


Figure 3.



Field Results

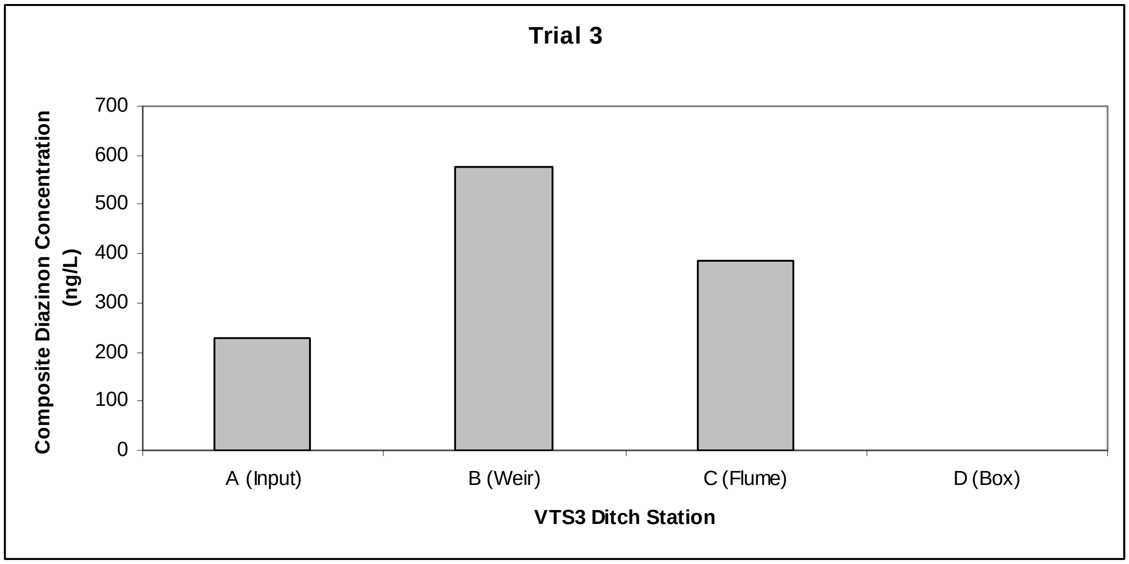
A team led by Brian Anderson of the Marine Pollution Studies Laboratory University of California at Davis, working in the central coast area of California conducted an evaluation of methods to mitigate diazinon in runoff water (Anderson et.al. 2008).

Vegetated ditches were evaluated as well as dosing runoff after the vegetated ditch section with Landguard OP-A® at 0.0001g/L water application rate. Samples were collected before and after the 230 m of vegetated ditch. At the end of the vegetated ditch Landguard OP-A® was dosed with samples collected 33m downstream. The electronic dosing unit previously described was used (Figure 4).

Figure 4. Anderson trial showing vegetated ditch and electronic dosing unit 2008

Multiple trials were conducted finding in aggregate the treatment of diazinon-contaminated runoff was controlled on average by 32.7% using aquatic vegetation. The diazinon concentrations found in the runoff waters in a single trial(Trial 3)are shown at the ditch input, at the weir (beginning of vegetated ditch) and the flume (end of vegetated ditch and enzyme dosing site), followed by the Box or ditch exit. The Box sample site represents the post-enzyme treatment concentrations. As has been noted in previous studies, diazinon is a particularly difficult pesticide to remove in vegetated treatment systems because of its high solubility and persistence in the water column. All diazinon remaining after vegetated treatment was effectively removed using the Landguard OP-A® enzyme treatment. All samples treated with this enzyme product demonstrated no detectable diazinon and all were non-toxic to *C. dubia*.

Figure 5. Diazinon concentrations in composite water samples used in toxicity tests with *C. dubia* in VTS3 Trial 3. (Anderson et.al 2008)



Summary

Application of Landguard OP-A® degradation enzyme at the correct concentration given considering the time before release to a surface water source has been shown to be effective in removing or reducing OP pesticide residues to less than the water quality standard. Since CSIRO is currently looking for a production partner to further develop and mass-produce the material, the cost per unit of treated runoff water remains in question.

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Using Mating Disruption to Reduce Use of OP Insecticides in Peaches

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Introduction

The 50th anniversary of the synthesis of the first insect sex pheromone is 2009. The insect used was the silk moth, *Bombyx mori*. Since that time hundreds of pheromones have been identified and are now utilized for better and safer pest management. The synthesis of these pheromones has led to some the greatest advances in integrated pest management ever.

One of the first agriculturally important moths to have its sex pheromone identified was Oriental fruit moth *Grapholitha molesta* (Busck) (OFM). Initially that synthesis led to better monitoring in stone fruits and, later, as a method of predicting population dynamics. This allowed for better timing of insecticides for control, resulting in fewer insecticide applications without reduction in control. In the early 1980's Australian entomologists began testing the feasibility of inundating orchards with this OFM pheromone component, (*Z*)-8-dodecenyl acetate (93%), (*E*)-8-dodecenyl acetate (6%), and (*Z*)-8-dodecenol (1%)). Field trials demonstrated the efficacy of the method in reducing OFM populations in Australian and South African orchards. Work by Dr. Dick Rice of UC Davis, in cooperation with farm advisors throughout the San Joaquin Valley, established that this method could be successful in California and throughout United States. Since that small beginning, in the mid 1980's, nearly 80% of all fresh market peach and nectarine farmers in California currently use the method know as mating disruption for management of OFM.

To further the adoption of OFM mating disruption by stone fruit farmers, a demonstration project was initiated in 2000. To accomplish this required sound information on the comparative efficacy of two approaches to managing pests (particularly OFM) in stone fruit and to demonstrate success of mating disruption on real farms. An Alliance was formed to implement such a pest management program. Reduction in surface water contamination from broad spectrum sprays was another benefit of implementing mating disruption. The approach (termed reduced risk) was compared to the conventional pest management utilizing more broad-spectrum materials. The corner stone of the project was management of OFM utilizing mating disruption. We were able to successfully demonstrate mating disruption for OFM as a viable and cost effective method of reducing infestation and to incorporate management of other pests when insecticides, previously used for OFM, were eliminated. However implementation of a reduced risk approach emphasized monitoring and knowledge of pest and beneficial arthropod populations to determine when to use strategies in addition to mating disruption. Some of these strategies included orchard floor disking, introduction of parasitoids, dormant oil sprays, and other insecticides considered environmentally benign. Methods of integrating reduced risk practices for the more conventional broad-spectrum insecticides were developed. This transition was done while maintaining equal or less pest damage and pesticide cost. We also believed the adoption of a reduced risk approach would preserve remaining organophosphate materials, such as phosmet and chlorpyrifos, from being removed as pest control tools. If such broadly toxic products could be used only when truly needed, the chance of them being regulated out of the market place would be lessened.

The Stone Fruit Pest Management Alliance Membership included stone fruit farmers represented by the California Tree Fruit Agreement, UC Cooperative Extension, UC Statewide IPM Program, California State University Fresno, California Department of Pesticide Regulation, and Region 9 of the Environmental Protection Agency. Additionally, the agrochemical industry contributed substantially to the success of this program.

During the four years of the Stone Fruit Pest Management Alliance, 26 orchard comparisons were made. These included 16 nectarine orchards, 8 peach orchards, and 2 plum orchards. In addition to the comparison orchards, 12 orchards following a soft IPM program were also followed. These 12 additional orchards included 6 peach orchards, 4 nectarine orchards, and 2 plum orchards These did not have a conventional orchard comparison. The information developed was based on the comparisons made in orchards in Fresno, Tulare, Kern, Kings, and Madera Counties. Theses counties produce 90% nectarines in California and nearly 70% of the fresh market peaches. Harvest dates ranged from May 3 to September 20. In general terms, nectarines pose the greatest pest management challenge, followed by peach. However, harvest date will also have a bearing on the severity of pest problems, particularly for San Jose scale and OFM.

Methods and materials

Management of OFM was done with pheromone confusion in all comparisons in years three and four. Because of the success achieved in the first two years, cooperators moved to mating disruption but, if supplemental sprays were used, the conventional orchard blocks received broad spectrum sprays (usually phosmet) while those in the reduced risk orchards used spinosad. Application of the pheromone dispensers was done when first moths were trapped in monitoring traps or by the first week of March, which ever occurred first. In most cases, only one application of dispensers was made at 150 didpensers per acre. Oriental fruit moth populations were monitored with standard pheromone traps (Trece®) and by shoot strikes and fruit damage caused by larval feeding

A major concern for stone fruit farmers moving to mating disruption is that of other pest problems developing when sprays for OFM are dropped. We followed populations of these insects as well. San Jose scale was monitored with standard SJS pheromone and sticky traps (Trece) and spur and fruit examination. Management of SJS was done with dormant oil applications in the reduced risk orchards while the conventional orchards relied either on dormant oil plus esfenvalerate or dormant oil plus chlorpyrifos. Peach twig borer (PTB) was also monitored with Trece pheromone traps and long life pheromone lures. *Bacillus thuringiensis* (Bt) or spinosad sprays were the primary materials used for PTB control in the reduced risk orchards. Diazinon or phosmet was used in the conventional orchards. In two selected orchards mating disruption with the use of the Suttera Puffers was used to control PTB. The puffers were used as and experimental technique because of lack of previous efficacy data. No costs figures were used for the puffer technology.

The development of reasonably priced and environmentally benign insecticides that are effective on pests of peaches (spinosad, spirotetramat, and rynaxpyr) have enable farmers to move to these reduced risk approaches that are environmentally and worker safe and extremely effective. These new insecticides also allow for a greater contribution from parasites and predators in controlling pests.

Harvest samples (500 to 1000 fruit) were collected from each of the orchards prior to damage sorting by picking crew. This was done throughout the orchard. Fruit and twig were sampled from spring to harvest to detect incipient pest problems prior to producing fruit damage.

Results

Figure 1. shows the average infestation of peach and nectarines, at harvest, from OFM for each year of the study and the four year average. The results of year one and two clearly show that mating disruption provided efficacy equal to that of multiple broad spectrum sprays. The four-year average for both management approaches was 1.6%, when figures were rounded.

Figure 2. shows total insect damage during the four years of the study. The reduced risk approach resulted in an average of 5.8% damage while the conventional approach averaged 5.6%. These figures are not statistically different (P>0.05,Fishers PLSD).

The two most damaging arthropod pests were forktailed bush katydid, *Scudderia furcata* Brunner von Wattenwyl, and western flower thrips, *Frankliniella occidentalis* Pergande. No damage was found due to peach twig borer. This was also the case for the orchards using PTB pheromone disruption. The two primary pests of greatest concern when the program was started were Oriental fruit moth and San Jose scale. Only minor damage was attributed to these latter two pests throughout the program.

The Alliance generated substantial information on reduced-risk pest management efficacy and cost. Knowledge was gained as to how well the various management techniques worked within actual commercial stone fruit production systems. The 4-year average per acre cost of pesticides in the PMA managed orchards was $189.75 (SE± $29.65). The same 4 -year average cost in the Conventionally managed orchards was $189.25 (SE± $25.88). Table 1 presents the annual costs. The average percent damage due to arthropods was 5.88 (SE± 1.52) and 5.60 (SE± 1.29) for The Reduced Risk and Conventional orchards respectively.

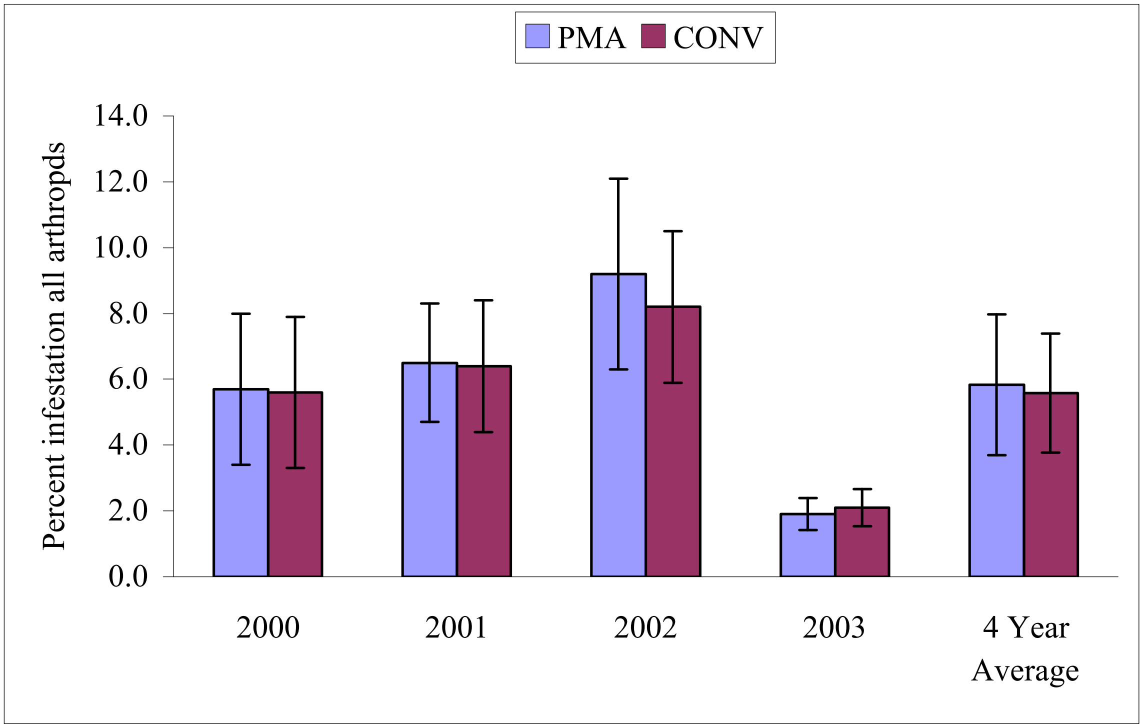
Based on the results of this four-year study, stone fruit farmers can effectively manage arthropod pests with reduced risk pesticides. The damage and costs of such a program is not different than the more widely used programs that emphasize organophosphates and carbamates. Oriental fruit moth mating disruption was the key component in managing this primary pest of peaches and nectarines.

Table 1. Annual cost comparison of Pest Management Alliance and Conventional pesticides.

Management Practice	2000	2001	2002	2003	4 Year Average
Reduced Risk	$221	$148	$197	$195	$190
Conventional	$222	$159	$183	$195	$190

Figure 1. Average infestation of peach and nectarine by Oriental fruit moth at harvest.

Figure 2. Percent infestation of peach and nectarine, at harvest, by all arthropods.



Using Aerosol Pheromone Puffers for Area-wide Suppression of Codling Moth in Walnuts

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Introduction

Successful use of pheromone mating disruption (PMD) for reducing codling moth (CM) damage in apples and pears, along with pressure from various sources to find alternatives to conventional insecticides, has led to intensive efforts to adapt PMD technology in California walnuts. Since 1999, efforts have been underway to improve efficacy, reduce cost, and demonstrate reliability of PMD in walnuts using a variety of experimental and commercial pheromone dispensing technologies. Most of the recent focus in PMD research and implementation has been with aerosol "puffers" because they offer cost-saving advantages over other currently available dispensing technologies as well as many conventional pesticide programs. Puffers consist of a plastic cabinet enclosing an aerosol canister containing codling moth pheromone (E,E-8,10-dodecadien-1-ol), a small digital clock for pre-programming automated pheromone releases, and a simple battery-powered gear-and-cam mechanism for actuating releases from the canister. Using 30 microliter puffs, canisters contain enough formulated pheromone to last approximately 200 days – enough for one entire growing season in California walnuts.

In 2005, two long-term, area-wide projects using aerosol pheromone puffers were initiated. Several additional large-scale trials were added in subsequent years. Putative benefits of using PMD over a large area for several years include reduced codling CM damage, lower in-orchard populations and, as a result, a reduction in insecticide use to control CM. Results of the trials confirm these benefits and have provided useful information on practical aspects of puffer deployment in walnuts.

Materials and Methods

Two trials were established in 2005 to evaluate aerosol pheromone puffers for codling moth management. Both consist of contiguous mature walnut orchards of several different varieties, some with historically high codling moth populations and damage and others with lower codling moth pressure and/or varieties with low relative CM susceptibility. One 600 acre site, with 22 individual blocks, is located near Lockeford in San Joaquin County. A Glenn County site is 185 acres of walnuts divided into three blocks.

Aerosol pheromone puffers (Puffer® CM, Suterra LLC) were installed each year prior to biofix of the overwintering codling moth generation in a square grid configuration at a rate of one puffer per two acres. A slightly higher density was used on the outside edges of blocks around the perimeter of each site. The units were hung in the upper ¼ of the tree canopy and programmed to emit a 40 microliter "puff" of formulated pheromone (18.05% active ingredient) at 15-minute intervals for a period of 12 hours each night, beginning at 5 PM.

Codling moth populations and flight activity were monitored in each block using standard codling moth traps, some baited with CMDA "combo" lures and hung high in the tree canopy (1 to 4 per block depending on size) and a smaller number with traditional "1X" pheromone lures (1 to 2 per block) hung low in the canopy. In PMD orchards, 1X traps act as an "early warning system": they should not catch moths in a pheromone-treated orchard. Data from "combo" traps provide a picture of CM generations and peaks in flight, useful for timing of sprays. All traps were checked weekly and lures changed as recommended by the manufacturer from first flight biofix through harvest in each block. In-season "canopy counts" of CM-damaged nuts (600-1000 nuts per block) were performed at the end of the first and second codling moth generations in each block. Harvest samples were collected during commercial harvesting operations in each block and examined to assess damage from codling moth.

Supplemental insecticide treatments were made in each block as deemed necessary by cooperating growers and their pest management advisors, based on the block's previous damage history, codling moth trap captures, and in-season damage assessments. In the first year or two of puffer use, cooperators were encouraged to treat aggressively using, as needed, materials and treatment intervals capable of suppressing codling moth populations and damage to low levels. In subsequent years, treatments with more selective, shorter residual, non-organophosphate insecticides were encouraged as needed to curb occasional outbreaks.

Results

At the San Joaquin County site, CM populations and damage were unacceptably high in some blocks in 2005, the first year of puffer use (Figure 1). This was attributed to an insufficiently aggressive supplemental insecticide treatment regime which, when modified in 2006, provided more satisfactory overall suppression. This set the stage for better success with fewer treatments in 2007 and 2008. By 2008, the fourth year of puffer use, codling moth populations (as indicated by combo trap captures (Figure 2) and in-season damage (per "canopy count" damage assessments, data not shown) declined to a point where no supplemental sprays were needed (Figure 3) and harvest damage was at or near zero in all blocks. Minor damage – well below levels observed in these blocks before or during early years of puffer deployment – was detected in harvest samples drawn from areas near the edges of blocks on the perimeter of the site.

At the Glenn site, seasonal trap captures generally declined from 2005 to 2006, but increased in 2007 and 2008 at some trapping locations (Figure 4). This was attributed, as at the San Joaquin County site, to a less-than-optimal supplemental treatment program until 2008, at least in northeastern portions of the site where trap captures were greatest. A conventionally managed walnut orchard with high codling moth pressure adjacent to the Glenn County site may also have contributed to the high CMDA trap activity observed. In spite of this population pressure, and with the imposition of an appropriately aggressive treatment regimen in 2008, codling moth harvest damage was low in 2008 (Figure 5).

The grower cooperators at the puffer trial sites are enthusiastic about the integration of aerosol puffers into their pest management program. In 2008, approximately 2,000 acres were under PMD with puffers in conjunction with UC-monitored tests in the principal walnut growing regions and an estimated 3,000 additional acres were under PMD in commercial orchards. It is anticipated this acreage will double in 2009. Future experimental work with PMD will focus on improving suppression on orchard edges and developing and testing new dispensers suitable for “medium density” deployment in orchards considered too small (less than ~40 acres) for successful puffer use (because of out-of-orchard drift and increasing influence of upwind edge gaps between puffer plumes).

Figure 1. Average percent codling moth at harvest, 2005-2008, in individual blocks at San Joaquin site.

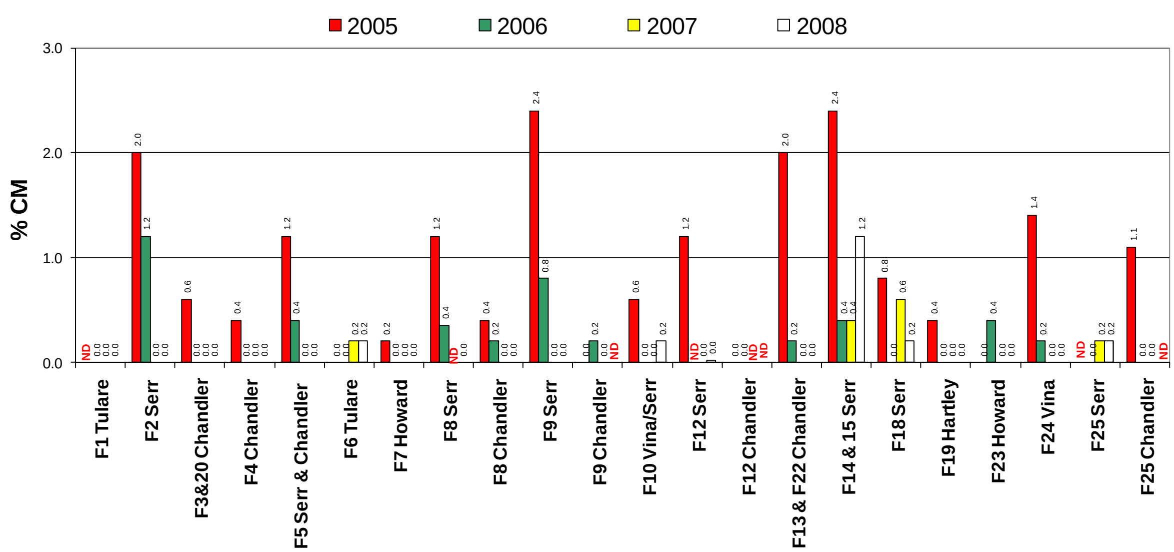


Figure 2. Total seasonal codling trap captures in CMDA-baited Delta traps, all blocks, San Joaquin County site, 2005-2008.

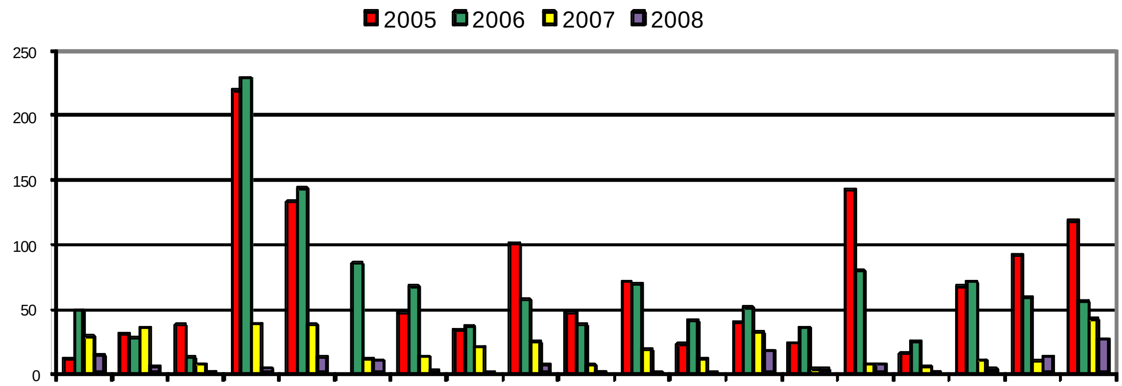


Figure 3. Annual acreage receiving supplental codling moth insecticide treatments, 2005-2008, by block, at the San Joaquin County site. Treatments specifically targeting codling moth counted as 1.0 times the acreage treated; sprays targeting multiple pests counted as 0.5 times treated acreage.

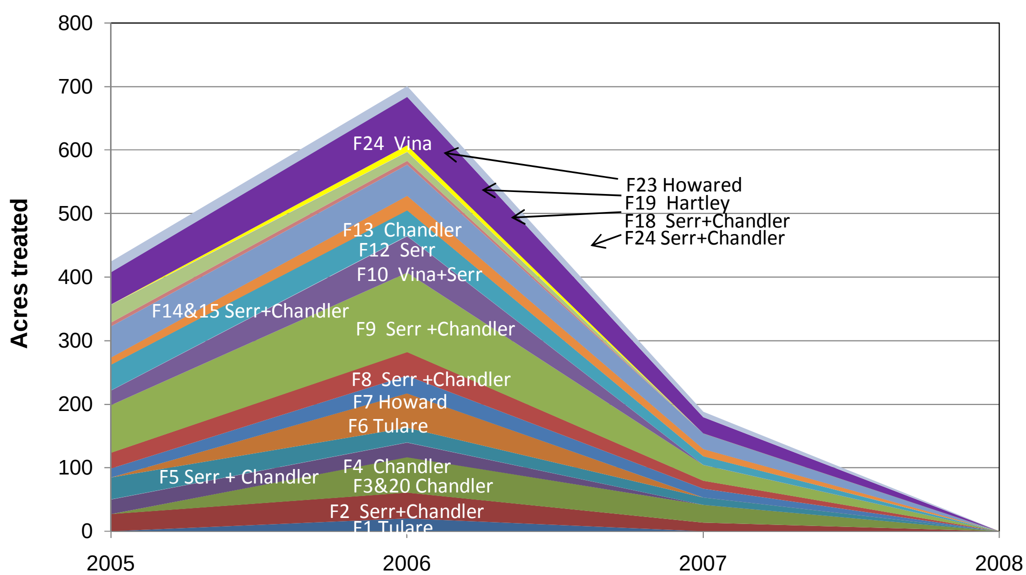


Figure 4. Total seasonal trap captures in CMDA-baited Delta traps located in three blocks at Glenn County site, 2005-2008.

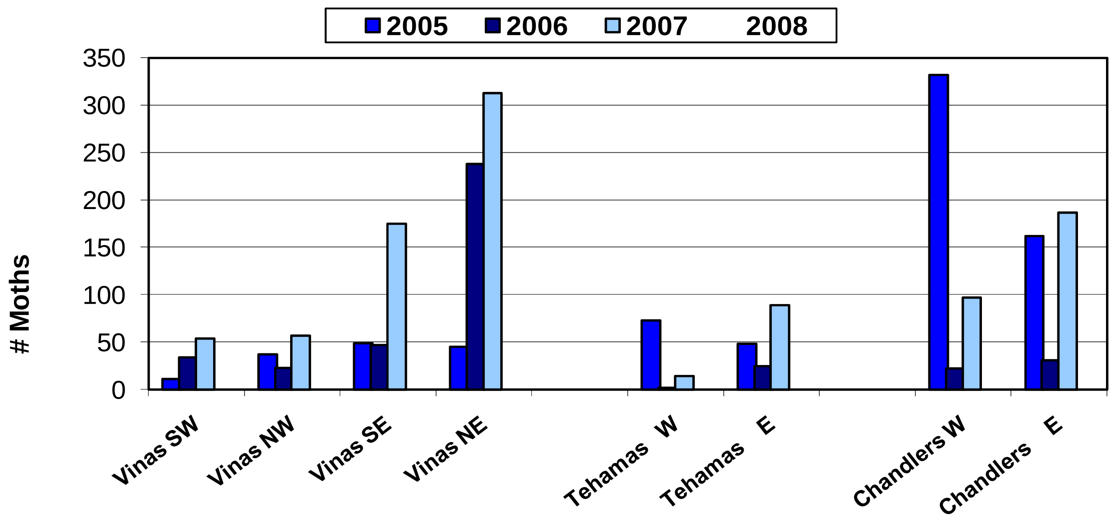
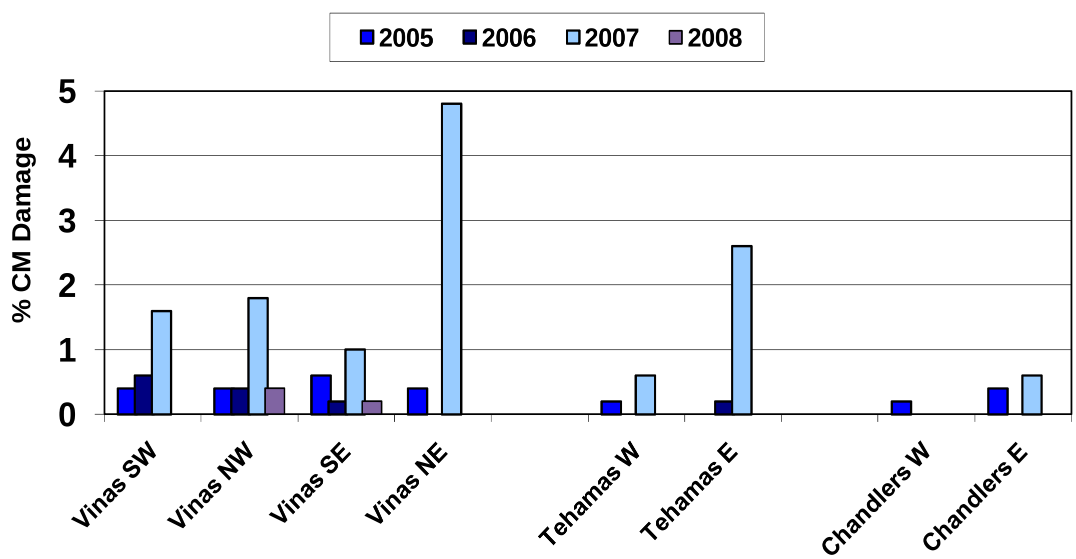


Figure 5. Average percent codling moth damage at harvest, Glenn County puffer trial, 2005-2008.



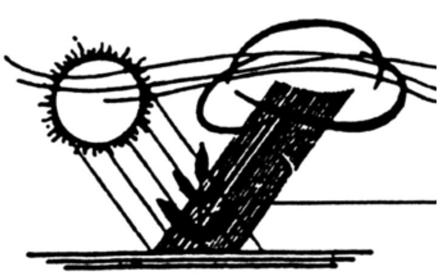
Session VI

Dairy management

Session Chairs:

Brook Gale

Rob Mikkelsen



Dairy Feed Management Basics to Reduce Nutrients to Cropland

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Introduction

This paper will provide an understanding of a national education project that has been funded by the USDA-Natural Resources Conservation Service. The primary goal is to develop a systematic approach for consultants and advisers to assist owners and managers of livestock and poultry operations in adoption of feed management practices that will be profitable and decrease impact on the environment. The project team has developed the infrastructure to implement NRCS's Feed Management Practice Standard 592 which is defined as "managing the quantity of available nutrients fed to livestock and poultry for their intended purpose". Integration of Feed Management into whole farm nutrient management is a new approach that can assist livestock and poultry producers with avoiding excess accumulation of nutrients on their farm, particularly nitrogen and phosphorus.

Feed represents the largest import of nutrients to most livestock and poultry farms, followed by commercial fertilizer (Klopfenstein at al., 2002). Feed Management opportunities currently exist to reduce imports of nutrients, particularly nitrogen and phosphorus, to most animal and livestock operations. The technologies and approaches to achieve these reductions vary in their degree of economic feasibility and environmental impact. It is important that agricultural professionals understand the degree of success that can be expected both from an economic and an environmental standpoint.

In 2006 the feed management education project was implemented for the species of beef, dairy, poultry and swine. The project is national in scope and is designed to encourage adoption of the NRCS Feed Management Conservation Practice Standard 592 and feed management practices that can have a positive impact on soil and water. A goal of the project is to assist NRCS staff and agricultural professionals increase their understanding of Feed Management, its impacts on environmental sustainability of livestock and poultry operations, and inclusion of a Feed Management Plan (FMP) as part of a comprehensive nutrient management plan (CNMP). The Feed Management curriculum is organized in a four-hour format for both technical service providers and nutrition consultants. Information is provided that links the FMP to the CNMP and the requirements for certification to write a feed management plan. Real farm case studies are used to provide training in use of on-farm assessment checklists for assessing the opportunity of a Feed Management Plan to impact whole farm nutrient balance; and, develop and implement a FMP. Electronic decision aid tools include: whole farm balance, manure excretion estimator, and the relative economics of a ration change vs. transporting manure. The manure excretion estimator tool and economics tool are both linked to feed nutrient use. Examples of a FMP template are provided, as well as a completed FMP.

Statement of Problem

The US Environmental Protection Agency (EPA) released new regulations for Concentrated Animal Feeding Operations and Animal Feeding Operations (CAFO/AFO) in 2003. Under the new regulations, permitted CAFO/AFO's will be required to develop a Nutrient Management Plan (NMP). One form of a NMP is a Comprehensive Nutrient Management Plan (CNMP) as defined by the Natural Resources Conservation Service. There are six core elements of a CNMP (see figure 1): 1) Feed Management, 2) Manure and Wastewater Handling and Storage, 3) Nutrient Management, 4) Land Treatment, 5) Record Keeping, and 6) Other Manure and Wastewater Utilization Options. Livestock and poultry operations defined as permitted CAFOs are required to have a NMP. Previously, when nutrient management plans have been developed, the contribution of feed management to whole farm nutrient management has not been considered. For those that choose to develop a CNMP, there will be a need for an understanding of the Feed Management element of the CNMP and the tools to assess the merits of a feed management plan and the tools to systematically develop a feed management plan.

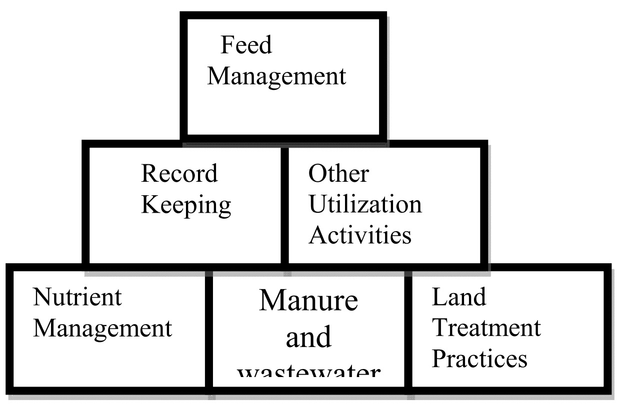

Figure 1. Six core elements of a comprehensive nutrient management plan.

Implementation Plan

Figure 2 outlines the primary roles of those involved with the assessment and implementation of NRCS's Feed Management Practice Standard 592. The primary role of the nutrient management planner is to determine if the conditions (whole farm nutrient imbalance, soil nutrient build-up, land base is not large enough, or seeking to enhance nutrient efficiencies) exist for the feed management practice to apply; and, to assess (with opportunity checklist) if the livestock or poultry farm is a good candidate for development of a completed feed management plan (FMP). The primary role of the nutritionist is the completion of the feed management plan checklist in preparation and development of the feed management plan.

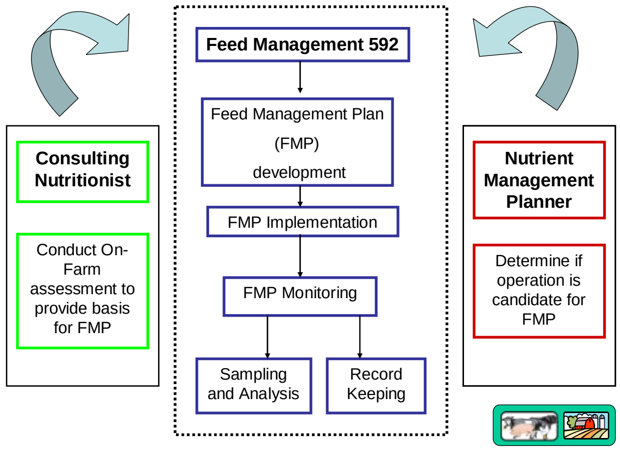

Figure 2 – Roles of nutrient management planner and consulting nutritionist in implementing Feed Management practice standard 592.

The roles and steps are shown as part of 4-hour training workshops (see figure 3) with five major steps involved in the assessment and development of a feed management plan. The workshops are designed with different emphases for the nutrient management planner versus the nutritionist. Since the nutrient management planner is more involved with the initial steps of the process, their workshop is designed to create a competency in use of the opportunity checklist and an awareness of the latter stages. In a nutritionist workshop, an awareness of the initial steps is created, while they receive detailed training on the use of the feed management plan checklist and development of the feed management plan. A key element of the workshops is that we have used real farm case studies to demonstrate the tools and assist with a clear understanding of the roles and interpersonal dynamics that might be expected.

The initial assessment by the nutrient management planner is done with species-specific (beef, dairy, poultry and swine) assessment tools called opportunity checklists. The checklists are designed to address a limited number of the most likely feed management practices that can reduce the import of feed nutrients to the farm. Examples of factors include: are diets formulated to meet the requirements of the animal, are animals fed in groups, are ingredients or diets analyzed for nutrient content, are diets formulated for protein fractions, are growth promotants and ionophores used, and are enzymes used. Each of these factors are focused on the reduction of nitrogen or phosphorus in manure or a reduction of imported nutrients. Once the farm has been determined to be a candidate for a FMP, then the nutritionist assumes his/her role.

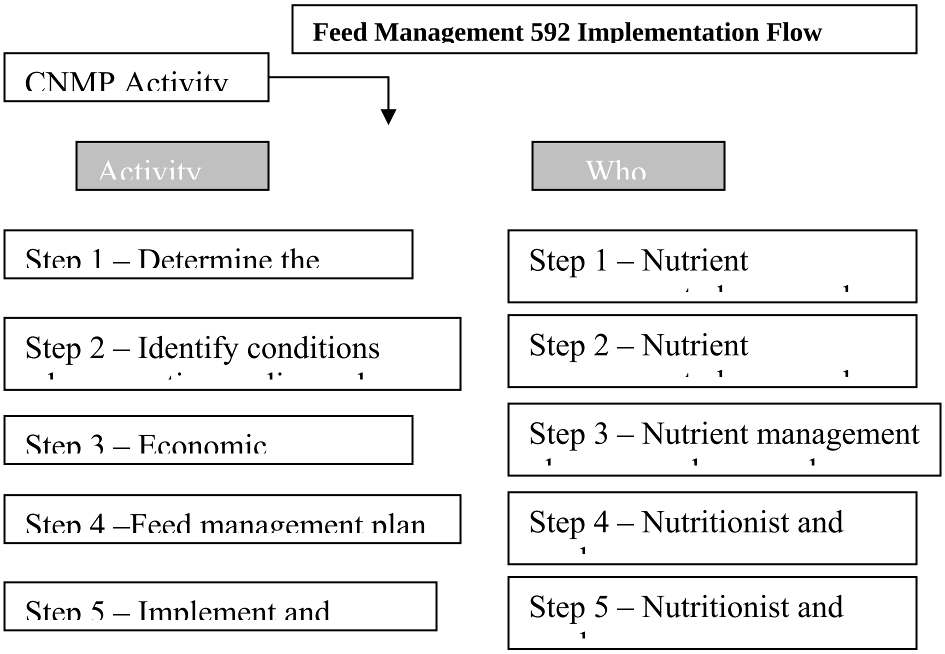

Figure 3. Steps and roles in development and implementation of a feed management plan.

The nutritionist has the responsibility to utilize the feed management plan checklist (tool) to collect information that will be used to complete the feed management plan. Categories of items in the feed management plan checklist are: targeting nutrient requirements, ration balancing, ration management practices, production aids-enhancers, and monitoring tools. The feed management plan template (tool) is designed to outline and document the feed management practices that will assist with minimizing the import of feed nutrients to the farm. In addition, it is designed to create a "live" document for management to use in strategic and tactical planning. Special attention is given to sampling frequency, analysis of specific nutrients, specific recommendations on practices to adopt, how the feed management plan will change the nutrient composition of manure, and specific review dates.

An intermediary step in the implementation of a FMP that will be considered by some livestock and poultry operations is the economic evaluation of the choice to make rations changes or transport manure a farther distance.

Dairy Specific Nutrient Reductions

Feeding for Reduced Crude Protein

The transition from feeding the dairy cow for her crude protein requirement has clearly progressed today to a more sophisticated approach of formulating for the estimated requirement of amino acids (NRC Recommendation for Dairy Cattle – 2001 - http://bob.nap.edu/books/0309069971/html/). While this transition has been occurring there has been a simultaneous progression of a greater awareness of the interrelationship of diet formulation and feed management on whole farm nutrient management. The focus of this example will be to develop the concept of ration balancing for increased profit and reduced environmental impact as it relates to nitrogen. In particular, the merits of formulating for estimated amino acid requirements with the use of ruminally undegraded protein sources (RUP) sources.

Amino Acid Formulation

Amino acid formulation for dairy cattle has been common practice since the availability of the Cornell Net Carbohydrate and Protein System (CNCPS- Fox et al., 1990) model and Cornell-Penn-Miner (CPM) model. We have used both models successfully to strategically formulate diets to evaluate the merits of sources of ruminally undegraded protein (RUP), ruminally protected amino acids, and free lysine-HCL (Xu, et al.,1998; Harrison, et al., 2000). Others (VonKeyeserligk et al., 1999; Dinn et al., 1998) have had positive experiences with use of the model to formulate diets to reduce the crude protein (CP) level in the diet while maintaining milk productivity.

More recent studies (Harrison et al., 2002, and Harrison et al., 2003) continue to provide evidence that formulating diets for available amino acids can provide the opportunity to reduce CP levels in the diet and reduce on-farm import of nitrogen. A field study (Harrison et al., 2002) was conducted with a high producing herd in WA state to compare their general herd diet formulated at ~ 18 % CP to a diet that was reformulated at ~ 17 % CP. Results showed that milk production could be maintained while decreasing nitrogen import to the farm (Tables 1 and 2. In addition, the diet reformulation resulted in an increase in income over feed cost (IOFC) (Table 3).

The Phosphorus Feeding Myth?

A major reason for overfeeding P to dairy cows is concerns related to reproductive efficiency (Hristov, 2004). Past research has related P deficiency to health and reproductive problems (failure to conceive, reduced calving rates). Extensive reviews on the topic were published (Satter and Wu, 1999; Wu and Satter, 2000; Ferguson and Sklan, 2004; and Lopez et al., 2004). In retrospect, it appears that low P intake was linked to impaired reproductive performance in cattle through a series of confounded and misinterpreted experimental data reported in the late 1920s through the 1950s.

Recent P Research

A summary of 13 trials with lactating dairy cows (392-393 cows) and heifers (116-123 heifers) showed no effect of dietary P on reproductive performance (Satter and Wu, 1999). Levels of P in the cow diets varied from 0.32 to 0.40 (low-P groups) and from 0.39 to 0.61% of dry matter (DM) (high-P groups). Heifers were fed 0.14-0.22 and 0.32-0.36% dietary P, respectively. Days to first estrus, days open, services per conception, days to first artificial insemination, and pregnancy rates were not different between the low- and high-P cows. Similarly, services per conception and pregnancy rates were not affected by dietary P level in the heifer groups.

More recently, Lopez et al. (2004) conducted an experiment with lactating dairy cows assigned to recommended (0.37%) or excess (0.57% of DM) dietary P. Cows were fed the respective diets after calving and reproductive parameters were monitored. The percentage of the anovular (not ovulating) cows (29.9 vs 27.1%, recommended and excess P, respectively), days to first progesterone increase (53 vs 53 d, all cows), days to first recorded estrus (68 vs 67 d, all cows), days to first service (89 vs 90 d, all cows), the duration of estrus (8.7 vs 8.7 h), total mounts (7.4 vs 7.8), total mounting time (25.8 vs 24.5 s), conception rates, pregnancies lost, days open for pregnant cows (112 vs 116 d), services per conception, and the estrous cycle length (23 vs 23 d) were not different between the recommended and excess P groups. The authors concluded that feeding P in excess of NRC (2001) requirements (0.37% of DM for the cows involved in this trial) did not improve reproductive performance.

Additional Resources

In addition to the tools and implementation process that has been described, the project team has developed fact sheets, a chapter for the NRCS Agriculture Waste Field Management Handbook, and internet accessible presentations from a nutrient management planner workshop. The recorded presentations can be accessed at http://www.ucs.iastate.edu/mnet/cnmp/home.html. Certification for the nutrient management planner is achieved by attending the Feed Management module of the Iowa State CNMP training (http://www.ucs.iastate.edu/mnet/cnmp/home.html) and meeting NRCS technical service provider requirements. Certification for the nutritionist is achieved by attending a 4 hour Feed Management education workshop and passing an American Registry of Professional Animal Scientists (ARPAS) species specific Feed Management certification exam (http://www.arpas.org/).

Conclusions

Development of Feed Management Plans is a new opportunity for consultants and advisors to the Livestock and Poultry industry. We encourage you to share this opportunity and assist livestock and poultry producers to remain economically viable and environmentally responsible.

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Dairy Lagoon Water Nitrogen Mineralization

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Introduction

In the Central Valley of California, dairies with manure flush systems produce large quantities of dilute (<2% solids) wastewater, which is stored in anaerobic lagoons prior to land application via surface irrigation on nearby crop fields. This lagoon water is often applied at excessive N rates due both to the inadequacy in design of the distribution systems and to the lack of knowledge of the fertilizer nutrient value of the material. In several areas of the Central Valley with shallow aquifers and sandy soils, inappropriate management of lagoon water has led to groundwater contamination with nitrate and salts (Davis, 1995; Harter et al., 2001; Harter et al., 2002; Lowry, 1987). Some researchers have concluded that that basing lagoon water application rates solely on NH_4^+ concentrations without considering the contribution from organic N may have resulted in excessive N additions and an increased potential for nitrate leaching (D. Meyer and Schwankl, 2000; R. Meyer et al., 2001; Harter et al., 2001).

In 2007, the Central Valley Regional Water Quality Control Board adopted comprehensive waste discharge requirements for all existing milk cow dairies that are intended to protect ground and surface water quality. A central feature of this regulation is an annual limit to total N applications from all sources of 1.4 times the quantity of N removed in the harvested crops on each field (CVRWQCB, 2007). This standard is mathematically equivalent to recovery by crops of 71% (100/1.4) of total applied N. This is a higher crop N use efficiency than is often observed in research plots in annual crop rotations. To match supply of N to crop demand with such high efficiency requires that the rate of mineralization of manure N be taken into account.

While there is an extensive research literature on the livestock manure and fate of N in soil (e.g., Beauchamp and Paul, 1989; Van Kessel and Reeves, 2002), dilute lagoon waters such as commonly produced in dairies in the western US have not been well characterized; and the few studies done with this type of lagoon water have not shown consistent results. Pettygrove et al. (2003) observed from -10% (i.e., immobilization) to 44% apparent net N mineralization of lagoon water solids during a six-week aerobic soil incubation. Researchers in Utah observed apparent net N mineralization of dairy lagoon water of up to 90% during a 10-week soil incubation (Shi et al., 2004). Pettygrove and Heinrich (2008) observed apparent net immobilization of added lagoon water NH_4^+ from eight Central Valley dairies during a 12-week soil incubation. Differences in experimental procedures and lagoon water composition make it difficult to compare the results from these experiments.

One contributor to difficulty in investigations with dairy lagoon water that is not encountered with solid manure or more concentrated slurries is lagoon water's relatively high proportion of N in the ammonium form, which typically accounts for between one-third and two-thirds of total N. When lagoon water is applied at realistic rates to field plots or containers of soil in the laboratory, the amount of N mineralized may be very small compared to the large amount of ammonium N, and this makes it difficult to quantify the rate of mineralization. One way to overcome this problem would be to use higher application rates; however lagoon water is very dilute, and high N rates would entail saturating the soil, which in turn might produce unrealistically high N losses through denitrification. Several researchers (e.g., Paul and Beauchamp, 1989) have observed high emissions of nitrous oxide gas (a denitrification end product) from manure-amended soil. Yet most researchers studying manure N mineralization rates do not attempt to quantify denitrification.

We used several techniques to address these methodology problems. First, using the standard aerobic laboratory manure amended soil incubation, we compared whole dairy lagoon water ("unaltered LW") to lagoon water that has been centrifuged/decanted to greatly increase the ratio of organic N to ammonium N. This "solids-concentrated" (SC-LW) also has a lower concentration of dissolved C. Secondly, we used ^{15}N labeling of lagoon water ammonium to estimate the loss of gaseous N. Such loss must be taken into account if actual mineralization is to be distinguished from apparent mineralization.

Materials and Methods

Dairy lagoon water (LW) from anaerobic storage lagoons was collected from seven confinement dairies in California's San Joaquin Valley. Settling basins (5 dairies) or mechanical screens (2 dairies) were in use at these dairies to reduce the content of coarse solids from the lagoon water.

Lagoon water samples were processed shortly after collection and analyzed for total solids (TS), total suspended solids (TSS), total N (TKN), total inorganic N (NH_4 and NO_3), dissolved organic N (DON), TSS-C and N, dissolved organic C (DOC), dissolved inorganic C (DIC), particle size (using 0.3 and 28 µm filters), pH, and electrical conductivity (EC). The dissolved fraction is defined as that passing through a 0.3 µm nominal glass fiber filter.

Three replicates of manure-amended soil and soil-only controls were prepared for destructive sampling and measurement of NH_4 and NO_3 at 1, 3, 6, and 9 weeks. Nitrite (NO_2) was determined in wk 1 samples. Each incubation container received 80 g of an air-dried 30:70 fine sandy loam soil-quartz sand mix. A large-tip pipette was used to surface apply 10 ml of lagoon water (one set of unaltered and a second set of solids-concentrated lagoon waters) to reach 55% of the soil's water holding capacity. The liquid was evenly applied in one aliquot. As a result the N loading rate was different for each dairy. Containers were incubated in the dark at 72 ^{o}F.

A second set of incubation containers received lagoon water (as collected) enriched to 2.5 atom% ^{15}N with 98 atom% ^{15}N ammonium sulfate ($(NH_4)_2SO_4$). At wk 3, the ^{15}N enriched incubation containers were destructively sampled for NO_3^- and NH_4^+ and the remaining soil lycophized and ball milled. Isotope ratios and total N were determined by a Carlo Erba NA 1500 Elemental Analyzer with a Fisson's Optima mass spectrometer. NH_4^+-N loss was calculated by the following equation:

$$N_{Loss} = \frac{N_{LW} - \left\lfloor \frac{A_{21} - A_0}{A_{LW} - A_0} \right\rfloor N_{21}}{N_{LW}} \qquad \text{[Eq.1]}$$

where N_{LW} is the amount of lagoon water NH_4-N applied (µg N g^{-1} soil), N_{21} is the total soil N content at day 21, A_{21} is atom% ^{15}N in the soil at day 21, A_{LW} is the calculated atom% ^{15}N in the lagoon water, A_0 is the initial atom% ^{15}N of the soil and lagoon water prior to enrichment (assumed to be 0.37 atom% ^{15}N) , and N_{Loss} is the fraction of $^{15}NH_4$-N that is unaccounted for (i.e. lost).

Results

Manure Composition

Manure characteristics for the unaltered LW samples used in this study are presented in Table 1. Despite differences among dairies in the manure collection and storage, the composition of 6 of 7 manures is similar. Lagoon water from Dairy 7 deviated greatly from the other samples, probably due to agitation of settled solids prior to our sample collection, which resulted in a large amount of coarser fibers in the sample. The carbon data from Dairy 7 reflects this accumulation of higher C:N plant material.

Organic N averaged 44% (range 33-80%) of the total Kjeldahl N, which is typical of dairy lagoon waters found in California's Central Valley (Mathews et al., 2001). Of the organic N fraction, 32% (range 7-45%) was dissolved (<0.3 µm). Excluding Dairy 7, an average of 93% of TSS consisted of particles between 0.3 µm and 28 µm in size.

Total C reported in Table 1 was calculated by summing TSS-C and TDC (DOC+DIC). Of the total C in lagoon water, DOC and DIC comprised 14% (range 3-19%) and 36% (range 7-49%), respectively. The high concentration of dissolved inorganic C (DIC) – likely present as bicarbonate – is probably due to urea hydrolysis, which releases carbonates. Urea is continually added to the lagoons from urine collected in the flush water.

The characteristics of the solids-concentrated (SC) LW that we produced for use in this study are presented in Table 2. (Due to the high initial solids content of Dairy 7, we did not concentrate the solids from this dairy.) Through the concentrating process, the SC LW samples contained 7-11 times higher concentrations of TSS but 78-98% less dissolved N and C than the original unaltered samples. Approximately 3-7% of the initial sample TSS (mostly the finest particles) was lost during the concentrating process. Despite this loss, the final TSS C:TSS-N ratios of the SC-LW were close to that measured in the unaltered LW (Tables 1 and 2).

Nitrogen Mineralization

Both the unaltered and SC lagoon waters were added to incubation containers at a volume equal to 55% of the sand-soil available water holding capacity. As a result, each treatment received a different amount of total and organic N (Table 3). For the unaltered LW, containers received between 39-126 mg total N kg^{-1} soil and 25-88 mg organic N kg^{-1} soil. For the SC LW each container received between 54-206 mg total N kg^{-1} soil, 96-99% of which is organic N.

N mineralization patterns for the unaltered and SC lagoon waters are shown in Fig. 1. For both treatments, NH_4-N concentrations rapidly declined and were not different from those in the soil-only control by wk 3 for the unaltered and by wk 6 for the SC LW-amended soils (results not shown).

In the first 7 days of the incubation, in the unaltered lagoon water treatments, there was apparent immobilization of NH_4-N followed by subsequent mineralization (Fig. 1a). By wk 9, apparent net N mineralization was 5-26% of the added organic N (Table 3).

Soil nitrite concentrations ranged from 0 to 42% of the day-7 total inorganic N pool. This accumulation of nitrite was temporary, with no nitrite detected at day 21.

In contrast to the unaltered LW, the SC LW treatment showed apparent net N mineralization throughout the incubation (Fig. 1b). By wk 9, apparent net N mineralization totaled 45% (range 41-51%) of added organic N (Table 3). The N mineralization pattern for the unaltered LW from Dairy 7 (Fig. 1a) is very similar to the general N mineralization pattern for the SC lagoon waters.

N losses

Results from the 3-week incubation with ^{15}N enriched unaltered LW samples are shown in Table 3. N_{Loss} (the fraction of added $^{15}NH_4$-N that was unaccounted for at week 3) was calculated using Eq. 1. At the end of 21 days, N_{Loss} was 23% (range 6-33%). Measured ammonia volatilization only accounted for a maximum loss of 1.4% of the NH_4-N added.

Discussion

Nitrogen mineralization

For the unaltered LW, apparent net N mineralization was variable, ranging from 5-26% of added organic N (Table 3). This is in the range of 0-14% and 0-44% net N mineralization from dairy shed effluent (similar in composition to our LW) observed by Barkle et al. (2001) and Stenger et al. (2001), respectively, but is much lower than the 60-90% net N mineralization observed by Shi et al. (2004). In contrast to Shi et al., Burger and Venterea (2008) measured no apparent net N mineralization over 180 d in incubations with liquid dairy manure applied to two soils of differing textures and at two temperatures -- 10 and 25^{o}C. However, their liquid manure had a higher solids content and higher C:N ratio than the materials used in our study.

The temporary immobilization of added NH_4-N that we observed with 4 of the 7 unaltered LW was unexpected, given the low C:N values of these materials (Fig. 1a). For those 4 unaltered LW samples, immobilization of added NH_4-N at day 7 averaged 11% (range 2-22%). This is much lower than the >80% immobilization of added NH_4-N from dairy shed effluent that Barkle et al. (2001) observed during the first 23 days of a 112-day aerobic soil incubation. Burger and Venterea (2008) also observed rapid, temporary immobilization, measuring a maximum of 40% immobilization of added liquid manure NH_4-N at day 8 of a 180-day incubation. Using ^{15}N tracer methods, they attributed this immobilization to N in microbial biomass. Our results suggest that the temporary "immobilization" we observed in this study may have been due not only to true immobilization in microbial biomass, but also to gaseous losses of N.

In our study, rapid decomposition of labile DOC may have resulted in a high microbial N demand leading to temporary NH_4 immobilization even though N was not limiting. When the DOC was removed from the unaltered LW samples, the resultant SC LW-amended soils showed no immobilization. Excluding Dairy 7, there was a positive linear correlation between initial DOC concentration and the % of added NH_4-N unaccounted (i.e. immobilized) for at day 7 (R^2= 0.94, $p<0.05$). Kirchmann and Lundvall (1993) also observed a strong correlation between the initial concentrations of a component of DOC, volatile fatty acids (VFA), and temporary N immobilization for anaerobically treated dairy and pig slurries. VFAs are formed under the anaerobic conditions found in dairy lagoons (Zhang, 2001) and can constitute a large fraction of DOC in anaerobic slurries (Paul and Beauchamp, 1989). VFAs are extremely labile, rapidly mineralizing within a few days of being added to soil (Kirchmann and Lundvall, 1993; Paul and Beauchamp, 1989).

However, it is also possible that the observed "immobilization" (disappearance of inorganic N) in the unaltered LW treatment was actually N loss due to denitrification. Dairies 1, 3, 4, and

6, which had the highest ^{15}N losses (Table 3) also had the most unaccounted for NH_4-N (i.e., apparent immobilization) at day 7 (Fig. 1a). It is possible that the most labile C fraction (DOC and small particles) stimulated denitrification, resulting in high N losses within the first week of the experiment. Once the most labile components were consumed, denitrification was possibly no longer significant, and the relatively more recalcitrant materials began to mineralize. If this were the case, the observed "immobilization" would actually reflect N losses through denitrification.

Compared to the unaltered LW treatment, apparent net N mineralization results for the SC LW-amended soils were less variable (Table 3). The N mineralization pattern for the unaltered LW from dairy 7 (Fig. 1a), which was compositionally similar to the SC LW samples (Table 1 and 2), is very similar to the general N mineralization pattern for the SC lagoon waters.

<u>Denitrification</u>

Because the whole soil ^{15}N content was used in calculating N_{Loss} (thus microbial biomass N is included), N losses can only be attributed to denitrification. As mentioned in the results section, N losses to ammonia volatilization were small. These results show that loss of N through denitrification was significant, with up to a third of added NH_4-N denitrified by 3 wks (Table 3). These results are similar to the average denitrification losses of 30% of added NH_4-N reported by Calderon et al. (2004) from 107 dairy manures of various compositions during a 6 wk aerobic soil incubation.

The high DOC content (14% of total C) in the unaltered LW samples may have led to favorable conditions for denitrification. Both DOC in total and volatile fatty acids (VFA) in particular have been shown to serve as an excellent C sources for denitrifiers, leading to increases in nitrous oxide fluxes from manure-amended soils (Paul and Beauchamp, 1989). We did not analyze our LW samples for VFAs, but it is reasonable to believe that they are present in the anaerobic conditions of the dairy lagoons (Zhang, 2001). Besides providing a readily available food source for denitrifiers, DOC is so labile (Paul and Beauchamp, 1989; Kirchmann and Lundvall, 1993) that microbes may temporarily deplete O_2 levels at microsites in the soil, leading to anaerobic conditions in an otherwise aerobic soil. The combination of anaerobic conditions and the preferred food source for denitrifiers may account for the loss of initial soil nitrate by denitrification. Although we found a significant relationship between DOC and apparently immobilized NH_4-N at wk 1, we found no significant relationship between DOC and N_{Loss} calculated by the ^{15}N disappearance at wk 3.

Concurrent with biotic denitrification, abotic denitrification, frequently referred to as chemodenitrification, may have occurred in our incubations. Adding high concentrations of NH_4^+ fertilizers can result in the temporary accumulation of nitrite (NO_2^-) (Bezdicek et al., 1971; Chapman and Liebig, 1952), which presumably occurs due to NH_3 toxicity to *Nitrobacter* (Aleem et al., 1957). This toxicity inhibits *Nitrobacter*, slowing conversion of NO_2^- to NO_3^-, and resulting in a temporary build-up of NO_2^-. At low pH microsites, NO_2^- is protonated to form nitrous acid (HNO_2) (pK_a=3.3), which can subsequently decompose in water to form NO and/or can nonenzymatically react with soil carbon to form N gasses (Stevenson, 1994). Even though the pH of the bulk soil may indicate that only low concentrations of HNO_2 should be found, localized zones of acidification due to nitrification may lead to optimal conditions for development of HNO_2. In studies with applied anhydrous ammonia, Venterea and Rolston (2000) have found that chemodenitrification can be a significant source of NO and N_2O even under aerobic conditions. However, the absolute amount of fertilizer N loss by this process may be relatively small (personal communication with Dennis Rolston).

In our study, several unaltered LW-amended soils had high NO_2-N concentrations relative to NH_4-N and NO_3-N at wk 1. Nitrite concentrations ranged from 0 to 42% of the wk 1 total inorganic N pool. The dairies that had had little or no detectable soil nitrite (Dairies 2, 5, and 7) were those with the lowest initial LW NH_4 concentrations, suggesting that a threshold LW NH_4 concentration must be exceeded before nitrite accumulation will occur. LW with low initial NH_4 concentrations (the threshold value was between 200-270 mg NH_4-N l^{-1} in this study) or that have been mixed with fresh water may not generate sufficient NO_2^- for abiotic denitrification to be significant. But, above that threshold, we observed a positive linear relationship between initial unaltered LW NH_4 concentrations and wk 1 NO_2^- concentrations ($n=5$, $R^2=0.92$, $p<0.05$). Because NO_2^- was only measured once, wk 1 nitrite concentrations may not represent the maximum nitrite concentrations reached either before or after wk 1. No nitrite was measured in SC LW-amended soils.

Although it is possible that both biotic and abiotic denitrification were occurring, we cannot quantify the contribution of each process to total N lost during the first 3 wks of the incubation. There was no significant relationship between DOC and N_{Loss} or day 7 nitrite and N_{Loss}, possibly indicating that neither process dominated.

Influence of Dissolved C and N on apparent net N Mineralization

The results of this study demonstrate the large influence that the dissolved C and N fraction has on apparent net N mineralization, as demonstrated by the great differences between the inorganic N produced in the unaltered lagoon water and the more concentrated lagoon water solids from which most of the dissolved C and N had been removed (SC LW) (Fig. 1). Apparent net N mineralization for the unaltered LW was lower, and more variable. Apparent net N mineralization for the SC LW treatments was relatively uniform (Table 3). These results suggest that the solid fraction (>0.3 µm) in lagoon waters from different dairies may behave similarly despite differences in the dairy manure collection and storage, cow diet, etc. If this is true, why is do we not also observe similar mineralization patterns with the unaltered LW?

The answer appears to be that the dissolved fraction is the controlling factor influencing apparent net N mineralization. As discussed above, denitrification (possibly both biotic and abiotic) apparently is significant. Others have shown that the magnitude of loss from both denitrification processes is dependent on the concentrations of DOC (Paul and Beauchamp, 1989) and nitrite (Venterea and Rolston, 2000) – and in our study, nitrite production was related to initial NH_4 concentrations). Therefore, we would expect that variability in LW dissolved C and N concentrations would result in variability in denitrification and therefore in apparent net N mineralization even though the solid fractions may be similar in composition. Once the influence of dissolved C and N had been removed, the SC LW all behaved similarly. Taking into account N_{loss} through denitrification, actual mineralization was 48% of added organic N (Table 3).

The large influence of the dissolved fraction on apparent net N mineralization may be unique to dilute liquid, anaerobic manures. Because solid and semi-solid manures typically have much higher concentrations of solid organic N and C, and lower relative concentrations of NH_4 and DOC, the influence of the dissolved fraction may be negligible on the overall N mineralization behavior of those materials. Our results on the influence of the dissolved C and N fraction might explain why published apparent net N mineralization results from laboratory soil incubation studies with liquid manure are so variable.

Conclusion

Our results suggest that when lagoon water is applied to soil undiluted, significant N losses through biotic and possibly abiotic denitrification can occur. If denitrification is ignored, lagoon waters in this study appeared to exhibit between 5-26% net mineralization by wk 9. When most of the dissolved C and N fraction was removed from these lagoon waters, the resulting solids exhibited between 41-51% apparent net mineralization by wk 9. These results indicate that the dissolved C and N fractions greatly influence the N mineralization behavior of lagoon water.

The results of this study should extrapolated to field situations with caution. Lagoon water is typically blended with irrigation water before application to fields. This dilution changes the composition of the lagoon water, possibly altering its mineralization behavior relative to undiluted material. For example, in our experiment, nitrite only formed when NH_4-N concentrations were >200 mg N l^{-1}. When dairy lagoon water is applied to soil without dilution (as in our laboratory experiments), nitrite may not form, and there may not be any N loss through chemodenitrification. Also the conditions in the laboratory do not represent the variability of the field environment. Despite these limitations, this research is valuable in demonstrating the possible conditions that may develop in the field.

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Table 1. Physical and chemical characteristics for the unaltered dairy lagoon waters used in this study

Dairy	1	2	3	4	5	6	7	Average
pH	7.6	7.9	7.5	7.3	8.2	8.2	7.2	7.7
EC (mS cm^{-1})	10.9	4.2	7.8	7.8	5.7	6.9	0.0	6.2
TS (g l^{-1})	10.2	3.0	7.7	6.1	4.0	5.8	22.9	8.5
TSS (g l^{-1})	3.4	0.8	2.8	1.6	0.7	2.2	21.1	4.7
TKN (mg N l^{-1})	1011	315	765	729	406	633	811	667
NH4-N (mg N l^{-1})	603	196	441	484	271	356	165	360
Dissolved Org N (mg N l^{-1})	150	24	116	92	60	122	46	87
TSS-N (mg N l^{-1})	227	74	183	120	54	142	579	197
Total C (mg C l^{-1})*	3577	1081	2662	2246	1195	1952	8432	3021
Dissolved Org C (mg C l^{-1})	540	160	290	430	220	270	250	309
TSS-C (mg C l^{-1})	1817	441	1342	896	385	952	7632	1924
Total C:TKN	3.5	3.4	3.5	3.1	2.9	3.1	10.4	4.5
Total C:Org N	8.8	9.1	8.2	9.1	8.9	7.0	13.1	9.8
TSS-C:TSS-N	8.0	6.0	7.3	7.5	7.1	6.7	13.2	8.0
Particle size <28 µm and >0.3 µm (% of TSS)	87	98	82	94	100	98	43	86

*** Total C was calculated by adding total suspended solid C (TSS-C) and total dissolved C (TDC)**

Table 2. Physical and chemical characteristics for the solids-concentrated (SC) lagoon waters used in this study

Dairy	1	2	3	4	5	6	Average
pH	7.8	6.7	7.6	7.6	6.7	7.1	7.3
EC (mS/cm)	1.7	0.8	1.2	1.5	1.0	1.7	1.3
TSS (g l^{-1})	28.8	5.5	25.6	13.6	7.7	17.0	16.4
Total N* (mg N l^{-1})	1650	432	1445	941	569	1191	1038
NH4-N (mg N l^{-1})	54	5	22	36	17	19	25
Dissolved Org N (mg N l^{-1})	17	2	13	18	15	19	14
TSS-N (mg N l^{-1})	1579	425	1411	887	537	1153	999
Total C** (mg C l^{-1})	12085	2526	10216	6647	3892	7379	7124
TSS-C (mg C l^{-1})	12011	2499	10164	6567	3843	7335	7070
Dissolved Org C (mg C l^{-1})	74	27	52	80	49	44	54
TSS-C:TSS-N	7.6	5.9	7.2	7.4	7.2	6.4	6.9

*** Total N = NH4-N +DON +TSS-N**

**** Total C = TSS-C + DOC**

Table 3. Apparent net N mineralization after a 9 wk aerobic soil incubation, N_{Loss} after a 3 wk aerobic soil incubation, and calculated actual N mineralized for unaltered and solid-concentrated (SC) dairy lagoon water. Values represent the mean and SE (n=3).

	Total N added		Apparent Net N mineralized		N_{Loss}*	Actual N mineralized**
	Unaltered	SC	Unaltered	SC	Unaltered	Unaltered
Dairy	mg N kg^{-1} soil		% of organic N added		% (SE)	% of organic N added
1	126	206	5	41	29 (3)	48
2	39	54	26	51	10 (8)	43
3	96	181	14	43	30 (1)	52
4	91	118	9	48	33 (1)	73
5	51	71	20	41	6 (2)	31
6	79	149	19	44	33 (2)	61
7	101	NA	24	NA	20 (5)	29
Mean (SE)	-	-	17 (3)	45 (2)	23 (4)	48 (6)

* N_{Loss} calculated using Eq. 1

** Calculated by adding apparent net N mineralization for the Unaltered LW with N_{Loss}.

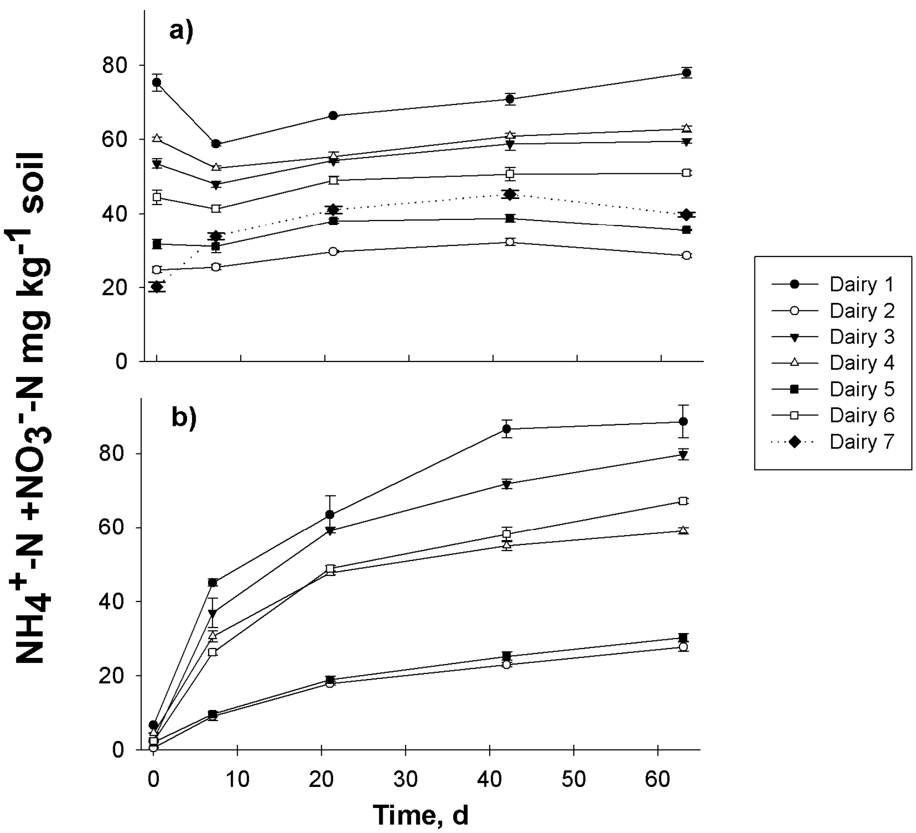

Figure 1. Inorganic N (NO_3-N + NH_4-N) accumulation during a 63 day aerobic soil-sand incubation from a) Unaltered and b) Solids-concentrated (SC) lagoon waters. Inorganic N from the soil-only control has been subtracted. The error bars represent the standard error of 3 replicates

SSLAP: A Steady-State Land Application Program

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Abstract

For land application practices to be sustainable, they must consider management strategies over both short- and long-terms. This paper presents a model, called SSLAP, for optimally scheduling land application rates once a system has approached steady state. The model includes a daily time-step and up to five different fertilizers can be considered simultaneously. Mineralization is represented using first-order decay models and temporary immobilization can also be considered. To use the model a grower identifies crops, planting dates, harvest dates, harvested nitrogen (N), fertilizer qualities, and possible application dates. Local climate data are used to modify crop development patterns and soil organic N mineralization rates. The model calculates daily crops needs and optimal application rates needed to meet crop demand while minimizing losses. Losses are controlled by reducing the amount of inorganic N present in the soil at times where leaching or denitrification is likely. Because the model is linear, solutions can be found rapidly and accurately using the simplex method. SSLAP has been programmed using Microsoft Excel 2007 and a preliminary version is available for optimizing dairy manure applications to forages. Future versions will be expanded to consider other organic fertilizers and crops.

Introduction

Land application rates for organic fertilizers should be designed to supply crops with the nitrogen (N) they need while minimizing negative impacts on groundwater. Water quality regulations will soon strongly encourage California's Central Valley dairies to limit N applications to 1.4 times crop N removal rates. Because some N losses due to leaching or denitrification are inevitable, farmers may find themselves challenged to supply crops with the nutrients they need while respecting this N supply:removal ratio. In-season application guidance is needed.

Plans for managing organic N are typically based on decay series, or similar crude approximations of the mineralization process. Nitrogen release rates from such series are usually tabulated on an annual basis making it difficult to coordinate N availability with changing crop demands (Pang and Letey 2000). Crohn (2006) presented a model for timing application rates throughout the year so that they meet crop needs while minimizing losses. Optimization proved feasible for organic systems. Even if the strategy is not adopted strictly, since operations do vary from year to year, the concepts that emerge by considering steady state inform farmers interested in sustainable solutions. This early model has been revised and expanded for consideration of a wide set of California conditions.

Model development

Organic N forms must mineralize to ammonium before they are significantly available to plants (Jones et al., 2005). Mineralization rates are affected by temperatures, moisture conditions, and the properties of the fertilizer (Beraud et al., 2005; Flavel, and Murphy, 2006; Hadas, et al. 2004; Hartz and Johnstone, 2006; Leirós et al. 1999), though moisture effects are difficult to predict (Agehara and Warncke, 2005). Over time, soils receiving organic amendments and fertilizers consistently will accumulate N until they reach an approximately steady-state condition. Upon reaching steady-state, the N mineralized annually will equal the amount added and the N will become available according to a predictable pattern. The time required for a newly amended field to approach steady-state is just a few years when moderate-release fertilizers are applied. Previously amended fields require still less time (Crohn, 2006). Crohn (2006) described an approach for optimizing dairy manure application schedules under steady-state conditions. Because the equations in the design model are linear, the system could be solved quickly and reliably with linear programming. SSLAP generalizes Crohn (2006) for cases where several different organic amendments are used during the course of a year. The revised model uses a daily times step and estimates denitrification and leaching losses. The model has been implemented for dairy forages systems but efforts are under way to expand it for use with organic agriculture systems.

To apply the model, a farmer identifies potential application dates, crop planting and harvest dates, and expected yields. A logistic relationship is used to model crop N demand as a function of growing degree-days and to set plant-available N (PAN) targets. It is also possible to select PAN targets manually. Estimates of the fertilizer N content, N inorganic-organic partitioning, and an expected mineralization rate are also needed. If a multiple compartment mineralization model is used, mineralization rates and partition fraction information are needed for each compartment. The model also depends on soil temperature information to modify mineralization rates using the Arrhenius relationship (Crohn and Valenzuela-Solano, 2003). It assumes that soils are irrigated during dry months when low soil moisture levels are most likely to constrain mineralization. Freeze-thaw and drying-rewetting effects are not considered by the model. The system is assumed to be at steady state in the sense that soil organic N derived from the organic fertilizer varies seasonally, but not from year-to-year.

Model Description

Nitrogen mineralization from applied organic fertilizers is widely represented as a first-order process (Fortuna et al. 2003, Gilmour et al. 2003). Decomposition and mineralization are modeled using two compartments, one to represent labile materials and the other to include recalcitrant compounds (Benbi and Richter, 2002; Valenzuela-Solano and Crohn, 2006; Wang et al. 2004). SSLAP permits up to five different organic or conventional fertilizers to be used within a single management plan.

Temperature effects are included by modifying time according to the Arrhenius equation, using an approach described in Crohn and Valenzuela-Solano (2003) and in Crohn (2006). This approach, called temperature-adjusted time (TAT), is analogous to using growing degree-days, but the Arrhenius relationship has a stronger foundation in biochemistry. TAT, or $t°$, has an SI unit of d but is given a more informative unit here of d° to indicate days adjusted for temperature (Crohn and Valenzuela-Solano, 2003). It is determined numerically by summing TAT across defined intervals, *i*,

$$t° = \sum_{\hat{t}_i < t} Q_{10}^{\left(1+\frac{T_r}{10}\right)\left(1-\frac{T_r}{T_i}\right)} \left(\hat{t}_{i+1} - \hat{t}_i\right), \qquad \text{i)}$$

where t_i is the interval i start time, T_i (K) is the mean soil temperature during that interval, T_r (K) is a reference temperature (here T_r = 298.15 K, or 25°C), and Q_{10} is the relative proportion by which k_r increases after a 10 K temperature increase from the reference temperature $(Q_{10} = k_{T_r+10}/k_{T_r})$. Experimental determinations of this popular parameter vary, but a frequent assumption is that $Q_{10} \approx 2$. (Andrén and Paustian, 1986; Lloyd and Taylor, 1994).
The mineralization of any material, m, during a given interval, i, is determined as a first order process in terms of soil TAT,

$$S_{i+1,m} = S_i\left[P_m e^{-k_{L,m}\left(t^\circ_{i-1}-t^\circ_i\right)} + \left(1-P_m\right)e^{-k_{R,m}\left(t^\circ_{i-1}-t^\circ_i\right)}\right], \qquad \text{ii)}$$

where $S_{i,m}$ (kg ha^{-1}) is the material m organic N at the beginning of interval i, P_m identifies the labile fraction of material m, and $k_{L,m}$ and $k_{R,m}$ (d$^{\circ-1}$) are the respective decay rates derived in terms of TAT for the labile and recalcitrant compartments, respectively. In general, $0 \le P_m \le 1$, but immobilization can be represented by setting $P_m \ge 1$. Use of TAT both keeps the decay rates constant throughout the year and permits the same value to be used in different climates. Organic fertilizer and amendments can be represented using one or two compartments. Crohn (2006) gave a simple formula for determining the temperature-adjusted years to approach steady state and showed that state-state conditions were approached within 2 to 8 years, depending on the half-life of the manure organic N.

Crop N Demand

Crop demand is predicted using a logistic expression based on growing degree-days which is indicated using growing degree-days (DD). Its form is

$$C_t = C\left\{1-\left[\frac{D+e^{BM}}{D+e^{B\left(M-t+t_P\right)}}\right]^D\right\}\left\{1-\left[\frac{D+e^{BM}}{D+e^{B\left(M-t_H\right)}}\right]^D\right\}^{-1}, \qquad \text{iii)}$$

where C (kg ha^{-1}) is the ultimate crop N uptake, t (DD) is time, t_P (DD) is the crop planting time, t_H (DD) is the crop harvest time since planting, and M (DD) locates the time of maximum crop uptake all in degree-days (Crohn 2006). The parameters D and B (DD^{-1}) are shape factors. Degree-days are used because they are a standard approach for tracking crop development. Crohn and Campbell-Mathews (2006) parameterized this curve for small grains. Local conditions are represented by different values of C, the amount of N harvested with the crop, and t_H, the number of GDD between planting and harvest. Although these crops develop differently, we found a single equation that adequately described N uptake by all grain crops when adjusted for local conditions using harvest time and yield N information along with local GDD data. N removal rates begin slowly, accelerate, and the decrease late in the season. Late season slowing may not be apparent if the crop is harvested before slowing is significant. SSLAP uses a parameterization that varies the peak N uptake (M) parameter for different cultivars according to whether it occurs early, mid, or late season. A similar, but more complex formula was also developed for forage corn using data reported by Karlen et al. (1987).

Optimization Algorithm

The Crohn (2006) model was designed to represent flood irrigated crops fertilized with dairy lagoon water. It divides the year into n planning periods and fertilization can only occur at the beginning of a planning period, j. The linear model schedules fertilizer N applications, A_j (kg ha^{-1}), so that target crop N demand for the same planning period, C_j (kg ha^{-1}, is assured. It depends on the user to predetermine application times, but solutions assign 0 kg ha^{-1} application rates when applications are not needed. Because of the enormous leaching potential associated with each irrigation event, no sharing is permitted between different planning periods. Denitrification losses were not emphasized in the model since field studies had shown such losses to be minor (Harter et al., 2002). The Crohn (2006) linear optimization model was expressed as,

$$\text{Min}\sum_{j=1}^{n} A_j \qquad \text{iv)}$$

$$A_j\left(1-a_j\right)\left(1-v_j\right)+\left(e^{kt_f}\sum_{i=1}^{j}A_i a_i e^{kt_i}+\sum_{i=j+1}^{n}A_i a_i e^{kt_i}\right)\frac{e^{-kt_j}-e^{-kt_{j+1}}}{e^{kt_f}-1}\geq C_j;\forall j$$

$$A_j \geq 0;\forall j$$

where k (d$^{\circ -1}$) is the lagoon water organic N mineralization rate, i and j represent specific planning periods initiating at times t_i and t_j (d°). Additional parameters include v_j, the fraction of fertilizer ammonia volatilized during application, a_j, the fraction of fertilizer N that is organic. The revised model is more sophisticated and incorporates a number of significant improvements that dramatically extends its applicability. The revisions allow simultaneous consideration of up to five fertilizer types. Inorganic N can now be more meaningfully conserved from on planning period to the next. In addition, two new parameters have been added to incorporate leaching and denitrification losses. The revision has the form,

$$\text{Min}\sum_{\forall j,m} A_{j,m} \qquad \text{v)}$$

$$N_{j,m}=A_{j,m}\left(1-a_{j,m}\right)\left(1-v_{j,m}\right)+P_m\left[e^{k_{L,m}t_f}\sum_{i=1}^{j}A_{i,m}a_{i,m}e^{k_{L,m}t_i}+\sum_{i=j+1}^{n}A_{i,m}a_{i,m}e^{k_{L,m}t_i}\right]\frac{e^{-k_{L,m}t_j}-e^{-k_{L,m}t_{j+1}}}{e^{k_L t_f}-1}+\ldots$$

$$\ldots\left(1-P_m\right)\left[e^{k_{R,m}t_f}\sum_{i=1}^{j}A_{i,m}a_{i,m}e^{k_{R,m}t_i}+\sum_{i=j+1}^{n}A_{i,m}a_{i,m}e^{k_{R,m}t_i}\right]\frac{e^{-k_{R,m}t_j}-e^{-k_{R,m}t_{j+1}}}{e^{k_{R,m}t_f}-1};\forall j$$

$$N_j+\left(1-q_{j-1}\right)\left(1-d_{j-1}\right)N_{j-1}-C_{j-1}\geq C_j;\forall j$$

$$A_{j,m}\geq 0;\forall j,m.$$

To allow applications of different kinds of fertilizers, the revised model adds a compartment subscript, m, to a number of the model parameters and variables, including $A_{j,m}$, $a_{j,m}$, $v_{j,m}$. Mineralization is now represented as a two compartment model. A new dependent variable, $N_{j,m}$, represents the total PAN derived during a given interval, j, from organic N mineralization from each of the organic fertilizers as well as from any applied inorganic fertilizer N.

SSLAP uses a daily time step to represent crop N demand, N mineralization, and losses. Losses include leaching, denitrification, and ammonia volatilization. Half of the initial ammonia contained in applied manures is assumed to volatilize from surface applications that are disked into the soil. There are no volatilization losses when liquid manures are applied in surface irrigation water or are injected Crohn (1996). Denitrification occurs for four days following each irrigation or precipitation event. Denitrification rates were calibrated to be consistent with Meisinger and Randall (1991) who simulated denitrification losses from Central Valley soils.

Denitrification rates are a function of the drainage class of the amended field. Leaching losses from the soil inorganic N pool are assumed to be proportional to the leaching fraction of applied irrigations. Precipitation events do not trigger leaching. Pre-irrigation leaches all soil inorganic N. The algorithm requires at least one pre-irrigation event to avoid a circular reference error. In the future, denitrification and leaching parameters will be derived using computer simulations. Several models for simulating soil and plant processes are available. The most widely used of these is NCSOIL (Nicolardot and Molina 1994). A locally derived alternative is ENVIRON-GRO (Feng et al. 2005). More recent European models targeted at organic agriculture include NDICEA and DNDC. DNDC was constructed with two components, one based on ecological drivers (e.g., climate, soil, vegetation, and anthropogenic activity) and a second to predict gas fluxes based on the soil environment (Brown et al. 2002). DNDC has been applied to diverse agroecosystems for predicting crop growth, soil temperature and moisture regimes, soil C dynamics, nitrate leaching, and trace gases emissions, including C and N contents in arid wheat production in China (Li et al. 2001) and the production of N_2O by agriculture in the UK and China. NDICEA was developed in the Netherlands specifically for use in organic systems as a research and management tool (Koopmans and Bokhorst 2002, Kroeze et al. 2003). NDICEA includes four key modules: water, organic matter, and N balances, and crop growth (Kroeze et al. 2003), and accounts for mineralization activity. We will review the available models to select the one that can be most effectively modified so that data on N losses due to leaching and denitrification may be considered separately. Monte-Carlo simulations using data corresponding to four to eight representative organically fertilized California agricultural systems will then be supplied to the programs in long-term simulations. From the resulting output we will note the amount of soil inorganic N present for each day of the year as well as corresponding denitrification and leaching losses. Mean daily loss rates for both denitrification and leaching will then be calculated as the ratio of the losses to the inorganic N present for each day. The influence of irrigation events will be studied so that weighting factors can be considered for controllable events. Values will be compared to the literature and either the resulting time-series or functional representations of the time series will then be used with the revised model.

Using SSLAP

The algorithm requires daily high and low temperature data as well as soil temperature information. The corresponding author will assist users in obtaining appropriate data for specific locations. All other information is conveniently entered into a single page with Microsoft Excel 2007. Earlier versions of Excel are not supported. Requested data include:

Soil Drainage Class: This soil classification is used to modify denitrification rates, which the conversion of soil nitrate-N to gaseous forms by microbes under low-oxygen conditions. Denitrification happens during a four day period following rain and irrigation events. The process is accelerated under warm conditions.

Irrigation Leaching Fraction: This is the fraction of applied water that moves below the root zone. This value affects nitrogen leaching losses.

Crop Descriptions: Rotations of up to three crops per year may be included. Currently supported crop types include silage corn, small grains, and Sudan grass. Small grains are broken down into early, mid, and late season peak N uptake patterns. Planting and harvest dates are entered directly. A calendar for specifying fertilizer application, irrigation, and representative precipitation dates is then generated starting with the month in which the first crop is planted. Harvested N is entered as the amount of N removed with the crop in pounds per acre.

Fertilizer Descriptions: The optimizer allows consideration of up to five different types of materials simultaneously. Users first invent names for each material. Mineralization patterns are then selected from a list of ten possibilities. Any inorganic N (ammonium or nitrate) contained in a material is immediately plant available. The fraction of the material's total N that is organic is therefore entered in a Day 0 box. The release pattern for each fertilizer "Type" is then displayed for 0, 30, 90, and 365 days following application. (Note that this is different that the inorganic N content which is the amount of inorganic N divided by the material's mass.) Release rates are adjusted for different initial inorganic N amounts and for the heat associated with different application dates. Entering 100% in the Day 0 box for any type represents a conventional fertilizer. Each material is also assigned an application technique which in turn determines the fraction of inorganic N lost through volatilization during land application. Losses are assumed to be 0% for surface irrigation, injection, and not manure, 50% for spray irrigation and spread and till, and 100% for spread no-till. Annual availability limits can also be entered for each material.
Irrigation/Material Application Auto-Scheduler: Irrigation start and stop dates are entered along with an application interval. Users can specify particular fertilizer materials that can be applied during each irrigation event. Irrigation/Material Application dates do not necessarily need to correspond to the crop planting and harvest dates, though in most cases they will. Watering intervals are between 1 and 30 days. Watering can refer to irrigation with fertilizer, irrigation alone, or precipitation alone. Users can select "never" to shut down watering. Denitrification occurs for all watering events, but leaching is limited to irrigations.
Calendar: Crop rotation and auto-scheduler events appear in a calendar that fills the majority of the input screen. Users can add additional irrigation, pre-irrigation, fertilization, and precipitation events directly into the calendar. Specific auto-scheduled events can also be suppressed using this tool. The calendar uses a conventional monthly format.

Example

Figure 1 describes a small grain - silage corn rotation. Note that all tables and figures shown in this paper were taken directly from the model input and output screens. The system is located on a well-drained soil and the irrigation leaching fraction is 20 percent. Between October 25 and March 5, precipitation is expected every 25 days. Corn is irrigated along with lagoon water from May 18 through August 14. Additional irrigation events are entered on the calendar (Figure 2) including manually entered irrigation events with material 2 (North Lagoon) on January 16 and March 19. Pre-irrigation events were also entered manually for October 17 and April 20. Table 1 shows the result summary for this plan. The ratio of N application to removal is 1.95, far above the regulatory limit. Inspection of N accumulation in the soil (Figure 3) suggests that much of the losses are due to leaching. Nitrogen accumulated because the algorithm assigned a 497 lb/ac application of lagoon water on October 5 in order to supply the small grain with early season nutrients (design application schedule not shown). The "Intentional leaching" value refers to pre-irrigation systems intended to remove salts from the soil. Such leaching will not be intended in many areas and this term may be revised in the future.
A reasonable alternative would be to instead apply solid manure since this material contains negligible inorganic N and will mineralize gradually over time. Table 2 shows the result summary when solid manure is supplied on October 23, just prior to the small grain planting. A design rate of 172 lb/ac results in a regulatory ratio of 1.34. Table 3 presents the application design schedule associated with this plan.

An additional strategy might include reducing the intensity of the pre-irrigation to standard irrigation levels. This further lowers the regulatory ratio to 1.28 by dropping the "intentional" leaching rate from 39 to 8 lb/ac (Table 4). An additional measure might be to triple crop with Sudan grass. That alternative reduces the regulatory N supply ratio to a very efficient 1.18. With Sudan grass, the solution calls for the application of 129 lb/ac of dry manure (Table 5).
Use of dry manure is desirable because solids that accumulate are difficult to apply while crops are growing. A possible risk, however, is that solids may temporarily immobilize N rather than mineralizing this vital nutrient. Though most manures are not expected to immobilize N, it does happen and immobilization by solid manures remains difficult to predict. Immobilization makes dry manure use sub-optimal in the scenarios considered here. If the dry manure mineralization rate is re-parameterized for the triple crop case so that it immobilizes an additional 4 percent of its initial organic N, peaking 20 days after addition in TAT, the algorithm rejects this material altogether (Table 6).

Conclusions

SSLAP is currently both an educational and a practical tool for assisting in the design of landspreading programs to meet regulatory restrictions. It will continue to improve as its denitrification and leaching components come into focus. It will also be expanded for use with certified organic agricultural systems. Copies are available from the first author.

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Table 1. Model result summary for two intensive pre-irrigation events, two crops, and no solid manure.

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
East Lagoon total:	275	**Total crop N removal:**	442
North Lagoon total:	588	**Intentional leaching:**	268
Lagoon Bottom total:	0	**Leaching with irrigation:**	50
Solid Manure total:	0	**Total leaching:**	318
Conventional total:	0	**Denitrification losses:**	103
All applied N:	863	**Volatilization losses:**	0
		Regulatory N supply ratio:	1.95

Table 2. Model result summary with two intensive pre-irrigation events, two crops, and solid manure added on October 23, just prior to planting the small grain.

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
total:	304	**Total crop N removal:**	442
total:	114	**Intentional leaching:**	39
total:	0	**Leaching with irrigation:**	41
total:	172	**Total leaching:**	80
total:	0	**Denitrification losses:**	69
All applied N:	591	**Volatilization losses:**	0
		Regulatory N supply ratio:	1.34

Table 3. Optimal application schedule for two intensive pre-irrigation events, two crops, and solid manure added on October 23, just prior to planting the small grain.

Date	Water	Material	N (lb/ac)
Oct. 23, 2009		Solid Manure	172(4)
Jan. 16, 2010	Irrigation	North Lagoon	88(2)
Mar. 19, 2010	Irrigation	North Lagoon	26(2)
Jun. 14, 2010	Irrigation	East Lagoon	10(1)
Jun. 23, 2010	Irrigation	East Lagoon	123(1)
Jul. 2, 2010	Irrigation	East Lagoon	110(1)
Jul. 11, 2010	Irrigation	East Lagoon	3(1)
Aug. 7, 2010	Irrigation	East Lagoon	58(1)

Table 4. Model output with just one intensive pre-irrigation event, two crops, and solid manure.

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
total:	323	**Total crop N removal:**	442
total:	131	**Intentional leaching:**	8
total:	0	**Leaching with irrigation:**	40
total:	110	**Total leaching:**	48
total:	0	**Denitrification losses:**	73
All applied N:	564	**Volatilization losses:**	0
		Regulatory N supply ratio:	1.28

Table 5. Model output with just one intensive pre-irrigation event, solid manure, and three crops including Sudan grass.

Nitrogen Schedule Result Summary

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
total:	301	**Total crop N removal:**	542
total:	212	**Intentional leaching:**	10
total:	0	**Leaching with irrigation:**	27
total:	129	**Total leaching:**	37
total:	0	**Denitrification losses:**	63
All applied N:	642	**Volatilization losses:**	0
		Regulatory N supply ratio:	1.18

Table 6. Model output with just one intensive pre-irrigation event, three crops, but where solid manure briefly immobilizes N

N Application Summary (lb/ac)		N Fate Summary (lb/ac)	
total:	322	**Total crop N removal:**	542
total:	335	**Intentional leaching:**	8
total:	0	**Leaching with irrigation:**	29
total:	0	**Total leaching:**	38
total:	0	**Denitrification losses:**	77
All applied N:	657	**Volatilization losses:**	0
		Regulatory N supply ratio:	1.21

Soil drainage class: Well drained

Irrigation leaching fraction: 20%

Crop Descriptions

	Crop 1	Crop 2	Crop 3
Crop type:	Mid Small Grain	Silage Corn	None
Planting date:	Oct. 24, 2009	May. 1, 2010	Aug. 26, 2010
Harvest date:	Apr. 8, 2010	Aug. 21, 2010	Oct. 14, 2010
Harvested N (lb/ac):	165	277	100 (No N uptake)

Irrigation/Material Application Auto-Scheduler

	Crop 1	Crop 2	Crop 3
Irrigation/Land Ap.	**Early Small Grain**	**Silage Corn**	**None**
Start date:	Oct. 25, 2009	May. 18, 2010	Aug. 26, 2010
Stop date:	Mar. 5, 2010	Aug. 14, 2010	Oct. 7, 2010
Watering interval (d)	25 days	9 days	10 days
Applied Material:	Precipitation only	East Lagoon	North Lagoon

Fertilizer Descriptions

	Material 1	Material 2	Material 3	Material 4	Material 5
Material identifier:	East Lagoon	North Lagoon	Lagoon Bottom	Solid Manure	Conventional
Days	Type 2	Type 3	Type 4	Type 8	Type 2
0	60%	50%	40%	0%	100%
30	65%	53%	54%	11%	100%
90	70%	56%	55%	18%	100%
365	86%	75%	61%	32%	100%
Annual applicaton #:	11	7	0	1	1
Annual application limit:	1000 lb/ac	1000 lb/ac	1000 lb/ac	1000 lb/ac	1000 lb/ac
Application technique:	Spray irrigation	Spray irrigation	Spray irrigation	Spread no-till	Spray irrigation

Figure 1. Main data entry elements.

January 2010

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
					<<1>>	<<1>>
3	4	5	6	7	8	9
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
10	11	12	13	14	15	**I 16**
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	**2 69(2)**
17	18	19	20	21	22	23
<<1>>	<<w>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
24	25	26	27	28	29	30
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
31						
<<1>>						

March 2010

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
7	8	9	10	11	12	13
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
14	15	16	17	18	**I 19**	20
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	**2 18(2)**	<<1>>
21	22	23	24	25	26	27
<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>	<<1>>
28	29	30	31			
<<1>>	<<1>>	<<1>>	<<1>>			

Figure 2. Example of the calendar entry including manually entered irrigation events with material 2 (North Lagoon) on January 16 and March 19. The “<<1>>” symbols represent that crop 1 is growing at this time. On January 16, the solution suggests an application of 69 lb/ac of material 2. Only 18 lb/ac are suggested for March 19. Screen appearance includes color codes to assist in data entry.

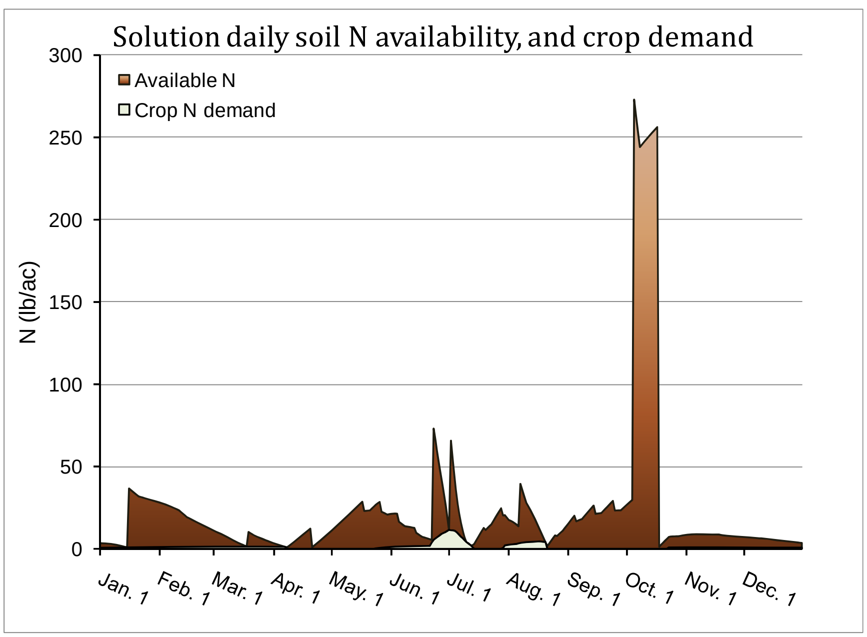

Figure 3. Soil N content and crop N demand over time. The October drop is due to an intense leaching event.

2009 Poster Abstracts

Chair:

Ben Faber
UCCE, Ventura County

POSTER SUBMISSION

Title of Paper:	**Grazing Effects on Plant Communities of the San Joaquin Experimental Range**
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ABSTRACT:

This study originated as a “Team Project” for our Range Ecology and Management course (Spring 2008) at Fresno State. The range course fulfills the Natural Resources component of the California Teacher’s Curriculum requirements. The San Joaquin Experimental Range (SJER) has been in operation since 1938 as a major research site for range management of California’s oak/grassland savanna ecosystem. The station is jointly managed by the US Forest Service, UC Davis, and CSU Fresno. Fresno State manages the cattle on the station for livestock research and educational activities. The objective of our project was to identify, inventory, and compare the types of plant vegetation present in grazed verses non-grazed areas of the SJER. Controlled (ungrazed) areas have been maintained since 1938 along with other areas that are grazed annually. Line transects were conducted to collect data from the grazed and nongrazed areas. Plant classes were divided into grasses, forbes, filaree, legumes and no growth areas. Transect data was extrapolated to represent plant percentages for each range condition. Our results show that in the ungrazed-natural area, grasses were the more dominant plant species. The other plant groups were very low compared to the dominant grass population. In the grazed area, grasses were still the dominant plant species, but the other groups were more prevalent. The differences were not as great between the plant groups in this system. Our conclusion is that grazing annual grasslands increased the plant diversity in these oak savanna systems. We encourage next year’s range class to conduct additional inventories to confirm our initial findings. Also, to identify the species of the major plant groups used in our study.

POSTER SUBMISSION

Title of Paper:	**Controlling Burning Nettle in a Permanent Pasture**
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ABSTRACT:

This study was a "Team Project" for our Range Ecology and Management course (Spring 2008) at Fresno State. We chose to address a problem in the irrigated pastures on the CSU Fresno College Farm. Burning Nettle (Urtica urens) is a problem weed affecting the grazing potential and feed quality of the sheep pastures. Our intent was to combine knowledge gained in Weed Science and Range Ecology to solve this weed problem. We wanted to implement an intergraded approach that included chemical and mechanical control measures. Four plots were identified with large plants (12-18 inches) and plots with new growth (2-8 inches) plus one mowed plot to evaluate chemical treatments on regrowth. Chemical treatments were combinations of: 2,4-D plus Roundup or Milestone, Milestone plus Roundup, and Shark plus Benuel. Chemical treatments were applied using a backpack CO2 sprayer. Visual evaluations were made on 3, 5, 7, and 21 days post application (DPA) for efficacy and regrowth. Treatments were not replicated. Results represent our effort to identify the most effective treatment as indicated by rapid or longer control. 2,4-D + Milestone and Shark + Banuel provided good control of small plants and was safe on the surrounding grass. The Round-up combinations were harder on the grasses but provided good control of small plants with 2,4-D, while Milestone + Round-up provided better control on larger nettle. With heavy infestations a three-way combination of Shark, Banuel and Milestone provided good control. Burning nettle starts growing sooner than the pasture grass so mowing the nettle allowed greater competitive growth of the grass. Early mowing is one option to help off-set the competitive growth of burning nettle in permanent pastures.

POSTER SUBMISSION

Title of Paper:	**Plant Science Club at Fresno State**
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ABSTRACT:

The goal of the California State University, Fresno Plant Science Club is to promote communication and involvement among students in the varied disciplines of plant and soil science. It encourages students to participate in extracurricular activities and scholarship programs, such as ASA activities, Golden Opportunity Scholarships, and Students of Agronomy, Soils, and Environmental Sciences (SASES). It is also committed to the goal of promoting public awareness of agriculture and actively supports the Plant Science Department's student recruitments through State FFA Field Day activities.

It is the belief of the organization that these goals will help to provide opportunities for growth, leadership, and academic success among plant science and other agriculture students. These goals will be achieved through regular meetings, guest speakers, professional meetings, and field trips and a supportive and casual atmosphere where fellowship is a priority. The Plant Science club will provide a framework for special interest groups, such as the Ornamental Horticulture Club, Students for Environmentally Sustainable Agriculture, and the Bee Club. An additional goal would be to network with other colleges through SASES and form bonds with other students nationwide

POSTER SUBMISSION

Title of Paper:	**Comparisons of Cotton Yield Monitor with Actual Field Measurements**
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ABSTRACT:

Obtaining cotton yield data from field research trials is becoming more difficult due to the changes in modern harvest equipment. New module builders, equipped with extenders make older weigh scales obsolete. Also, the next generation of harvesters with self-moduling capacity will no longer use conventional unloading systems necessary for smaller loads. The on-board yield monitor (YM) is one viable option of harvesting research plots using any size equipment. A comparison was made using an Ag Leader (PF3000) cotton yield monitor with actual scale weights from a replicated field trial conducted on Fresno State's College Farm in 2008. Results of statistical analysis of both measurements will be presented. The objective of this study was to test if different conclusions are drawn from the YM data compared to the field scale measurements. In addition to replicated plot harvests, gross weights from larger areas will also be compared. The first analysis of gross totals from 34 individual four row plots differed by 3.7 percent (25603 lb and 24656 lb for scale and YM weights, respectively). The replicated plots are still being analyzed for statistical differences and final interpretation of treatment results. Our challenge is to understand and explain variations observed between weights. In some field applications, relative yield differences between treatments are just as useful as exact plot values. However, yield monitoring will only be applicable if reliable and accurate data is obtained. This activity is part of an independent study project conducted on the University Agriculture Laboratory (College Farm) at Fresno State. Gaining experience in GPS, monitoring technology, statistical analysis and applied research is beneficial to producing top graduates ready to enter the current job market.

POSTER SUBMISSION

Title of Paper:	**Control of Cavity Spot using Ridomil, Reason and Prophyt**
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ABSTRACT:

Cavity spot is an important disease of fresh market carrots. Symptoms are cosmetic blemishes that may result in significantly reduced marketability. In California, cavity spot is caused by Pythium violae, P. ultimum, P. sulcatum and P. irregulare. Until recently Ridomil Gold (mefanoxam) was the sole chemical registered for cavity spot in carrot. A trial was conducted at a cavity spot disease nursery at Califronai State University, Fresno to evaluate the effectiveness of alternating Ridomil Gold, Resaon (fenamidone) and Prophyt (potassium phosphate) using various fungicide application schedules. Six treatments, plus an untreated control were examined for disease incidence. Two of the treatments alternated between Ridomil gold and Reason, and two alternated between Ridomil Gold and Prophyt. The other treatments were Ridomil Gold and Prophyt alone. Treatments that included Prophyt were not significantly different than the untreated control. All other treatments had significantly lower incidence than the untreated control. Fuungicide3 programs with alternation between Ridomil Gold and Reason control cavity spot as well as Ridomil Gold treatments.

POSTER SUBMISSION

Title of Paper:	**A Peat Alternative in our Own Backyard - Composted Dairy Manure as an Environmentally Sound Media Component for the California Container Nursery Industry**
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ABSTRACT:
The California nursery industry ranks number one in the US with a production value of $3.89 billion and sales exceeding $12 billion in 2006-07. This industry relies almost exclusively on media mixes of various organic/inorganic components and not native soils for container production. The primary organic components are ground bark (fir, redwood etc.) and sphagnum peat. Although bark is widely used, it possesses a relatively high C:N ratio and often must be composted to remove phytotoxic compounds (phenols, tannins and resins etc.). Although peat has many desirable traits (e.g. high water holding capacity, good CEC etc.) it is expensive and current harvesting methods/rates have brought into question its environmental impact. In an effort to utilize more sustainable media components, many container nurseries are attempting to incorporate various composted materials into their mixes. Unfortunately, the lack of uniformity and even the occasional presence of disease or weed seed in many of these peat substitutes is often a problem. The objective of this study was to compare common nursery plant performance when grown in common media formulations and a dairy manure composted with proprietary in-vessel accelerated compositing technology. The successful incorporation of this composted manure into the California container nursery industry will 1) reduce our dependence on harvested peat and 2) significantly reduce the solid waste stream from California dairies. For this study, seed germination rate/percentage, days to flowering, final height/dry weight from common Marigold (Tagetes sp.) and Bell Pepper (Capsicum sp.) grown under the following media formulations: 1) Coir, 2) Composted Manure, 3) Peat, 4) Bark/Coir 5) Bark/Composted Manure, 6) Bark/Perlite/Composted Manure and 7) Bark/Perlite/Coir during a typical eight week greenhouse production cycle will be presented.

POSTER SUBMISSION

Title of Paper: **An Evaluation of Controlling Tomato Pests with a Thermal Device**

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ABSTRACT:

Due to increasing concerns regarding pesticide use and their effect on human health and the environment, there is a need for safer and greener technology in the area of pest management. Thermal pest control is a low tech approach proven to work in both urban and packing house settings, but not on field crops. The device being tested is the Lazo TPC machine (Lazo TPC Global, Inc.); which works by using propane to heat air, which is then blown over the crop using a PTO driven fan. Efficacy of the machine was tested on “shady lady” variety tomatoes on the CSUF farm using a randomized complete block design with 5 replicates. Treatments tested included an untreated control, Thermal Pest Control (TPC), and industry standard conventional pesticides. Bi weekly foliar sampling for insects showed similar populations at the beginning of the season, but later in the season TPC plots had significantly lower pest populations. At harvest, there were no significant differences in total yield or USDA maturity class of the tomatoes, however TPC treated plots did have a significantly great proportion of culls due to worm damage.

POSTER SUBMISSION

Title of Paper: **Sensitivity of agricultural runoff to rising levels of CO_2 and climate change in the San Joaquin Valley watershed of California**

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ABSTRACT

The Soil and Water Assessment Tool (SWAT) was used to assess the impact of climate change on sediment, nitrate, phosphorus and pesticide (diazinon and chlorpyrifos) runoff in the San Joaquin watershed in California. This study used modeling techniques that include variations of CO_2, temperature, and precipitation to quantify these responses. Precipitation had a greater impact on agricultural runoff compared to changes in either CO_2 concentration or temperature. Increase of precipitation by ±10% and ±20% generally changed agricultural runoff proportionally. Solely increasing CO_2 concentration resulted in an increase in nitrate, phosphorus, and chlorpyrifos yield by 4.2, 7.8, and 6.4%, respectively, and a decrease in sediment and diazinon yield by 6.3 and 5.3%, respectively, in comparison to the present-day reference scenario. Only increasing temperature reduced yields of all agricultural runoff components. The results suggest that agricultural runoff in the San Joaquin watershed is sensitive to precipitation, temperature, and CO_2 concentration changes.

POSTER SUBMISSION

Title of Paper: **Influence of Compost on growth rate, sensitivity and plant vigor of Strawberry, Tomato and Lettuce.**

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ABSTRACT

Soil plays an important role in agricultural crop production cycle and is considered to be one of the vital components of Soil-Plant-Atmosphere-Continuum (SPAC). Addition of amendments such as compost to soils significantly increases the soil organic matter quality and improves the soil fertility. In addition to supplying the essential nutrients, composts also contribute to the soil salinity by increasing the electrical conductivity (ECe) of soils. Compost salinity is typically measured using an EC5:1 however, so the ECe that results from a compost-soil mixture cannot be calculated with mass-weighting alone. In order to better understand the effect of added compost on soil salinity, there is a need to estimate the ECe of soils amended with different composts at different rates. We have therefore adapted several models that appear in the literature for the purpose of estimating the ECe of soil compost mixtures. We are also assessing the impact of nine different composts on soil salinity, growth rate, sensitivity and plant vigor of tomato, lettuce and strawberry plants subjected to two different rates of compost application. Each of the compost treatments was applied at two rates. The first rate of application, 10 tons/acre, was based on the growers practice and is similar for all the three crops. The second rate of application was calculated using the Soil-Plant-Atmosphere-Water Hydrology (SPAW) model and mass balance equations such that the ECe of the soil-compost mixture would result in approximately 25% yield reduction for each of the selected crops. Currently, the plantings have been established within a greenhouse and a number of soil and plant characteristics are being monitored. Soil samples taken before and after the experiment will be used to assess the impact of various composts on ECe of soil.

POSTER SUBMISSION

Title of Paper:	**Ethephon, Cytokinin, and Gibberellic Acid's Affects on Guayule (Parthenium argentatum) Seed Germination**
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ABSTRACT:

Guayule (Parthenium argentatum Gray) is a semi-arid woody shrub that produces high quality, non-allergenic latex that is vital for the medical industry. This agronomic crop can be a desirable alternative for the water limited farming locations in areas like Arizona, California, and Texas. Due to its low germination rates, guayule is difficult to establish in the greenhouse and field. Overcoming its seed coat and embryo dormancy has been attempted by various pre-treatments in the past. These methods have not been repeatedly proven to be more effective at increasing germination rates in a timely and cost effective way. The objective of this study is to determine the effect of the phytohormone gibberellic acid with ethylene or cytokinin on guayule's seed germination and growth rates. Past research has suggested a "cross-talk" between these phytohormones to overcome abscisic acid's inhibitory affects on germination to allow the dormant seeds to germinate. Gibberellic acid has been proven to improve guayule's germination rates some, but ethephon or kinetin may enhance those rates to a significantly more desirable rate. Seeds of three different guayule varieties were soaked in gibberellic acid plus ethephon or kinetin than germinated at a 20° Celsius and 8/16 hour light/dark rotation. Germination rates and seedling growth measurements were evaluated. Final germination tests are being completed and will be included in the statistical analyses. This research will further improve guayule's establishment rates for breeding programs, crop production practices and future research projects. Our poster review will summarize our results on improving guayule seed development and germination

POSTER SUBMISSION

Title of Paper:	**Reclamation Potential of Amendments for Soils Irrigated with Saline-sodic Drainage Water**
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ABSTRACT:

On the Westside of the San Joaquin valley of California, re-use of drainage water (DW) for irrigation— referred to as Integrated On-Farm Drainage Management (IFDM)— is an important tool for salinity and drainage management. However, the saline-sodic nature of this DW causes clay dispersion and reduces infiltration and hydraulic conductivity (K) of soil. The main objective of this study was to evaluate the effect of three amendments (gypsum, sulfur, poultry manure) on K, SAR, pH, and EC of highly dispersed soils in the IFDM at Red Rock Ranch. These soils receive sequentially re-used, highly concentrated DW (EC 10-15 dS/m; SAR 15-20), hence the effect of infiltration water salinity was also evaluated. A split-plot experiment with treatments replicated three times was conducted from May 2006 to June 2008. The main plot factor (amendment) consisted of gypsum or poultry manure at 10 tons/acre, or sulfur at 2 tons/acre, applied twice yearly to 1 m2 plots. A plot receiving no amendment was used as a control. The sub-plot factor was salinity of the infiltrating water (0.5, 6, and 12 dS/m). Unsaturated K at tensions of 0.5, 2 & 6 cm was determined from data obtained with a Decagon® "mini-disk" infiltrometer. While the three amendments significantly reduced ($P < 0.05$) soil SAR and pH at the 0-5 cm depth, the high application rates of these amendments had no impact on soil salinity (EC). K was significantly increased after three amendment applications. The reduced SAR and increased K indicate potential for these amendments to improve soil hydraulic properties and the sustainability of IFDM. Economic feasibility and practicality of commercial application of amendments at the rates used in this study remains to be determined.

POSTER SUBMISSION

Title: **Simazine Degradation Rates in Central Valley Soils with Annual or No Simazine Use Histories**

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ABSTRACT:

Simazine is a commonly used preemergent herbicide in Central Valley vineyards, valued for its relatively low cost and long residual activity. Studies have shown that simazine may be subject to enhanced biodegradation in some areas, which can decrease the herbicide half-life and result in reduced residual weed control efficacy. This study compares the simazine degradation rate and relative weed control in two vineyard soils, one treated annually with simazine (adapted) and one with no recent simazine use (non-adapted). In greenhouse and field experiments, simazine was applied to each soil, and soil samples were taken at regular intervals for 49 and 224 days respectively to assess the simazine concentration. In both the greenhouse and field, the simazine degradation rate was faster in the adapted soil. In the greenhouse experiment, the adapted soil had significantly lower simazine concentrations than the non-adapted soil in samples taken 14 to 49 days after treatment (DAT). In the field experiment, simazine concentration was significantly lower in the adapted field only at 112 DAT. In addition, biomass for wheat planted in the greenhouse experiment and weed counts in the field experiments were used to assess the efficacy of the simazine treatments. In the greenhouse, there was no significant difference in wheat biomass between the two treated soils; however, plants grown in both soils were smaller than their respective controls. In the field, the non-adapted site had better weed control than the adapted site at 56, 112, 168 and 224 DAT although this was only statistically significant at 112 DAT. Preliminary data from these experiments indicates that enhanced biodegradation of simazine does occur in Central Valley vineyards and may impact efficacy.

POSTER SUBMISSION

Title of Paper: **Effects of organic amendment on degradation of 1,3-dichloropropene and chloropicrin in soil**

Author(s): Ruijun Qin1, 2, Suduan Gao1, Husein Ajwa2, Bradley D. Hanson1, Thomas J. Trout3, Dong Wang1
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ABSTRACT:

Soil fumigants 1,3-dichloropropene (1,3-D) and chloropicrin (CP), are promising alternatives to the phased-out methyl bromide. However, these fumigants are volatile organic compounds and contribute to air pollution from emissions. Organic amendment to soils has been found to reduce emissions by increasing their adsorption or degradation, but conditions to maximize this effect has not been well defined. Laboratory incubation experiments were conducted to investigate important factors affecting the degradation of 1,3-D and CP in sandy loam soil under amendment with various composted organic materials at varying temperature (10, 30, and 45 ºC) and soil water content(air-dry to field capacity). Degradation of 1,3-D and CP over time followed pseudo first-order kinetics. The degradation of both 1,3-D isomers (cis-1,3-D and trans-1,3-D) was similar while the degradation of CP was generally faster than 1,3-D. Increased temperature accelerated fumigant degradation significantly, particularly for 1,3-D. Sterilization of the amended soils by autoclave did not reduce fumigant degradations indicating the accelerated degradation was by chemical reaction between organics and fumigants. The degradation of 1,3-D increased slightly with increased soil moisture, while the degradation of CP was not affected. Amendment with steer manure, chicken manure, organic composts, and grape pomace all accelerated fumigant degradation rate 2-3 times for 1,3-D compared to non-amended soil. The amendment effects on CP degradation was greater than 1,3-D. Fumigant degradation rates increased as the amount of steer manure increased and there was no interaction between soil moisture and the manure. These results suggest that soil moisture, temperature and organic amendments are important factors on the degradation of 1,3-D and CP and can be adjusted to achieve emission reduction under practical conditions.

POSTER SUBMISSION

Title of Paper: **Dynamic Modeling of Organophosphate Pesticide Load in Surface Water in the Northern San Joaquin Valley Watershed of California**

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Abstract:

The hydrology, sediment, and pesticide transport components of the Soil and Water Assessment Tool (SWAT) were evaluated on the San Joaquin Valley watershed in California. The Nash–Sutcliffe coefficients for monthly stream flow and sediment load ranged from 0.49 to 0.99 over the watershed during the study period of 1992–2005. The calibrated SWAT model was applied to simulate fate and transport processes of two organophosphate pesticides of diazinon and chlorpyrifos. The model generated satisfactory predictions of dissolved pesticide loads relative to the observed data. The model also showed great success in capturing spatial patterns of dissolved diazinon and chlorpyrifos loads according to the soil properties and landscape morphology over the large agricultural watershed. This study indicated that curve number was the major factor influencing the hydrology while pesticide fate and transport were mainly affected by surface runoff and pesticide application within the study area.

POSTER SUBMISSION

Title of Paper: **Mitigation efficacy of vegetated buffers in reducing non-point source pollution: A review**

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ABSTRACT

Vegetated buffers are a well-studied and widely used agricultural management practice for reducing non-point source pollution. A wealth of existing literature provided experimental data on their mitigation efficacy. This paper aggregated many of these results and performed a meta-analysis to quantify the relationships between pollutant removal efficacy and buffer width, buffer slope, soil type, and vegetation type. Theoretical models for removal efficacy (Y) vs. buffer width (w) were derived and tested against data from the surveyed literature using statistical analyses. A model of the form , ( ) successfully captured the relationship between buffer width and pollutant removal, where K reflects the removal capacity of the buffer and b reflects its probability to remove any single particle of pollutant in a unit distance. The estimates of K were 90.9, 93.2, 92.0, and 89.5 for sediment, pesticides, nitrogen (N) and phosphorus (P), respectively. Buffer width alone explains 37, 60, 44 and 35% of the total variance in removal efficacy for sediment, pesticides, N and P, respectively. Buffer slope was linearly associated with sediment removal efficacy either positively (when slope $\leq$ 9%) or negatively (when slope > 9%). Buffers composed of trees have higher N and P removal efficacy. Soil drainage type did not show a significant effect on pollutant removal efficacy. Models for all the studied pollutants were statistically significant with P-values < 0.001. Based on our analysis, a 30 m buffer under favorable slope conditions ($\approx$ 9%) removes over 85% of all the studied pollutants. These models predicting optimal buffer width/slope can be instrumental in the design and implementation of vegetated buffers for treating agricultural runoff to meet specific water quality objectives. The quantitative relationships also provide valuable information for modeling vegetated buffer efficacy at the watershed scale.

POSTER SUBMISSION

Comparison of using irrigation and organic amendment to reduce emissions from soil fumigation

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ABSTRACT:

Many perennial and annual crops require pre-plant soil fumigation to control soil pests for establishing healthy crops and profitable yields. Fumigant use, however, is highly regulated for minimizing emissions to improve air quality in California. To develop practical agricultural practices, we conducted three field trials to evaluate the effectiveness of irrigation and organic amendment on fumigant emissions from broadcast shank application of Telone C35. One field trial indicated that amendment with composted manure at 5 ton/ac under HDPE tarp did not reduce emissions compared to the control (bare soil without manure application). A second field trial tested treatments including control, composted manure rates of 5 and 10 ton/acre, post-fumigation water seals, and combination of manure (5 ton/ac) and the intermittent water seals. Water treatments with or without manure incorporation reduced emissions significantly; but the manure application at both rates did not reduce emissions compared to the control. Emission reduction by water seals was more pronounced on flux peak for both 1,3 dichloropropene and chloropicrin than cumulative emission loss over a 10-day monitoring period. The significant peak emission reduction from water treatment is important to reduce potentially acute exposure risk to workers and bystanders. These data showed that manure amendments alone up to 10 tons per acre are unlikely to reduce fumigant emissions under field conditions. Much higher manure rates may be needed to reduce emissions. A recent field trial tested composted manure application rate at 25 ton/ac and results will be available in the near future. Higher manure application rates, however, would increase the cost, which may not be feasible for some low-profit margin commodities.

POSTER SUBMISSION

Selenium Incorporation and Performance of Beef Cattle Grazing Pastures Irrigated with Saline-sodic Drainage Water

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ABSTRACT:

Selenium incorporation and animal performance were investigated in beef cattle grazing perennial forage pastures previously irrigated for 4-7 years with saline drainage water at Red Rock Ranch. During the 2007-2008 study period mainly tailwater was applied to the pastures due to a shortage of drainage water, but soil salinity remained high (>14 dS/m ECe) as did total Se (2-3 ppm). Each year, 20 Galvi Black Angus heifers from a single herd were divided into 4 groups with nearly equal total body weight. Pastures, 20 acres, of tall wheatgrass (TWG), *Thinopyrum ponticum* var. *'Jose'* and creeping wildrye (CWR), *Leymus triticoides* var. '*Rio*' were divided into four equal paddocks subdivided into north and south sections, which were rotationally grazed by two sub-groups of cattle (north and south) of 5 heifers. Forage dry matter (standing biomass) was sampled before and after heifers entered a paddock. Animal measurements included body weights and blood, liver and muscle samples. In 2007, blood Se increased rapidly, from 0.15 ppm to over 0.5 ppm (upper limit of "normal range"), within 50 days of grazing the pastures. Heifers grazing TWG forage had blood Se concentrations similar to those grazing CWR forage (0.9 ppm) after 195 days of grazing. In 2008, blood Se increased more rapidly in TWG heifers and was higher (1.2 ppm) than in CWR heifers (0.8 ppm) at the end of grazing. In both years, liver Se concentrations were 4 to 8 times higher after grazing than recommended maximums (i.e., 0.5 ppm). Acceptable body weight gains and absence of clinical signs of Se toxicity suggest that young beef cattle can safely graze these high Se forages for one season

POSTER SUBMISSION

Title of Paper: **Grow rate of lettuce: Implications for nitrogen fertilization**

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ABSTRACT:

Head lettuce is a short-term crop that has moderate nitrogen (N) demand. Lettuce typically matures in 65 to 70 days during the summer months in the coastal California production districts and contains 100 - 120 lbs of N in the above ground biomass. Typical grower N fertilization programs vary widely but generally average from 150 to well over 200 lbs of N/A. Lettuce is a shallow rooted crop that requires frequent irrigation to maintain rapid growth and quality; these conditions create challenges for efficiently managing nitrogen fertilization. During the first 40 days after planting lettuce takes up approximately 20 to 25 lbs of nitrogen. However, in the subsequent 20 days the crop takes up 80 - 100 lbs of nitrogen which is equal to 4 - 5 lbs of nitrogen uptake per acre per day. Clearly to achieve maximum lettuce growth rate it is important to have sufficient nitrate nitrogen in the root zone during the phase of exponential growth. Soil nitrate can be leached by excessive irrigation and therefore irrigation management is key to efficient nitrogen management. We evaluated irrigation and nitrogen management in lettuce in three commercial scale trials in 2008 by comparing best management practices (BMP) with standard practices. Nitrate leaching was reduced in plots irrigated based on estimated evapotranspiration demand of the crop. Large applications of nitrogen early in the growth cycle were not effective for maximizing yields and were at risk for leaching if excessive amounts of irrigation water were applied. Residual soil nitrate can be measured by the soil nitrate quick test and can supplement applied fertilizer nitrogen to supply nitrogen needed to maximize lettuce growth during the exponential growth phase of the growth cycle of lettuce.

POSTER SUBMISSION
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Pretreatment Approach to Defoliation of Acala Cotton

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Harvest Aid studies were conducted at the Westside Research and Extension Center in Five Points California to evaluate the evaluate the effect of early applications of Ginstar or Ginstar plus Finish. In 2007 Ginstar treatments at 3-6 oz rate applied at the 6 nodes above cracked boll followed by a secondary treatment of 6-8 oz of Ginstar or Sodium Chlorate gave 20 percent higher defoliation, 30 percent higher desiccation, and 15 percent improved open boll compared to similar treatments with a two shot approach applied at the standard 4 NACB stage. The 4 NACB treatments did not improve open boll even after 32 DAT. Yield data showed a yield reduction with an early application of Finish and a slight loss with an early application of Ginstar in 2007 but not in 2006. Micronaire was slightly reduced with the 6 NACB timing but not in a negative way.

The 2008 studies have not been completed but will be presented. A field of Phytogen 725 has been managed at the WSR&ES for this study. A follow up on a 2 step approach done in 2006 and 2007 which showed improved defoliation and boll opening by starting with a 4 oz. rate of Ginstar at 6 NACB followed by higher rates of harvest aids along with ethephon at 4 NACB to bring about an earlier harvest. Preliminary data indicated that this approach worked well but there are still questions remaining on possible yield loss. Early applications of Shark will be evaluated also for defoliation and earlier termination.

IN MEMORY: DAVID R. WOODRUFF
June 14, 1943 – June 24, 2008

Dave Woodruff was a man that didn't make a lot of noise. He didn't need to. His straightforward presence, integrity and faith spoke volumes through a soft voice and commanded respect from all who knew him. At 65 years old his life was tragically cut short in a train accident at an uncontrolled crossing north of Shafter, CA. He was doing what he always did, what many of us do to make farming work every day – checking/sampling fields, thinking of 2 dozen other things that need to get done yesterday – and somehow it was over in a split second.

Dave began his lifelong work in agriculture as a kid helping his father grow vegetables on a small southern California farm. After earning a BS and MS in Plant Science from UC Riverside Dave worked as a UC Cooperative Extension Farm Advisor from 1968 to 1976 doing agronomy and soils work for 2 years in Imperial Valley and 6 years in Kern County. He left extension to work as a private soils/fertility consultant, serving Kern County growers during the days when half of Kern County was planted to cotton. As cropping patterns evolved Dave also did a lot of work with potatoes, roses and carrots. He served 10 years on the Carrot Advisory Board and was a board member of our organization, the California Chapter of the American Society of Agronomy from 2005 – 2008. He was a long-time attendee of the California Plant & Soil Conference.

Dave's greatest love was his family and his faith. He was a long-time member and Elder of Olive Knolls Church in Bakersfield. He and his wife, Gretchen, had 3 kids that went to Beardsley School (K-8) where Dave served for 31 years as a school board member. Their new recreation center was named in his honor this summer.

One of Dave's duties as a director on the Carrot Board was to serve as moderator of the annual meetings. As part of his meeting introduction, he would routinely tell the audience a clean joke or two which never failed to result in howls and laughter from his grower audience. We offered him a new joke book; but he would graciously decline because the old jokes were simply part of his "shtick".

Dave would easily agree that there are easier ways of making a living in this world than in doing agriculture. But Dave, like most of his us, chose agriculture as a profession because it represents a real, and even noble bond with the earth. Sadly, with the progression of time and events, there are fewer of us left in the ranks who share this commonality, making his loss all the more significant.

Dave would want us to remember, to take note of his loss to us; not to say what a great man he was, (for he was truly humble), but so we could remember to love our families, love the special connection to the earth and growing things that we are blessed to know and work with, to be thankful for every moment of sunshine and chilling and bloom and to take care as we travel the highways and county roads.

Wes Selvidge of Buttonwillow Land & Cattle, a 5th generation son of one of Kern County's first farming families and long-time friend and client of Dave summed it up best:

> **"Dave Woodruff was truly a man of the soil. Neither heat nor cold could keep him from doing what he loved best, roaming the fields of Kern County, gathering information on the multitude of crops grown.**

His experience as an agronomist/farm advisor was relied upon by many growers. If Dave didn't have the answer in his head, which was rare, he would do some research and give you a comprehensive answer.

If the Lord has a garden in heaven it will be well tended."

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California Chapter – American Society of Agronomy
2009 Plant and Soil Conference Evaluation

Chapter web site: ***http://calasa.ucdavis.edu***.

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

1. Conference Evaluation

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

2. What session topics do you recommend for future conferences?

a. ____

b. ____

3. Please suggest Chapter members who would be an asset to the Chapter as Board members.

a. ____

b. ____

4. Who would you suggest the Chapter honor in future years? The person should be nearing the end of their career. Please provide their name, a brief statement regarding their contribution to California agriculture, and the name of a person who could tell us more about your proposed honoree.

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5 Please rank your preference for the location of next year's conference. (Use 1 for first choice, 2 for second, etc.)

____ Fresno ____ Visalia ____ Modesto ____ Sacramento ____ Bakersfield

____ Other (please provide) ________________________

6. Additional comments

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