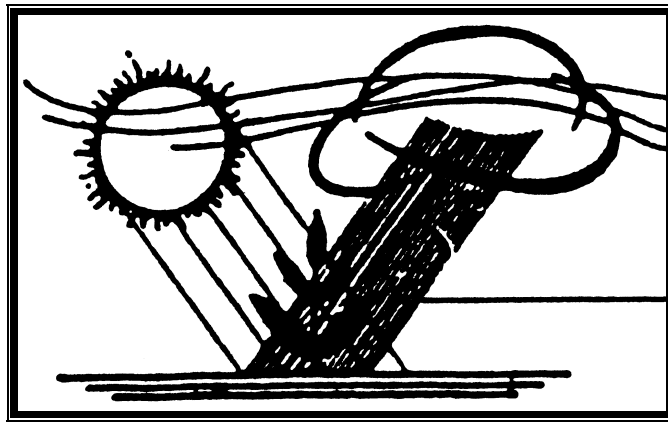


CONFERENCE PROCEEDINGS

2004

California Plant and Soil Conference

California Agriculture: Working Toward Sustainability



California Chapter of the American Society of Agronomy

Co-sponsored by the California Plant Health Association

February 3 & 4, 2004

Visalia Holiday Inn
9000 W. Airport Drive - Visalia, California

To download additional copies of the proceedings or learn about the activities of the California Chapter of the American Society of Agronomy, visit the Chapter's web site at:

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TUESDAY, FEBRUARY 3, 2004

GENERAL SESSION

CALIFORNIA AGRICULTURE – WORKING TOWARD SUSTAINABILITY

Session Chair: Casey Walsh Cady, CA Dept. Food and Agriculture

- 10:00 Introduction – Session Chair
- 10:10 **Prospects for Agriculture in California – Meeting the Challenges, Creating the Future** – Jim Costa, Senator (Retired)
- 10:40 **Challenges to California Soil Sustainability, Past, Present and Future** - Mike Singer, UC Davis, Dept. Chair, Dept. of Land, Air and Water Resources
- 11:10 **A Path to a More Profitable and Equitable Future for California Family Farmers and Rural Communities** - Leland Swenson, Executive Director, Community Alliance with Family Farmers
- 11:40 Discussion
- 12:00 **California Plant Health Association Luncheon**
Speaker: (to be announced)

CONCURRENT SESSIONS

I. COMPREHENSIVE APPROACHES TO SOIL NUTRIENT MANAGEMENT

Session Chairs: **Tim Hartz**, UC Davis; **Richard Smith**, UCCE, Monterey County

- 1:30 Introduction – Session Chairs
- 1:40 **Phosphorus Management for Agronomic Success and Environmental Protection --** Rob Mikkelsen, Potash and Phosphate Institute
- 2:00 **Nitrogen Contributions from Organic Amendments and Fertilizers** – Stuart Pettygrove, UC Davis, Dept. of Land, Air and Water Resources
- 2:20 **Brassica Cover Crops: Impacts on Plant Nutrition and Pest Management** – Richard Smith, UCCE, Monterey County
- 2:40 Discussion 3:00 BREAK
- 3:20 **Impacts of Drip Irrigation on Fertilization of Vegetables** – Tim Hartz, UC Davis, Dept. of Vegetable Crops

- 3:40 **Refining Stone Fruit Deficiency and Sufficiency Nutrient Levels** – Scott Johnson, UC Davis, Dept. of Pomology, Kearney Ag Center
- 4:00 **Early Season Soil Nitrate Monitoring for Nitrogen Management of Cotton** – Bob Hutmacher, UCCE, Shafter Research & Extension Center
- 4:20 Discussion 4:30 ADJOURN

II. IMPACTS OF WATER REGULATION ON CALIFORNIA AGRICULTURE

Session Chairs: **Larry Schwankl**, UC Davis; **Ben Nydam**, Dellavalle Labs; **Jim Ayars**, USDA, ARS

- 1:30 Introduction: Session Chairs
- 1:40 **Water Transfers – Have We Learned Anything Lately?** – Van Tenny, Glenn-Colusa Irrigation District
- 2:00 **Changes in Water Policy Motivate Land and Water Sales** – Dennis Wichelns, California Water Institute
- 2:20 **A Buyer’s Perspective on the California Water Market** – Charles McNiesh, Pajaro Valley Water Management Agency
- 2:40 Discussion
- 3:00 BREAK
- 3:20 **Ag Discharge Waivers** – Bill Thomas, Livingston & Mattesich, Attorneys
- 3:40 **Coalition Approaches to Ag Discharge Regulation** – David Orth, Kings River Conservation District
- 4:00 **California Animal Confinement Regulations in Chaos** – Jeff Palsgaard, Merced County Dept. of Environmental Health
- 4:20 Discussion
- 4:30 ADJOURN

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

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

WEDNESDAY, FEBRUARY 4, 2004
CONCURRENT SESSIONS

III. IRRIGATION AND WATER MANAGEMENT ISSUES

Session Chairs: **Larry Schwankl**, UC Davis; **Ben Nydam**, Dellavalle Labs; **Jim Ayars**, USDA, ARS

- 8:30 Introduction – Session Chairs
- 8:40 **Drip Irrigation Under Saline, Shallow Ground Water Conditions** – Blaine Hanson, UC Davis, Dept. of Land, Air and Water Resources
- 9:00 **Water Requirements of California Straw-berries** – Tom Trout, USDA, ARS, Parlier
- 9:20 **Regulated Deficit Irrigation in California's Orchards and Vineyards: Realizing the Potential** – Dave Goldhamer, UCCE, Kearney Ag Center
- 9:40 Discussion 10:00 BREAK
- 10:20 **A Web Based Model for Estimating Peach Tree Water Use** – Scott Johnson, UCCE, Kearney Ag Center
- 10:40 **Can Mitigation Practices Provide Protection for Ground and Surface Waters?** – Terry Prichard, UCCE, San Joaquin County
- 11:00 **Micro Irrigation in Almonds – To Bury or Not to Bury?** – Eric Merz, Almendros Twinland, LLC
- 11:20 Discussion

IV. NEW TECHNOLOGIES IN PEST MANAGEMENT

Session Chairs: **Tom Babb**, CA Dept. of Pesticide Regulation; **Jim Gregory**, Verdegal Brothers

- 8:30 Introduction – Session Chairs
- 8:40 **How the New Ground Water Regulations Affect Pest Management Practices** – John Troiano, CA Dept. of Pesticide Regulation
- 9:00 **The Role of Technical Service Providers in NRCS Pest Management Programs** – Diane Holcomb, USDA, NRCS
- 9:20 **Alternatives to Methyl Bromide for Soil Fumigation in Strawberry Production** – John Dunniway, UC Davis, Dept. of Plant Pathology
- 9:40 Discussion 10:00 BREAK
- 10:20 **Reduced Tillage and the Pink Bollworm Program** – Jim Rudig, CA Dept. of Food & Ag
- 10:40 **Robotic Weed Sprayers in Production**

Agriculture – Ken Giles, UC Davis, Dept. of Biological & Ag Engineering

- 11:00 **Managing Vertebrate Pests in Field Crops** - Desley Whisson, UCCE, Wildlife, Fish & Conservation Biology
- 11:20 Discussion
- 12:00 **CONFERENCE LUNCHEON:** Presentation of Honorees, Scholarship awards, Election of new officers

V. EMERGING FIELD TECHNOLOGIES IN CALIFORNIA AGRICULTURE

Session Chairs: **Joe Fabry**, Fabry Ag Consulting; **Ron Brase**, California AgQuest Consulting

- 1:30 Introduction – Session Chairs
- 1:40 **A New Approach to Monitoring Soil Moisture** – Blain Hansen, UC Davis, Dept. of Land, Air and Water Resources
- 2:00 **Specialty Crop Research for the SJV** - Manuel Jimenez, UCCE, Tulare County
- 2:20 **Genetic Marker Assistance for Selection of Disease Resistance in Grain** - Lee Jackson, UC Davis, Dept. of Agronomy & Range Science
- 2:40 **Methyl Bromide Alternatives for Perennial Crops and Nurseries** – Sally Schneider, USDA-ARS, Parlier
- 3:00 Discussion 3:20 ADJOURN

VI. ALTERNATIVE NUTRIENT MANAGEMENT STRATEGIES

Session Chairs: **Bob Fry**, USDA; **Bruce Roberts**, UCCE, Kings County

- 1:30 Introduction – Session Chairs
- 1:40 **Emerging Manure Management Goals and Strategies** – Bob Fry, USDA, NRCS
- 2:00 **Biosolids: Sources and Management** – David Crohn, UC Riverside, Environmental Sciences
- 2:20 **Sources, Potential Use and Revenues of Biomass** – Bryan Jenkins, UC Davis, Biological & Agricultural Engineering
- 2:40 **Forage Production with Saline Drain Water** – Stephen Kaffka, UC Davis, Agronomy & Range Science
- 3:00 Discussion
- 3:20 ADJOURN

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CALIFORNIA AGRICULTURE - WORKING TOWARD SUSTAINABILITY

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California Chapter of American Society of Agronomy

Past Presidents

Year	President
1972	Duanne S. Mikkelson
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California Chapter of American Society of Agronomy

Past Honorees

Year	Honoree	Year	Honoree
1973	J. Earl Coke	1998	Bill Isom
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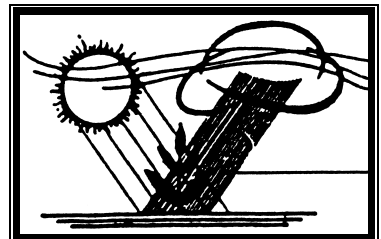
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Two-year term	Tom Babb, California Dept. of Pesticide Regulation Bob Fry, USDA-NRCS Ben Nydam, Dellavalle Laboratory, Inc.
Three-year term	James Ayars, USDA-ARS Joe Fabry, Fabry Ag Consulting Tim Hartz, UC Davis, Dept. of Vegetable Crops
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2004 Honorees

Harry Agamalian

Jim Brownell

Fred Starrh



Harry S. Agamalian

Harry Agamalian was born in Santa Barbara in 1931. He worked on his family's farm growing up and attended UC, Davis. He received a B.S. in Agronomy in 1955. He was hired as a farm advisor in 1955 but took a leave of absence in 1957 to complete his military service as a 2nd Lieutenant in Ft. Benning Georgia. In 1963 he took a sabbatical and returned to school at the University of Arizona where he received his M.S. in Weed Science in 1964. He excelled as the Agronomy and Weed Science Farm Advisor for Monterey County for 36 years prior to his retirement in 1991. Upon retirement, he was granted Emeritus status and continued to serve on a part-time basis until 1998.

Harry was one of the best-known and most productive Farm Advisors on the Central Coast. He published over 148 publications and worked tirelessly on field research and extension of research information to growers one on one and through countless meetings. He was active in various societies such as the American Society of Agronomy, the California Chapter of the American Society of Agronomy, the Weed Science Society of America, the California Weed Science Society and the Western Society for Weed Science. He has served on and chaired numerous committees in these organizations and was California Weed Science Society President in 1978 and was granted the Outstanding Weed Scientist award in 1997. He was also selected as a Fellow in the Western Society of Weed Science in 1990.

During his career, Harry was active participant in the California Seed Certification Program and assisted in the development of California small white bean varieties 53 and 59 that were grown in the King City area. He introduced Merced rye as a winter cover crop and conducted the first variety trial of the Cuzco Peru corn varieties that later led to the establishment of the production of the "corn nut" production and processing facility in Greenfield.

Harry was at the forefront of development of weed control techniques in dry beans and winter cereals, and is probably best known for his activities in developing weed control techniques for vegetable crops, many of which are now common practice in the Salinas Valley. Harry has an International reputation for his activities in weed control and conducted sabbaticals in England on weed biology and in Germany on herbicide persistence in soils. He served as a Weed Scientist and Vegetable Mechanization Specialist to Hungary, Bulgaria, Yugoslavia and the Union of South Africa; and in 1986, by special invitation, he was invited to China as a Weed Scientist and gave lectures to the Beijing Weed Science Society and vegetable growers cooperatives.

In his retirement, Harry has remained active in consulting and projects, such as managing the celery variety trials for the California Celery Research Advisory Board from Oxnard to Salinas. In addition to all of these activities and accomplishments Harry is a member of the Salinas Rotary Club where he serves as a director and serves as a volunteer at the AT&T Pebble Beach Pro-Am Golf tournament.

Jim Brownell

Born in Jeannette PA in 1932, married Dolly Priester in 1951, four children, Vicki Cooksey (Fresno), Jerry (Singapore), Kate (Gold Beach OR), and Chris (Fresno), ten grand children and one great grandson.

Classroom education included a BS in Agronomy from Penn State, MS in Soil fertility from Univ. Minn., Ph. D. from UC Davis in soil chemistry. Taught soils, irrigation, plant nutrition, laboratory techniques and other stuff at Fresno State College and the California State University, Fresno 1958-60 and 1969-92. Advised undergraduate and graduate students, still trying to figure out how many.

In the interim between the Fresno State jobs, worked four years in the research laboratory of DiGiorgio Farms for R. S. Ayers supervising laboratory and field sampling operations assaying fertility and irrigation practices and recommending improvements, Five years as a Lab Tech. IV at UC Davis in the Department of Soils and Plant Nutrition with P. R. Stout. Job description was “problem Soils specialist”. Trained atomic absorption analyst by T. Arkeley, the UC developer of that instrument. Sampled range plants throughout northern California in an attempt to find out why our soils let pregnant mothers (cows) get grass tetany.

Rehired at Fresno State (soon to be California State University) by W. E Beihler department of Plant Science to teach undergraduate and graduate classes in soils, plant nutrition, and laboratory techniques. Advised students both undergraduate and graduate on courses and research,

Consulted on soil management, irrigation, fertilizer and soil amendment use, waste materials utilization, swimming pool chemistry, soil selection for sun dried brick production. On a sabbatical in Australia worked on “black cotton” soils with David Anthony of Auscott, sponsored by J. G. Boswell. And, on another sabbatical, lived as a Fulbright Scholar in Egypt attempting to locate soil for sun dried brick manufacture from sources other than the Nile mud.

Principle author of a proposal that created the Agricultural Energy Technology Project (AETP) at California State University resulting in funding by the legislature at \$1.4 million and the initial funding for the Center for Irrigation Technology (CIT). The successful completion of this project culminated in the formation of the California Agricultural Technology Institute (CATI) and the permanent funding for CIT.

Retired as Professor of Soils emeritus in 1992, moved to Cambria. Recently completed a consultancy with Westlands Water District, compiling fifteen years of soil salinity data for the lawsuit with the landholders about the lack of a system wide drain. Working as a Director of Greenspace, the Cambria Land Trust, on a seed collection of *Pinus radiata, macrocarpa* (Cambria’s Monterey Pine) germinating and growing seedlings to be inoculated with Pine Pitch Caner spores to select a resistant line of trees.

Fred Starrh

Mr. Fred Starrh is an accomplished leader in California agriculture. Fred began his farming career in Kern County on the 30 acres his father purchased in 1936. Fred formed a farming partnership with his father in 1951. Since that time, the family partnership has grown from 30 acres to 13,000 acres. The diversified farming operation today produces cotton, alfalfa, carrots, almonds and pistachios. Fred's son, Larry is actively involved with farm management of the Starrh and Starrh Cotton Growers family farm. Together they represent the second and third generation of family farmers contributing to California's agriculture industry.

Fred Starrh has been an active participant in the development of the San Joaquin Valley (SJV) cotton industry. He was the first chairman of the revised San Joaquin Valley Cotton Board. During this period, Fred ushered the state's cotton industry through the transition from its long standing "one variety" to a "uniform quality" district. Thus insuring the marketing advantage of SJV quality cotton. Fred was instrumental in opening the SJV for the production of Pima cotton in California. This action spurred the development of Pima production and ginning of extra long staple quality fibers demanded worldwide. Taking quality a step further, in 1998 Fred played an integral role in the organization of the SJV Quality Cotton Growers Association. This "mutual benefit association" is for growers to exclusively produce and market the highest quality SJV cotton to world markets.

Fred's contributions to California extend beyond his impressive impacts on the cotton industry. His influence has also changed national policy from many trips to Washington representing CA agriculture. He has been an innovative leader in improving on-farm irrigation practices. Fred was an early adopter of soil moisture sensing technology to fine tune irrigation scheduling. He developed cultural systems that optimized the use of sprinkler irrigation systems. Fred's interest in efficient water use has spread to the installation of sub-surface drip systems that are producing 4.5 bale cotton yields using blended canal water with higher saline ground water. Innovative adaptations of technology and policy changes to improve farming practices have been Fred's hallmark as a Kern County farmer. This extends from changing California law to allow for the movement of cotton modules to modifying equipment to accommodate sprinkler lines or drip systems. Fred's leadership is also evident in his efforts to address air quality issues of the SJV. Fred began paving farm roads to prevent dust and to improve field accessibility before it became such a controversial issue.

Fred has shared his experience and expertise with the Kern County Farm Bureau where he served as president, state director, state cotton committee chair and national cotton committee chair. He has served as chair of the American Cotton Producers Committee of the National Cotton Council. Fred has served as Western Cotton Growers President, California Cotton Growers Association President, UC Shafter Research and Extension Center Industry Advisory Committee chair, Cotton Incorporated board chair in 1991 and on the USDA Agriculture Technical Advisory Committee. Fred has served on numerous search committees for positions in the Agronomy & Range Science Department at UC Davis. Fred has also served his local community. He has served on local irrigation district boards and was a board member on the Kern High School District Board for 17 years.

Fred Starrh is truly a statesman and innovative farmer who represents the agriculture leadership of California. Fred's contributions to California agriculture will have lasting effects on our state's industry.

2004 Scholarship Winners and their Essays

(based on the following question)

*How would you define agricultural sustainability:
do you think production agriculture in California is sustainable;
and how will your studies in agriculture influence this?*

Scholarship Committee:

Jim Ayars

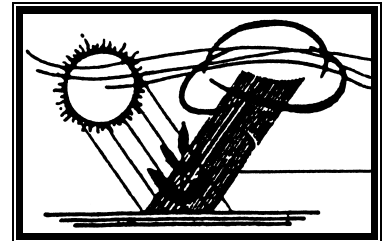
Tom Babb

Casey Walsh Cady

Bruce Roberts

Dennis Westcot

Dave Zoldoske



Melissa Marie Simoes, Cal Poly, San Luis Obispo

Current production agriculture is sustainable in America, especially in California. With California being a leading producer of agricultural products, sustainability is important. By having access to soil fertility records, maintaining the land will be an easier task to complete, therefore “agricultural sustainability” is defined as maintaining the soil and producing crops of high quality while keeping the consumer in mind with regards to prices and attaining a reasonable return on investments for the farmer.

Becoming knowledgeable about natural resource base, environmental quality, society, the economy and nutrition as a whole, agriculture can be managed and in turn, produce societal benefits. The Albrecht method is probably the most beneficial, in my opinion, suitable to its do-able theory of “feeding the soil and letting the soil feed the plants”. By following this method, and in addition, include recycling soil nutrients and keep food quality at a maximum; the maintenance of agricultural land is over exceedingly possible.

My studies in agriculture have influenced the achievement of sustainable agriculture. In just four months of completing soil analysis, crop trials, and experiments pertaining to increased yield, I found the maintenance of the land to be of great importance. Benefits to society, the environment, and highly valued nutrition are attainable. Decreasing the application of fertilizers will decrease costs to the farmer, decrease chemical pollution in the environment, and increase profits. By prevailing over the expense of nitrate fertilizer costs, the agriculturalist can then, in turn, decrease the costs to the consumer making everyone content.

Agriculture is sustainable; it is just a “work in progress”. It will only continue to flourish, once the agriculturalists as a whole can see the big picture and understand that if action doesn’t occur soon, the land will be depleted and there will be larger problems to solve. By maintaining the theory “everything is built on soil”, one can see that the first step is to maintain the important element of all, the soil.

Hugo Calvillo, California State University, Fresno

Agriculture production is both a wonderful and controversial issue, depending on your point of view. Activist groups and the media's ability to take information and exploit it to their benefit have influenced the viewpoint of the majority of people. Agriculture is like any other industry, change is part of doing business. The sustainability of agriculture is measured by the positive flow of cash at the end of a couple years and the ability to sustain production. In agriculture, some years are great while in other years, you barely break even.

Agriculture sustainability is the ability to continually produce a product and be able to sustain the farm and your livelihood economically. California agriculture production has become less sustainable, but with the right mindset and proper adaptation of technology and new methods it is possible.

The small farmer that depends on farming for his livelihood is getting phased out. There will be a limited amount of market space for specialty farmers, and the macro markets will belong to the agricultural firms that modify their operations to turn a profit. The key to sustainable agriculture in California is diversity. Agricultural firms are able to diversify and take advantage of economies of scale to make agriculture profitable. A perfect example of this is J.G. Boswell and their upward integration in cotton production. They do everything from production to grading and marketing their cotton. They eliminate the middleman and make the profit that would have gone to the middleman.

In my current work with NRCS we encourage any efforts to introduce conservation tillage (CT). For example we have a Program called EQIP that provides cost sharing for farmers that introduce CT into their operation. CT is also a good way to reduce production cost, and it aids in maintaining soil health. The reduction in inputs helps keep farmers in business. If you adapt to the technology and change with the times, agriculture can be sustainable.

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Session I

Comprehensive Approaches

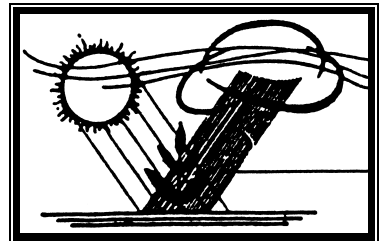
To

Soil Nutrient Management

Session Chairs:

Tim Hartz, UC Davis, Dept. of Vegetable Crops

Richard Smith, UCCE Monterey County



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Phosphorus Management for Agronomic Success and Environmental Protection

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Why Use Phosphorus?

Phosphorus fertilization should be considered a long-term investment in soil fertility as an essential component for crop production. In general, only a portion of a single P application will be used by this year's crop. The remaining P will go to increasing the long-term soil fertility. The benefits from P fertilization has been recognized for many years.

Through the mid-19th century, adequate P supplies were severely lacking in most of the long-cultivated agricultural lands in the eastern U.S. and no abundant sources were accessible to alleviate crop P deficiencies. Addition of animal manures was a satisfactory source of N as animals consumed nitrogen-fixing forages and hay, however the recycled manure did not provide any **new** inputs of P, K, or other essential nutrients. During this time, ground bones were treated with sulfuric acid to form single superphosphate [$\text{Ca}(\text{H}_2\text{PO}_4)_2 + \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$]. In the search for valuable P sources during this period, even the battlefields of Europe were excavated for human skeletons to convert to P fertilizer (Mikkelsen and Bruulsema, 2004).

Phosphorus is an essential macronutrient required by all plants for growth, development, and reproduction. There are many important biochemicals in plants that contain P. Phospholipids are a primary structural component of membranes that surround each plant cell and organelle. Inside the cell, genetic information (RNA and DNA) contains P as an integral constituent. The high-energy molecule ATP controls protein and enzyme synthesis, as well as energy transfer. Other essential functions such as photosynthesis, seed formation, and phytic acid storage are closely linked with adequate P supplies.

A common misconception concerning nutrient management is that the soils in the U.S. have been over-fertilized with P and K. Data from soil testing laboratories show that we are actually depleting nutrients in many Western states and the number of soils that could benefit from more fertilization keeps increasing! A primary problem with P management is the economic limitation for proper manure transport to areas where the nutrients are needed. Another current problem with P management is identification of the conditions where a positive crop response to nutrients is expected and then educational efforts to implement appropriate practices.

Phosphorus Loss Pathways

Current concerns involve the balance of agronomic productivity resulting from fertilization with desirable environmental protection. Phosphorus can be lost from fields through four major processes- any of which may be a dominant loss pathway in a scenario common in some part of the state. However, one or more pathways may contribute to P loss for an individual field site.

1. Runoff Carrying Soil-bound P

The largest pool source of P in the field is the soil itself. The processes that occur during erosion generally result in the loss of particles (clay) with the highest P concentration. Soils with higher soil-test P concentrations will generally have higher P loss in eroded particles. Any management practice that reduces erosion loss will also reduce P loss.

2. Runoff Carrying Soluble P

For a given soil, the dissolved P concentration in runoff increases as the soil test P concentration increases. The amount of soluble P that is released from a soil depends on many factors, including soil texture, soil mineralogy, and the history of fertilization. There are relatively few field management practices to reduce soluble P loss from the field

3. Subsurface Soluble P Losses

Direct movement of P from subsoil to surface water is possible on sites with drains and ditches that exit the field. This loss mechanism is not frequently observed, but is most commonly associated with a history of high rates of animal manure application.

4. Runoff Carrying P from Nutrient Sources Applied to the Soil

There is a consistent relationship between P application rate (regardless of source) and the concentration of P in runoff. Controlling the application rate and placement of P can minimize these losses. The solubility of the P source may also play an important role, with runoff P losses from manured soils exceeding those receiving inorganic P fertilizer (Tarkalson and Mikkelsen, 2004).

It is important to remember that within a given watershed, a wide range of P loss potential exists. For example, the Upper Vermilion River Watershed (Ohio) was identified as one of the primary P contributors to Lake Erie. However, subsequent analysis of the area revealed that only 1% of the soil was ultimately considered as a P pollution hazard (Ward, 1994). Identifying specifically where the problems are coming from allows effort and resources to be focused on real problem areas, not the 99% of soils in this case that were not identified as a problem.

Phosphorus Management on Fields Receiving Animal Manure:

There is abundant literature available to show the value of animal manure as a nutrient source for crop production. However, the utilization of nutrients from manure is generally much more uncertain than with commercial fertilizers. For example, the nutrient content of the manure is frequently unknown, the rate of nutrient availability (mineralization) may be difficult to predict and not synchronized with plant demand, the extent of volatile losses is uncertain, application rates are not closely measured, and the ratio of nutrients is not what plants require. The use of manure as a N source for plants generally results in over-application of other essential nutrients and salts. These limitations, along with the increased costs and labor associated with manure collecting, hauling, pumping and spreading has frequently changed its perceived value from a resource to a disposal problem (Mikkelsen, 2000A).

A nutrient budget of a typical North Carolina dairy farm revealed that feed concentrates (0.7% P) contribute the greatest amount of P imported onto the farm. Milk was the largest off-farm P export (average 1.9 g P/kg milk). This specific farm had an average P surplus of 20 kg P/ha/yr [18 lb P/A/yr] (Tarkalson and Mikkelsen, 2003). On a nearby poultry farm, they found that annual P surpluses exceeded 65 kg P/ha/yr [58 lb P/A/yr].

In California, a nutrient balance on a dairy showed that approximately 70 kg P/ha [62 lb P/A/yr] was applied to surrounding crop land each year in the liquid manure, with harvested removals of 31 kg P/ha/yr [28 lb P/A/yr] (Meyer and Schwankl, 2000). This resulted in an annual surplus of nearly 40 kg P/ha/yr [36 lb P/A/yr]. These rates of P accumulation far exceed any agronomic requirement and represent a condition that would never be duplicated with commercially purchased fertilizer. Even on vegetable farms that are managed organically (with composted manure used as the primary source of nutrients), rapid P accumulation occurs in soil due to the imbalance between inputs and harvested crops

(Mikkelsen, 2000B). This rapid P accumulation highlights the fact that the “value” of manure as a nutrient source is not merely the sum of its nutrient content- especially if there is no need for these plant nutrients on the farm.

One of the promising techniques for reducing P loss is application of aluminum sulfate (alum) to bind soluble P. Applied to manure, lagoons, and soil, the alum can precipitate soluble P and reduce its potential for loss. While this amendment can reduce soluble P loss, it is no long-term substitute for balancing nutrient inputs and exports on a farm.

Nutrient Management in Soils Testing Very High in Phosphorus

It is useful to examine the trends in agricultural nutrient budgets in the U.S. since they provide insight into the balance of inputs and outputs in crop production. Unlike the condition with manure (where nutrients are frequently perceived to have little or no value), purchasers of commercial fertilizers invest money in nutrients with an expectation of an economic return. A recent P budget for North America (Fixen and Johnston, 2002) shows that crop removal of P exceeds P applied as fertilizer by 29% (Table 1). When recoverable manure is included in the calculation, crop removal represents 95% of inputs. This survey dispels the notion that most soils in North America are rapidly becoming P saturated. In California, the average ratio of removal and input is less than one, although this does not reflect localized areas of excessive application and other areas where soil nutrient depletion is occurring through crop harvest.

However, there are many areas where soil P concentrations far exceed the agronomic requirement for crop production. While there is a valid justification for raising soil P concentrations above the minimum requirement, many soils exceed this agronomic threshold. The continued use of nutrients where there is no longer an agronomic justification may have negative environmental and economic consequences.

The concentration of P in surface runoff increases in proportion to the soil concentration. If there is no justification for continued increases in soil P, then the risk of P loss is enhanced, with no expectation of any gain. These impacts illustrate the importance of a regular soil-testing program. University personnel and local experts have conducted numerous soil fertility trials to determine the conditions where a favorable yield response can be expected. Fertilization in great excess of these recommendations is not likely to result in any benefits, although specific adjustments for individual crops, cold soil temperature, mineralogy, etc. may be needed.

The beneficial effects of P fertilization on crop quality and nutritional value must be remembered. Phosphorus has an important role in growing healthy crops that can leave abundant organic matter to reduce soil erosion and build soil humus. Economic sustainability is best achieved when the per unit cost of production is kept to a minimum- a condition achieved with adequate levels of plant nutrients. The majority of environmental problems associated with P result from poor soil management and use of excessive quantities of organic materials. Proper soil testing for determining appropriate fertilization rates will improve the quality of the soil and provide a favorable environment for long-term crop production. Implementation of best management practices will benefit water quality through reduced soil and nutrient loss.

Table 1. Partial phosphorus (expressed as P₂O₅) budget for North America (average of 1998 to 2000).

Region	Crop Removal	Applied Fertilizer Manure	Recoverable <u>without</u>	Balance <u>with</u>	Removal/Use Ratio	
	-----	----- billion lb	-----		manure	
California	0.35	0.36	0.20	0.21	0.96	0.62
Six leading Corn states	5.1	3.0	0.9	-1.3	1.71	1.33
United States	11.4	8.8	3.3	0.7	1.30	0.95
North America	13.3	10.3	3.7	0.7	1.29	0.95

from Fixen and Johnston, 2002

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Nitrogen Contributions From Organic Amendments and Fertilizers

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Introduction

In California, animal manures, biosolids, green wastes, food processing wastes, and a variety of other organic materials are applied to cropland as fertilizers and soil amendments. At the time of application, these may be relatively fresh, partially decomposed, or thoroughly composted or weathered. In California, the total quantity of these organic materials applied to crops undoubtedly represents a significant amount of N compared to commercial fertilizer N used in the state. For example, dairy manure N applied to crops in the state amounts to about 15% of the amount of N applied in the form of commercial fertilizer. This estimate is based on annual commercial fertilizer sales of 500,000 US tons of actual N and one million cows excreting 300 lb N/year, of which 50% is volatilized or otherwise lost between the time of excretion and application to cropland. These figures are approximate and are likely an underestimate of the dairy manure N quantity applied to cropland in the state. The fraction of this manure N applied that is in the organic form (i.e., not in the ammonium form at the time of application) is not known, but may be approximately half of the total dairy manure N.

What fraction of the organic N in the manures and other materials is mineralized in the soil and therefore available to crops? Research on this topic stretches back at least to the mid-1800s, when unreplicated plots with and without farmyard manure amendments were established at the Rothamsted experiment station in England. Even though a large body of published research and case studies has accumulated on this topic, our ability to accurately predict organic N mineralization in specific situations remains limited. However, recent research that incorporates temperature and moisture effects into mineralization models may improve the situation. Also, researchers continue to make progress on manure and soil N mineralization tests.

Significance of N Availability to Environmental Protection

Public concerns with farming impacts on water quality resulted in the passage of the federal Clean Water Act in 1972. Environmental regulations and guidelines since then have been established to encourage farmers to apply organic wastes to crops at “agronomic rates”, rather than at disposal rates. The agronomic rate is defined as the minimum amount (e.g., of nitrogen) that is justified based on crop need. Definitions of agronomic rate in some states also include the concept of environmental benefit or protection.

The US EPA requires that biosolids (reclaimed and processed municipal sewage sludge) be applied to cropland at agronomic rates of N. In EPA guidelines for estimating the agronomic rate, both the inorganic N and the portion of organic N that will be mineralized during the first season are counted. The EPA’s guidelines on land application rates of biosolids are based on a specific assumed organic N mineralization rate. This has been criticized as overly generalized, given the well known sensitivity of mineralization to local soil and weather conditions.

Currently in California, regulations require that dairy manure not be applied in a way that pollutes surface waters, although there is no specific limit on manure N rates per acre. In the Central Valley, potentially more restrictive regulations are under development by the Regional Water Quality Control Board. Some dairies may face more stringent limits than currently in force on the number of cows allowed per acre of cropland available for manure application. Currently, evaluation of cows per acre is

based on crop N uptake. Dairy producers will need to manage manure N more carefully. For this, credible estimates of manure N mineralization will be critical.

Definition of Terms Related to N Mineralization

There is some confusion over the terms used to describe “N availability” of organic materials. A suggestion is that the term “N availability” not be used. Instead one or more of the following terms should be used:

Gross N mineralization: The rate of conversion of organic N to inorganic N (ammonium). Usually measured over time periods of hours.

Net N mineralization: The net result of two processes – mineralization and the reverse process, immobilization. Like gross mineralization, expressed as a rate.

Percent or fraction N mineralization: Cumulative net mineralized N, typically over a period of one year or one “season”, expressed as a percent or fraction of organic N. The “decay series” quantity is an example of an annual N mineralization fraction.

First order N mineralization rate constant: The net N mineralization rate, k , expressed as the fraction of organic N mineralized (net) per unit time. Typically the unit of time used is the day. For example, $k = 0.01 \text{ day}^{-1}$ means that 1% of the organic N present on a given day will be mineralized. The first order mineralization rate constant is described by the equation

$$N_m = N_o (1 - e^{-kt}) \quad [\text{Eq. 1}]$$

where N_m (mg kg^{-1}) is the mineralized N at time t (days), N_o (mg kg^{-1}) is the mineralization potential, and k (d^{-1}) is the mineralization rate constant. See below for a discussion of first order models.

Organic N half-life: Length of time (usually expressed in days) that is required for a net 50% of the organic N initially present to be mineralized. The half-life ($t_{1/2}$) is related to the first order mineralization rate constant by the equation

$$t_{1/2} = 0.692/k \quad [\text{Eq. 2}]$$

N fertilizer replacement value: The percent or fraction of organic N that achieves the same crop yield (or in some cases crop N uptake) as obtained by application of specific inorganic N fertilizer rate.

These definitions reveal the need for great caution in interpreting the scientific literature or when using book values of N mineralization to set application rates of organic N materials. Caution is needed due to the following problems:

1. Net mineralization rates are the combined result of two processes (N mineralization and N immobilization), rather than a single process. Because two processes are involved, more factors influence the outcome.

2. Net N mineralization rate is not a reflection solely of the properties of the organic material but also of the environmental conditions including temperature, moisture, and several soil physical, chemical and biological properties.
3. Other N loss or transformation processes can occur simultaneously in the soil with mineralization-immobilization. These include denitrification, ammonia volatilization, leaching, and plant uptake. These processes are difficult to predict and even in controlled experiments are difficult to measure. Also, there are interactions. For example, denitrification is often enhanced in the presence of manure due to the presence of organic C compounds that stimulate microbial activity and consume soil oxygen faster.
4. Traditionally, N mineralization rates have been expressed on a per-year or per-season basis. This makes sense in regions of the world where a single crop is planted in spring and harvested in the fall, and temperatures or moisture are very limiting during the non-crop period, e.g., where the soil is very cold or frozen in winter. This does not apply in much of California where winter temperatures are mild and where double or triple cropping is practiced. Also, because N mineralization of manures and other relatively decomposable organic materials occurs rapidly at first, then more slowly, one should not assume, for example, that if the net mineralization for a year is 30% of the organic N, the amount over a one-month period will be $1/12^{\text{th}}$ of 30%. The actual amount will be greater, depending on the rate constant.
5. One should not use net mineralization percentage to calculate directly the amount of N that will be taken up by plants. For example, application of 100 lb organic N with a 30% net mineralization rate will result in production of 30 lb of inorganic N in the soil. This 30 lb N will then be subject to the same loss pathways (denitrification, leaching, volatilization) as fertilizer inorganic N. Therefore, the crop will obtain less than the 30 lb of the N. Furthermore, mineralized manure N and inorganic fertilizer N could be subject to different degrees of N loss, resulting in different quantities taken up by crops. As explained above, denitrification is stimulated by the presence of C in manure and will often be higher than when the same amount of inorganic N is applied. On the other hand, manure C and N may lead to an increase in the mineralization of organic soil N. Also, nitrate derived from mineralization of applied organic materials may be present in the soil at a different time than the applied commercial N, and this could lead to a difference in leaching losses of N from the two sources.

In summary, practitioners (farmers, crop advisers) should be wary of applying published values for “N availability” to specific situations. They should not assume that experimentally derived mineralization constants can be used directly as the amount of mineralized N that will be taken up by plants or substituted for a like amount of commercial fertilizer N.

Mineralization values

The following discussion will focus on animal manures. Generalized mineralization values are shown in the following table.

Table 1. General ranges of net N mineralization for animal manures

Material	Net organic N mineralized per year
Fresh manure	20 – 70%
Aged/weathered manure	10 – 25%
Cured or nearly cured compost	Net immobiliz. – 20%
Manure solids from anaerobic storage ponds	Unknown – some evidence for 10 – 30%

Few researchers have investigated long-term recovery of N from manure applied to soils. In a three-year pot study with ¹⁵N-labelled poultry manures, N recovery by cereals ranged from 19 to 36% (fresh manure), 17-24% (anaerobically incubated) or 12-14% (aerobically incubated). On average, 62% of manure N was found in the soil after 3 years. Gaseous losses ranged from 7 to 26% of N (Kirchmann, 1989).

Long-term studies at Rothamsted, U.K. on a silty clay loam and a sandy loam showed that more than 100 kg N/ha (89 lb N/acre) per year were lost from soils when large applications of animal manure, sewage sludge and composts were being applied (Addiscott et al., 1991). In other studies at Rothamsted using ¹⁵N-labelled fertilizer, 50-80% of fertilizer N was fertilizer found in the crop, and 10-25% in soil. A key finding was that most of the labeled N was in organic N forms, not in “left over” fertilizer N (Powlson et al. 1991 as cited in Addiscott et al., 1991).

Converting Annual Mineralization Percentages to Rate Constants

As indicated above, a problem with using published annual (or seasonal) N availability values for manure is that they do not tell us what happens over shorter time periods. This is an especially important limitation in California where crops can be planted and manure applied almost any time of the year.

The following summary is drawn from an unpublished manuscript, with permission of Dr. Andrew Chang, Dept. of Environmental Sciences, University of California, Riverside.

Annual decay series values, such as published by Pratt et al. (1973) can be converted to rate constants (fraction mineralized per day) and half-life values by fitting to equations 1 and 2 shown above. Stanford and Smith (1972) and Smith and Paul (1990) developed this approach and published representative values for net mineralization rates and first-order rate constants for some ecosystems.

Other researchers have successfully fit experimental data to models with plant and microbially-derived pools with a range of susceptibility of decomposition. The main criticism of creating a number of pools is that so many parameters are created that the limited quantity of data creates excellent fits for curves regardless of the physical reality of the situation.

Pratt et al. (1973) presented an approach for calculating the yearly rates of N mineralization expressed as a series of fractional proportions of any given application of manure, hereinafter referred to as, a decay series. For fresh bovine waste with 3.5% N, they used a 0.75, 0.15, 0.10, 0.05 decay series; meaning that if 100 kg of organic N were applied in this form, 75% of the N would be mineralized the first year (75 kg); 15% of the remaining 25 kg would mineralize the second year (4kg); 10% of the remaining 21 kg would mineralize the third year (2 kg); etc.

The decay series values for the first year are likely somewhat inflated above actual values, because they include the manure N already in mineral form, as well as N which will be mineralized during the first year. Conceptually, the decay series depicts a first order reaction kinetics. Fitting this decay series into the mathematical form of Eq. 1 results in $k = 3.8 \times 10^{-3} \text{ days}^{-1}$ and a half-life of 182 days for the manure application.

Pratt et al. (1973) determined that much less N would mineralize the first year if the manure had been exposed to the weather elements while deposited and dried outdoors over time before it was collected for disposal. Nitrogen decay series for these manure types vary with the total N contents and their calculated k values and half-life values are given in shown in Table 2.

Table 2. N Mineralization for different types of bovine manure¹.

Decay series	Manure Type	k (days ⁻¹)	Half-life (days)
0.75, 0.15, 0.10, 0.05	Fresh 3.5% N	0.0038	180
0.40, 0.25, 0.06	Dried 2.5% N	0.0014	500
0.35, 0.15, 0.10, 0.05	Dried 1.5 % N	0.0012	590
0.20, 0.10, 0.05	Dried 1.0% N	0.00061	1100

¹The k values and half-life calculations are based on first year of the decay series using Eq. 1.

Many other researchers have experimentally determined rate constants. For dried or relatively fresh manures, most have reported rate constants between the low and high values shown in Table 2, i.e., between 0.00061 and 0.0038.

Other researchers have determined effects of temperature on mineralization and have developed methods for incorporating these effects into predictive models. For example, Griffin and Honeycutt (2000) evaluated growing degree days (GDD) as a predictor of mineralization of N in poultry, swine, beef, and dairy manure. They were able to predict nitrate accumulation in soil across temperature regimes by using GDD.

Future Progress and Research Needs

1. For California cropping systems, N mineralization models that incorporate temperature and moisture effects and use shorter time steps (e.g., daily or weekly) are needed and would be more useful than seasonal or annual values of N mineralization.
2. More knowledge is needed about the mineralization of organic wastes (such as dairy manure) that have undergone decomposition in anaerobic storage ponds.
3. Knowledge of long-term (multi-year) mineralization rates is needed, especially in intensively cropped coarse-textured soils in California. There has been very little research on the capacity of soils to accumulate unmineralized N from manures and other organic materials.
4. An alternative approach to estimation of long-term mineralization rates is the development of a laboratory test for mineralizable N in soils and manures. Progress is being made on this front. For example, Haney et al. (2001) have developed a test in which CO₂ evolution is measured during a 24-hr incubation. They found that the results were highly correlated with N mineralized in heavily manured soils.

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Brassica Cover Crops: Impacts on Plant Nutrition and Pest Management

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Introduction

Cover cropping is an age old agricultural practice that provides benefits to cropping systems such as increasing nitrogen supply to subsequent crops, conserving and cycling nutrients (Ingles et al. 1994), improving soil physical properties (Lal et al. 1991) and reducing erosion (Meisinger et al. 1991). However, cover crops have disadvantages that limit their use, such as direct cash costs and lost opportunity while the cover crop is growing. In the Salinas Valley, cover crops are utilized on about 5% of the acreage (Tom Hearne, personal communication). However, growers are interested in cultural practices that allow them to improve lettuce rotations and that may suppress *Sclerotinia minor*, Lettuce Drop, the key soilborne disease. Unfortunately, given economic pressures such as high land rents and lower returns for rotational crops, effective rotations are not always possible. Mustard cover crops (*Brassica and Sinapis spp.*) have been researched for a number of years in Europe, Australia and the Pacific Northwest as a means of suppressing nematodes and certain soilborne diseases, and they are now being examined in the Salinas Valley for benefits that they may provide lettuce rotations.

Plants in the mustard family, Brassicaceae, contain chemicals such as glucosinolates. Numerous studies have indicated broad biocidal activity of the breakdown products of glucosinolates (Brown and Morra, 1997). Glucosinolates are not phytotoxic themselves, but as the plant cells are ruptured, they are enzymatically converted to isothiocyanates (ITCs), thiocyanates, and other compounds that may provide control of soilborne diseases and weeds. ITCs are generally regarded as the most toxic of the glucosinolate breakdown products. Over fifteen soilborne diseases have been documented in the literature as suppressed by residue from mustard cover crops. Some of these experiments were simple laboratory experiments, but increasingly there are field studies that indicate the impact of mustard residues on soilborne diseases. Diseases that have been shown to be controlled in part by mustard cover crops include: *Sclerotinia sclerotiorum* (Smolinska and Horbowicz, 1999) and *Verticillium dahliae* (Olivier et al. 1999). Mustard cover crops also have impacts on weeds. For instance, rapeseed foliage incorporated into the soil controlled common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) to a level nearly equal that of a standard herbicide treatment (Boydston and Hang 1995). However, more modest control (i.e. 30 – 40%) of redroot pigweed and velvet leaf (*Abutilon theophrasti* Medik.) was observed in soybeans (Krishnan et al. 1998). The levels of ITCs that are found in soils following incorporation of mustard cover crop residues are typically much lower than levels of ITCs applied as commercial fumigants (i.e. Vapam): 1 nmol/gram soil from mustard cover crops versus 517 to 1294 nmol/gram soil for mustard cover crops and Vapam, respectively. This fact coupled with the low residence time of the ITCs in the soil following incorporation - less than 4 days (Morra and Kirkegaard, 2002) have prompted researchers to investigate additional explanations for the beneficial effect observed from mustard cover crops. For instance, Smolinska (2000) observed a weakening of fungal spores and sclerotia by ITCs followed parasitization by soil microbes.

There are no reports in the literature of control of Lettuce Drop with mustard cover crops. However, growers are motivated by the potential that mustard cover crops have for controlling this disease and the number of acres planted to mustard cover crops in the Salinas Valley has increased

significantly in the last two years. The potential for control of soilborne disease provides an economic incentive for growers to invest in cover crop production on additional acres on their ranches. Broccoli is a significant rotational crop for growers in the Salinas Valley with 55,000 acres of production in 2002, and it has been shown to and provides suppression of *Verticillium dahliae* (Subbarao et al. 1999) and *Sclerotinia minor* (Hao and Subbarao, 2003). However, broccoli production is not always as remunerative as would be desirable, and growers are looking at substituting mustard cover crops in lettuce rotations because they are inexpensive and fast to grown and may allow them to potentially rotate back to lettuce more quickly.

Mustard cover crops also may also have significant impacts with regards to cycling nitrogen. Preliminary data indicates that mustard cover crops are capable of absorbing large quantities of nitrogen into the above ground biomass and mineralizing it rapidly upon incorporation into the soil. This may be a useful characteristic of mustards and it merits more investigation; the nitrogen that they mineralize, if accounted for, could potentially affect fertilization practices of subsequent vegetable crops. Over the past two seasons we investigated the impact of mustard cover crops on Lettuce Drop and weeds and have made preliminary observations on their nitrogen cycling characteristics. The results of these studies are reported here.

Objectives

1. To evaluate the impact of mustard cover crops on Lettuce drop and weeds in lettuce
2. To evaluate the nitrogen cycling characteristics of mustard cover crops

Materials and Methods

The following are details on trials that are reported in this article: *Soilborne pests: Trials No. 1)*

Three trials were established in 2003 to evaluate the impact of mustard cover crops on the incidence of Lettuce Drop and weeds. The mustard blend Caliente 119 (see table below) was compared with a bare control or Merced Rye. Lettuce was planted following incorporation of the cover crop and was evaluated for weed emergence at thinning and for the incidence of Lettuce Drop at harvest. In addition, four pot studies were conducted in the greenhouse in which various mustard cover crops and Merced rye residues applied at field-equivalent rates to pots that were seeded with burning nettle (*Urtica urens* L.), common purslane (*Portuaca oleracea* L.) and shepherds purse (*Capsella bursa-pastoris* L.). Subsequent weed emergence was evaluated.

Nitrogen Cycling: Trials No. 2) Eight trials were conducted in 2002 to evaluate the productivity of mustard cover crop in various planting slots and locations in the Salinas Valley. Small plots (3.3 to 6.6 feet wide by 25 to 30 feet long) of six species of mustard cover crops were planted on three planting dates and three locations (cool, moderate and warm sites in the Salinas Valley).

The cover crops were evaluated for biomass production and nitrogen content. *Trials No. 3)* Two trials were established in the fall of 2001 and 2002 comparing the following cover crops: mustard cover crop, Caliente 105; Merced rye (*Secale cereale*); Cayuse oats (*Avena sativa*); and a legume mix (35% Bell Beans (*Vicia faba*), 25% Magnus peas (*Pisum sativum*), 15% common vetch (*Vicia sativa*), 15% Lana vetch (*Vicia villosa* ssp. *dasycarpa*), 10% Cayuse oats). At various intervals during the growth cycle, they were evaluated for biomass production, weed competition, and nitrogen accumulation. At maturity, they were flail chopped and rototilled into the soil.

Mineralization of nitrogen was evaluated every two weeks for 8 weeks following incorporation into the soil. *Trial No. 4)* A trial was established in the winter of 2002 in which areas cover cropped to Pacific Gold and bare control were subsequently cropped to spinach. The cover cropped and bare areas were fertilized with 80 lbs of N/A at mid-growth of the cover crop and no additional fertilizer was applied for the remainder of the trial. The cover crop was flail chopped

and rototilled into the soil in early March, 2003 and was planted to the spinach variety Bolero two weeks later. The yield of spinach, the nitrogen content of the spinach and the nitrate and ammonium content of the soil were evaluated in early May (40 days following planting).

Mustard cover crops used in these studies

Mustard Cover Crop	Type	Species
Caliente 105	Indian and white blend	<i>Brassica juncea</i> and <i>Sinapis alba</i>
Caliente 119	Indian and white blend	<i>B. juncea</i> and <i>S. alba</i>
Erica	Canola	<i>B. napus</i>
Humus	Canola	<i>B. napus</i>
Ida Gold	White	<i>S. alba</i>
ISCI 61	Indian	<i>B. juncea</i>
Martigena	White	<i>S. alba</i>
Pacific Gold	Indian	<i>B. juncea</i>

Results

Soilborne Pests: Trial No. 1. There was a low incidence of Lettuce Drop in the trials conducted in 2003. However, there was a slight but significant reduction in the incidence of Lettuce Drop in one of the three trials (table 1). These results are encouraging, but preliminary, and it will be necessary to evaluate the impact of mustard cover crops at sites with greater disease pressure. Mustard cover crops also slightly reduced the emergence of weeds in these three trials (data not shown). In four greenhouse evaluations, mustard cover crops significantly reduced emergence of shepherds purse and burning nettle over the untreated and Merced Rye cover crop treated pots (figure 1). There were some slight differences in weed emergence among the two species of mustard cover crops that were tested, but in general, it appeared that Indian and white mustards equally suppressed weed emergence.

Nutrient Cycling: Trial No. 2. Mustard cover crops accumulate large quantities of nitrogen in the above ground biomass (table 2). For instance, the cover crops grown in Soledad and King City accumulated over 50 lbs of N in the first 30 to 38 days and by maturity, had routinely accumulated over 250 lbs of N/A. **Trial No. 3** Mustard cover crops mineralized nitrogen at a faster rate than cereals, but slower than legumes in both years of this trial (figure 2). **Trial No. 4** Indian mustard cover crop rapidly mineralized significant quantities of nitrogen and improved the yield and total nitrogen content of a subsequent 40-day spinach crop (table 3).

Discussion

Mustard cover crops have distinct attributes from cereals and legumes. Cereals are generally regarded for high biomass production, fibrous root system and long-lasting beneficial impacts on soil tilth and water infiltration, while legumes are notable for their nitrogen fixation attributes. Mustards provide distinct attributes from cereals and legumes. They can have high biomass, but generally maintain higher concentrations of nitrogen in the above ground biomass which can result in high total N content in their biomass. The nitrogen in their biomass mineralizes nitrogen more quickly than cereals, but not as quite as rapid as legumes. The rapid mineralization of N from mustards can be a source of N for subsequent crop growth as was seen in the spinach trial reported here. This is an area that deserves more investigation as efficient cycling of nitrogen from cover crops to subsequent cash crops is a technique that could reduce the nitrate “leakiness” of vegetable cropping systems. However, the rapid mineralization of nitrogen from mustards could be a

negative attribute. In the Salinas Valley, mustard cover crops are frequently grown in the fall following the cropping season. They are then incorporated into the soil (i.e. in November) and the soil is left fallow over the winter. Under this scenario, there exists the potential for nitrogen contained in the mustards to rapidly mineralize and for nitrate losses to occur with the winter rains. Nitrogen leaching in the winter from mustard cover crops was observed in Eastern Washington (Weinert et al. 2002). However, in another study in Quebec, lower levels of N were seen in leachate water from forage radish plots than the bare control (Isse, 1999).

Mustard cover crops provide a significant input of carbon (C) to vegetable production rotations (table 2). It has been shown that management practices that increase the levels of C to crop production systems helps to retain N in the soil system (Poudel et al. 2001). Lettuce returns low quantities of C to the soil (Mitchell et al. 1999) and mustard cover crops could provide a needed source of C for vegetable crop rotations in the Salinas Valley. The potential that mustard cover crops provide for control of soilborne diseases is an added economic incentive for growers to utilize mustard cover crops in situations where they may not ordinarily consider their use. In these initial studies, mustard cover crops did not have dramatic impacts on weeds or the incidence of Lettuce Drop. However, these studies are preliminary and more long-term studies need to be conducted to examine the cumulative effects of their impacts on soilborne pests. In addition, there may be potential to improve the pest management capabilities of mustard cover crops. For instance, it has been estimated that only 1% of the glucosinolates contained in mustard cover crops is released to the soil (Morra and Kirkegaard, 2002). It is possible that there is untapped potential in mustard cover crops and future research on improving the release of glucosinolates to the soil and improving the residence time of the released toxic breakdown products may improve the control of soilborne pests.

In summary, mustard cover crops have distinct attributes from cereal and legume cover crops. They have the potential to provide a level of control of soilborne diseases and weeds. This may be an added incentive for growers to utilize them, thereby increasing the levels of C that are added to the soil in cool season vegetable production systems. Mustards also have distinct nitrogen cycling characteristics from cereal cover crops which deserves further study to better understand how they may improve nitrogen fertilization practices of cool season vegetables.

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Table 1. Lettuce Drop evaluations at harvest at three sites

Cover Crop Treatment	Chualar	Gonzales	Somavia Rd.	
	No. of diseased plants/30 feet of row	No. of diseased plants/50 feet of row	No. of diseased plants/100 feet of row	Percent infected heads
Merced Rye	0.4	----	----	----
Mustard Cover Crops	0.6	1.2	9.7	2.0
Bare Control	----	2.4	13.1	2.8
LSD (0.05)	n.s.	0.9	n.s.	n.s.

Table 2. March 2002 planting date biomass and nitrogen content evaluations

Variety	Salinas				Soledad				King City ²	
	May 2 (35) ¹		June 4 (68)		May 10 (38)		June 10 (69)		May 10 (30)	
	Biomass T/A	N content Lbs/A	Biomass T/A	N content Lbs/A	Biomass T/A	N content Lbs/A	Biomass T/A	N content Lbs/A	Biomass T/A	N content Lbs/A
Caliente 105	0.45	32.6	4.02	219.8	0.69	66.3	3.38	264.0	0.73	76.2
Martigena	----	----	----	----	0.75	60.5	3.70	278.9	0.58	61.5
IdaGold	0.60	38.2	3.58	227.9	0.82	59.7	4.54	310.0	0.87	88.8
Pacific Gold	0.49	41.1	4.22	189.4	0.65	61.8	3.27	291.0	0.85	79.3
Humus	0.37	25.6	3.61	239.4	0.56	48.3	2.62	261.6	0.46	53.4
Ericca	----	----	----	----	0.62	59.5	2.85	259.0	0.65	74.0
LSD (0.05)	0.04	5.8	0.33	31.2	0.04	3.5	0.33	29.8	0.07	7.2

1 - number in parenthesis are days after planting; 2- trial was terminated before cover crop matured

Table 3. Spinach yield, mineral nitrogen in soil, and nitrogen in spinach tissue at harvest on May 5, 2003

Cover Crop Treatment	NO ₃ in Soil	NH ₄ in soil	Spinach yield (tons/acre)	Percent N in Leaves	Nitrogen/A in Spinach Leaves
Uncover cropped	0.7	0.42	1.6	3.3	105.6
Mustard	2.4	1.12	2.5	4.9	245.0
LSD (0.05)	1.4	0.32	0.4	0.5	40.5

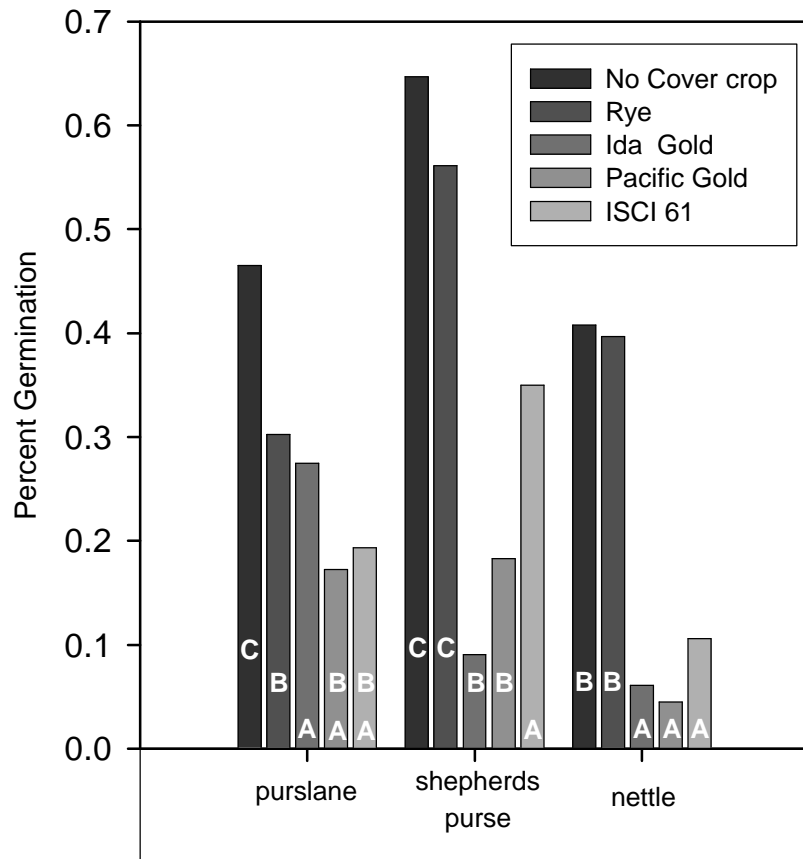


Figure 1. Percent germination of three weeds in pots amended with various cover crops.

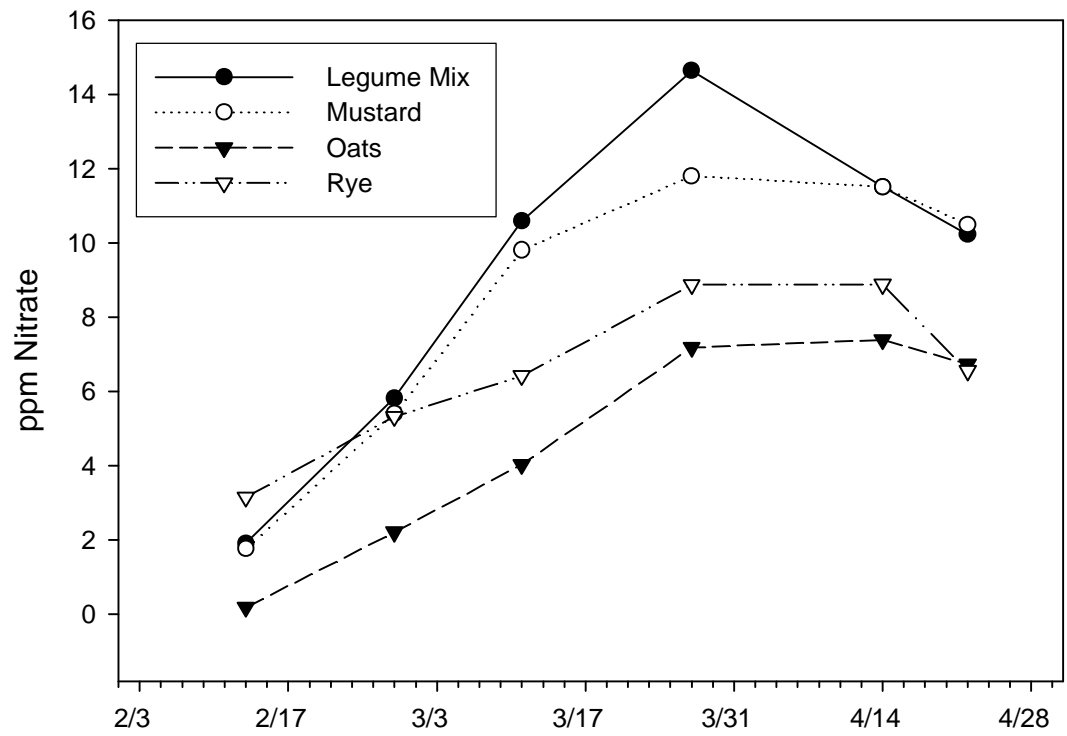


Figure 2. Nitrate release to soil following incorporation of cover crops, 2003 trial

Drip Irrigation and Soil Fertility Management

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The California vegetable industry is in the midst of an irrigation revolution. After many years of slow growth, drip irrigation has finally taken off. Use of drip in both the Central Valley and the coastal areas is now commonplace for the production of tomatoes, peppers, celery, lettuce and other vegetables. While growers recognize that drip irrigation requires radical changes in water management strategies, the impact of drip on soil fertility management is less obvious. The most frequently discussed effect of drip irrigation on fertilizer needs is the potential for reduced N leaching losses through greater irrigation efficiency. There are a number of other ways in which the conversion to drip irrigation may require adjustments to fertilizer strategies. The following discussion highlights some of those issues.

Buried vs. surface drip:

There are two fundamentally different drip irrigation systems for vegetable crop production: 1) temporary surface system that are installed after crop establishment and removed before harvest, and 2) semi-permanent, buried systems that are left in place for multiple crops. Surface systems dominate in the coastal production areas, while buried systems are used almost exclusively in the Central Valley. Appropriate fertility management may be profoundly different with the two systems. With a temporary surface system, phosphorus application is typically done before system installation. The wetting is from the top down, pushing soluble nutrients toward the root zone. Because the system is temporary, and conventional tillage is practiced between crops, there is no significant 'mining' of nutrients from a particular region of the soil profile, nor are the effects of maintenance chemicals (acids, for example) spatially concentrated. By contrast, with a semi-permanent, buried system the surface 4-6 inches of soil may (depending on soil characteristics and system depth) often be too dry for active nutrient uptake. Evaporation from the soil surface may move soluble nutrients into this dry zone, beyond the reach of the crop. Since successive crops will draw the bulk of their nutrients from a confined area in the soil, the nutrient status of that area may change substantially over time. Acid-based products applied through the drip system can change pH of the wetted area, potentially affecting micronutrient availability.

Nitrogen management:

The assumption that converting to drip irrigation will allow a grower to reduce N fertilizer use is an oversimplification. More efficient irrigation will reduce N leaching loss, but growers do not always achieve improved efficiency with drip irrigation; for example, a study of drip irrigation management in commercial celery fields showed that significant over-irrigation was common (Breschini and Hartz, 2002). Also, if yield expectations are higher with drip, additional N may be needed to accommodate the extra crop productivity. For example, if drip increases tomato yield by 6-8 tons/acre, the N in that additional fruit biomass could be as much as 30 lb/acre.

Another reason why drip irrigation may increase N fertilizer requirements is that the limited wetted zone reduces the amount of N mineralization from soil organic matter. This is an issue primarily with buried systems, because most N mineralization occurs in the tillage zone, which may remain dry during much of the season. Tillage practices that confine crop residues to the surface few inches of soil, and irrigating up a crop with the drip instead of sprinklers, will minimize the availability of N in those residues. Lastly, with buried systems, evaporation from the soil surface over time can deposit a considerable quantity of NO₃-N in the dry surface soil; while this N may be recovered by a subsequent crop, it may be largely beyond the reach of the current crop. N fertigated early in the cropping cycle is particularly susceptible to this fate, since crop uptake is relatively slow until mid-season, and

evaporation is more rapid before the crop canopy shades the soil surface.

In summary, N requirements with drip irrigation will not be substantially lower than for *efficiently-managed* conventionally irrigation, and may in some cases be higher. Maximum N efficiency with drip can be achieved by a) efficiently controlling irrigation to minimize in-season leaching; b) sprinkling for stand establishment, thereby increasing the recovery of mineralized N; and c) timing N fertigation to match the crop uptake pattern.

P management:

With appropriate safeguards, phosphorus can be applied through drip lines without chemical precipitation and emitter plugging. However, fertigating P may not be the most efficient approach to P fertilization. The degree to which fertigated P moves with the wetting front is affected by soil texture and pH. In fine-textured, alkaline soils fertigated P may not move more than a few inches from the emitters. Depending on the depth of the tape, that may not be close enough to efficiently supply young plants with limited root systems. Where buried drip systems are used, conventional banding of preplant P fertilizer may still be the most appropriate technique for growing direct-seeded crops. If transplants are used, the transplants can be charged with a shot of P fertilizer as they leave the nursery, or with a starter solution at transplanting, to support growth until roots can mine P applied through the drip tape.

In calculating P requirements for drip-irrigated culture it is important to understand that plant-available P generally declines with soil depth. It is not unusual for the top 6 inches of soil to have a bicarbonate P level 20-40% higher than that of the 6-18 inch depth. Since buried drip concentrates roots deeper in the soil than does conventional irrigation, soil sampling of the primary rooting zone may give a more accurate reflection of soil P status than would the conventional sampling of the top 6 or 12 inches.

K management:

Drip irrigation provides an ideal vehicle for potassium application. Many California soils have a significant capacity to 'fix' applied K, and in these soils only a small percentage of K applied as a preplant or early sidedress is actually taken up by the crop. Fertigating K in small doses during a crop's rapid uptake phase delivers K directly to the concentrated root zone where uptake can occur before significant soil fixation. Partially offsetting this advantage is the fact that, as is the case with P, soil K declines with depth; soil sampling to determine K fertigation needs is most appropriately done by sampling the concentrated root zone, not the entire soil profile. Over several years of cropping the exchangeable K levels may decline in that confined root zone much more quickly than is typically the case in conventionally-irrigated fields, where crops draw K from the entire soil profile, and the K released from crop residue is more readily distributed into the rooting zone. If significant yield increase is expected from the conversion to drip, K application rates may need adjustment upward; for example, each ton of tomato fruit typically contains 4-6 lb K / acre.

Micronutrient management:

Micronutrients are only occasionally an issue in California soils, regardless of the type of irrigation used. The concentration of plant-available micronutrients tend to decrease with soil depth, so fields with buried drip systems are marginally more likely to encounter deficiencies. Another potential problem with buried systems is that over time the use of fertilizers and acid-based maintenance chemicals can lower soil pH in the wetted zone, making some micronutrients less available. This is unlikely to be an issue in installations less than 5 years old, particularly in soils with a high buffering capacity.

Nutrient monitoring:

As in conventionally-irrigated fields, soil availability of P, K, and micronutrients are best assessed by annual preplant sampling. For buried drip systems the sample should be drawn from the primary rooting zone rather than from the entire soil profile. In-season soil NO₃-N testing can be a valuable practice, particularly in the early portion of a cropping cycle, before the crop enters the rapid uptake phase. There is an on-farm 'quick test' method of NO₃-N determination (Hartz et al., 2002) that is accurate enough to guide early-season fertigation decisions. A soil NO₃-N concentration > 20 PPM is sufficient to support crop growth in the short term. Once the crop enters the rapid growth phase (when macronutrient uptake increases dramatically) the interpretation of soil NO₃-N levels is more difficult since, in the confined rooting zone, crop uptake can reduce NO₃-N concentrations quickly. At that point a schedule of N fertigation should be followed, based on assumed crop uptake rate; continued soil NO₃-N testing can be used to help determine whether the fertigation rate is excessive.

The use of soil solution access tubes (also called suction lysimeters) for routine monitoring of macronutrient concentrations in soil solution have been advocated as a technique uniquely suited to drip-irrigated production. There are a number of problems with this technique that make it unreliable, the most important of which is the spatial variability of soil nutrient concentration. The area from which the lysimeter draws soil solution is limited, and the concentration of macronutrients (particularly NO₃-N) is highly stratified in the root zone. Therefore, the solution from one tube may or may not accurately reflect the average of the root zone; to have confidence in this technique, combining samples from instruments in different areas of the field and different locations with respect to emitters would be needed, making this a laborious technique.

Similarly, petiole sap analysis has been touted as an ideal diagnostic for drip irrigation. While this approach has some merit, it has limitations as well. Foremost among these is accuracy. The common 'Cardy' meters used to measure NO₃-N and K in petiole sap are subject to significant errors, due mostly to competing ion effects and fouling of the ion-selective membranes. Even if the meters are maintained properly, and calibrated correctly each day of use, the readings obtained should be viewed as approximations, essentially a 'sufficient/deficient' diagnostic. The measurement precision is simply not good enough to justify endless tweaking of the fertigation schedule. Conventional laboratory analysis will generally yield more accurate results, and it is the only way to get information on P and micronutrient levels in tissue. For an expanded discussion on the value and limitations of tissue analysis see Hartz (2003).

Putting it all together:

Conversion to drip irrigation should require only minimal adjustment of P and K fertility management. Determination of P and K requirements should be based primarily on preplant soil testing, with most P applied preplant as in conventionally-irrigated culture. Where K is required, fertigation is likely to be the most efficient approach. Particularly with fruiting crops like tomato, tissue K concentrations can drop rapidly when maximum growth rate is reached, so the K fertigation schedule should keep ahead of the curve. If substantial improvement in irrigation efficiency is achieved in the conversion to drip, a reduction in overall N use may be possible. The N fertigation program should be based on a general crop template that takes into account the changes in N uptake by growth stage; adjustments to this template (usually downward) can be made based on in-season soil NO₃-N testing of the rooting zone. Tissue analysis should be viewed as a technique to confirm the sufficiency of the fertility plan, rather than the primary diagnostic to drive future fertigation. This is particularly true of petiole sap analysis, given the inherent variability of that measurement.

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Refining Stone Fruit Deficiency and Sufficiency Nutrient Levels

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Introduction

The standard procedure for determining nutritional status of stone fruit trees was established many years ago. It involves taking a sample of mature leaves in June or July and analyzing for all macro and micro nutrients. Tables have been published indicating sufficiency ranges and deficiency thresholds (and sometimes toxicity levels) for each element. These tables were developed from leaves showing deficiency symptoms, from hydroponic experiments with small seedlings and from surveys of healthy and deficient orchards. For some nutrients, there has not been enough experience with deficiencies in the field to establish a threshold. Generally, these studies have not related the nutrient status of the tree to the different components of yield or fruit quality except in a qualitative way.

Over the past 5 years we have developed a system for studying the nutrition of mature peach and nectarine trees in the field. We planted trees in 60 large sand tanks and have been differentially fertilizing them in order to obtain widely varying nutrient contents. The full details of the treatments and results have been presented elsewhere (Johnson et al., 2003) and will not be reported here. For the purpose of this paper only the average fruit weight data from 2002 and 2003 on Zee Lady peach and Grand Pearl nectarine will be used. This information, together with a rather obscure method of analyzing nutritional data, will be presented as evidence for changing the currently established deficiency thresholds.

Boundary Line Analysis

In 1972, Webb proposed the use of a boundary line for many different types of biological data (Webb, 1972). He claimed for a given body of data where there is a cause and effect relationship between two variables, there exists a line at the edge of the data set representing the best performance in the population. In other words, there is a theoretical maximum potential that can be achieved by the dependent variable at any given value of the independent variable. Recently, Schnug et al. (1996) applied this concept specifically to nutritional effects on yield of field crops. With enough data points, a clear boundary line emerges which indicates the loss of yield potential at deficient (and sometimes excess) nutrient levels. Schnug et al. (1995) have proposed a method for mathematically estimating this line. As we analyzed nutritional effects on fruit weight from our sand tank experiment, the data often appeared very scattered. However, it became clear that maximum fruit weight was never achieved at low

levels of any given nutrient. We felt the boundary line approach as described above was a logical way to analyze these data sets. In order to maximize the number of data points, we combined all 60 peach and 60 nectarine trees from 2002 and 2003 to give 240 separate points. Since there were differences in absolute fruit weight between years and varieties, we expressed the data on a relative fruit weight basis, where the largest fruit from a given data set was given a value of 1.

Fruit Weight Analysis

For some of the nutrients, an obvious boundary line could be drawn where relative fruit weight is plotted against the level of that nutrient in leaves. For example, boron probably illustrates this best (Fig. 1) and the relationship seems to remain the same between years and between varieties. This boundary line suggests maximum potential fruit weight is decreased at boron levels below about 25 to 27 ppm. Currently, the published deficiency threshold value for peaches and nectarines is 18 ppm (Johnson and Uriu, 1989).

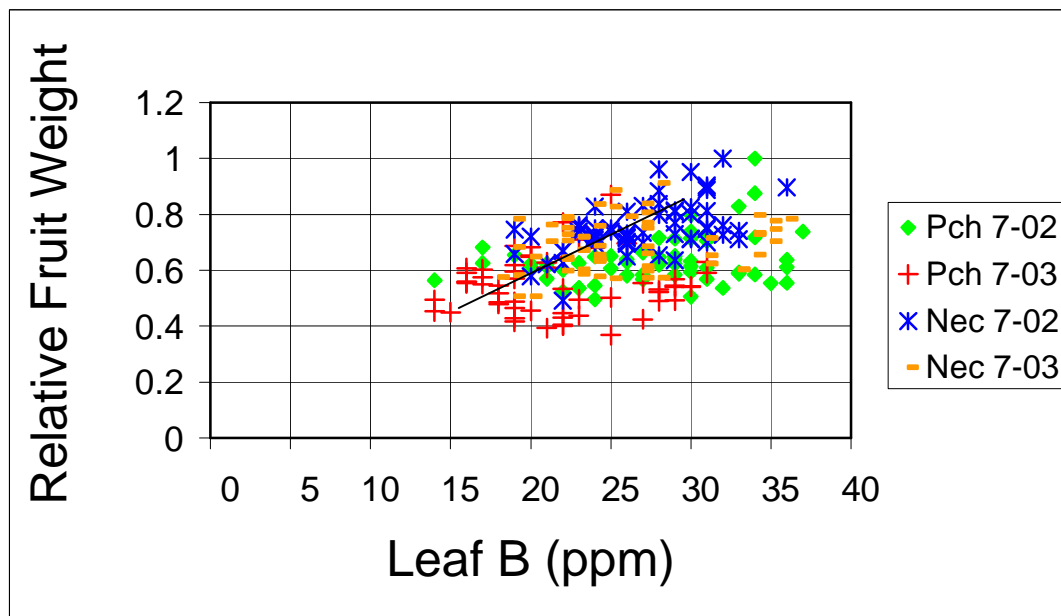


Fig. 1. The relationship between relative fruit weight and July leaf boron content for Zee Lady peach and Grand Pearl nectarine in 2002 and 2003. The boundary line was drawn by hand.

Several other nutrients also showed quite clear boundary lines. Applying the same approach as with boron, deficiency thresholds can be estimated as follows: Phosphorus – 0.12 % (no published value); Copper – 5 ppm (no published value); Zinc – 10 ppm (published value = 15 ppm). Trees with zinc levels below 10 ppm often showed mild deficiency symptoms early in the spring. Above this threshold, no symptoms were observed. The iron (Fe) data set also showed a distinct boundary line, but the nectarine line was offset from the peach. Perhaps different varieties have varying requirements for (or different sensitivities to) a given nutrient such as Fe, which would require the establishment of different thresholds. However, from a practical standpoint it would be difficult to develop these for the hundreds of varieties grown commercially. In addition, the difference between the nectarine and the peach was not great. Therefore, taking the average of the nectarine and the peach, a threshold value of about 60 ppm (based on a May leaf sample) is obtained which is the currently published value.

The situation with the other nutrients is more uncertain. There were not a lot of trees with low magnesium (Mg), but those few trees suggested a clear boundary line decreasing below a value of about 0.4 to 0.5 %. The currently published value of 0.25 % is considerably lower than this, but until we have more data points to solidify the relationship, there is insufficient justification to change it. For calcium (Ca), there was clearly a loss of fruit size below 1.0%, but the scatter in the data made it difficult to

know where to draw the boundary line. The deficiency threshold could be anywhere between 1.0 and 1.7%. Likewise, the situation with nitrogen (N) was also quite confusing. Clearly, N has a strong effect on fruit size and the plot of relative fruit weight vs leaf N supported the idea of a boundary line. However, the line appeared to shift from year to year and between the peach and nectarine. Therefore, it is impossible to determine if the currently published threshold of 2.3% needs to be modified. Finally, for potassium (K) and manganese (Mn), we have been unable to lower the leaf nutrient levels below currently published values, so no reevaluation can be done. Table 1 summarizes our proposed changes for each of these 10 nutrients.

Table 1. Currently published nutrient deficiency thresholds for peaches and nectarines (See Johnson & Uriu, 1989) and proposed changes based on boundary line analysis of sand tank fruit weight data.

Nutrient	Published Deficiency Threshold	Proposed Deficiency Threshold
N	2.3%	ID ^y
P	--	0.12%
K	1.0%	ID
Ca	--	ID
Mg	0.25%	ID
Fe	60 ^z	60
Mn	20	ID
Zn	15	10
B	18	25
Cu	--	5

^zBased on May leaf sample, rather than standard June-July period.

^yID – Insufficient data.

As we continue this experiment for several more years, we will be able to expand the data set, thus establishing clear-cut boundary lines for each nutrient. In addition, we plan to apply this same type of analysis to other parameters of productivity and fruit quality such as vegetative growth, fruit set, flower density, fruit sugar content and fruit defects. Hopefully, the end result will be clearly defined deficiency thresholds that will help stone fruit growers manage tree nutrition much more precisely.

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Early Season Soil Nitrate Monitoring for Cotton Nitrogen Management Decisions

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Introduction

Fertilization of cotton, as with most crops, is conducted primarily with yield and quality objectives in mind. For CA cotton production, objectives often are directed toward optimizing lint yield while maintaining excellent fiber quality. Available information from crop N use estimates, estimated soil test N, and within-season applications (additional foliar or soil-applied N) are all part of the system used to promote good yield performance through maintenance of adequate plant nutrient status to support economic yields. Field experiments evaluating nitrogen management options and responses of CA crops have been numerous over the years, and there is experimental evidence from many of these studies indicating that crop fertilization can be managed so that agronomic, economic, and environmental efficiencies can be significantly improved simultaneously (Hutmacher et al (2001); Boquet and Breitenbeck (2000).

There are several incentives for considering adjustment of the nitrogen management practices of cotton and other CA crops. With cotton, mid- and late-season N management has an impact on the crop's progress toward, cutout, readiness for defoliation and ease of harvesting. High N levels during bloom and early boll filling can also promote vegetative development at the expense of fruit retention under some conditions (Boquet and Breitenbeck (2000). High N levels in cotton can delay harvest, can have a negative impact on the costs of defoliation and efficacy in leaf removal, and can increase problems with some late-season pests (silverleaf whitefly, aphids) that can influence lint quality (Cisneros and Godfrey (1998)). Recent increases in energy costs, which constitute a large part of N fertilizer production costs, are also being passed on as increases in N fertilizer cost.

An additional area of concern is the fate of N applied in excess of plant requirements. If crops grown in the rotation sequence don't have deep enough roots to intercept applied and residual nitrogen, its eventual movement through the soil profile can result in nitrate contamination of groundwater.

Objectives

Objectives were to identify crop growth and yield responses to applied nitrogen (N) in a field study in the San Joaquin Valley (SJV) of California using mostly grower fields, and provide information to improve fertilizer N management using soil residual N estimates. Baseline fertilizer application rates for the lowest applied nitrogen treatments were based on residual soil nitrate-N ($\text{NO}_3\text{-N}$) levels determined on soil samples from the upper 2 ft of soil collected prior to spring N fertilization and within about one to two weeks post-planting each year.

Methods

Experiments were conducted on 5 to 6 grower fields per year in Fresno, Madera, Merced, Kings, Tulare and Kern Counties plus two sites located on the University of CA West Side and Shafter Research and Extension Centers in the San Joaquin Valley. Some field sites were utilized for multiple years (about 1/3 of the field sites over the five-year period), while the remaining sites were newly

chosen each season due to grower decisions on crop rotations. Four field replications in a randomized complete block were used. Four nitrogen (N) fertilization treatments were established each year. Application rates were equal to the desired N treatment level in lb N/ac, minus the calculated soil residual N value in lb NO₃-N/ac determined in the upper 2 feet of the soil profile. Residual N levels were calculated using soil samples collected within about one to two weeks after planting, prior to any N fertilizer applications. If the initial amount of soil residual NO₃-N was greater than 50 lbs NO₃-N/ac, the residual value was used as the baseline for the 50 lb N treatment. All other treatments were added in 50 lb increments after deducting the N present in the baseline.

Soil PO₄-P and exchangeable-K were also tested on soil samples, and fertilizer applications were made as necessary to make sure that soil phosphorus and potassium levels were non-limiting to yield in this nitrogen experiment. In 1996, four treatments of 50, 100, 150 and 200 lb N/ac were applied in late May (prior to the first post-planting irrigation), and in three supplemental treatments (50, 100 or 150 lb N/ac initially applied), a second N application of 50 lb N/ac was applied in June just prior to the second irrigation. In 1997 through 2000, the experiments were simplified to four basic treatments (50, 100 150 and 200 lb N/ac) due to the lack of crop growth and yield responses to split-application treatments.

In all field plot locations, soil samples were collected to a depth of 2 ft at a time within about a week after planting and analyzed for soil NO₃-N and NH₄-N. In addition, for the purposes of evaluating nitrate movement, soil samples were also collected to a depth of 8 feet two times per year in all plots using a power-driven soil core sampling device with a 1.75 inch diameter tube. The two times were within 3 to 4 weeks after planting, and again within 1 to 3 weeks after harvest. Each of three replicate plots within each treatment at each location was sampled in 1 foot increments to a depth of 4 feet, and then in 2 foot increments to an ending depth of 8 feet, resulting in 6 separate samples per sample hole.

The soil samples were kept refrigerated (2 to 4 degrees C) until subsamples were collected for specific analyses. Separate subsamples were collected to evaluate gravimetric soil water content and to provide subsamples to collect 2 N KCl extracts as well as air-dried soil samples. A 2 N KCl extract on the soil samples was used to determine soil NO₃-N and NH₄-N (Carlson (1978)). A separate subsample air dried at 35 to 45 degrees C was prepared from a composite of the three to four sample locations for each depth within each plot, and was subsequently also analyzed for NO₃-N, plus PO₄-P, ammonium acetate exchangeable-K and other nutrient, pH or salinity analyses as each site required (Keeney and Nelson (1982)). Bulk density was determined on 1.75 inch diameter soil core samples collected at 6 inch increments from three field replications per research site using only the post-harvest soil samples.

At all locations, seed cotton was mechanically harvested using commercial-type spindle pickers. Seed cotton yields were weighed in the field and 6 lb sub samples taken for determination of moisture content. Lint and seed yields were calculated and adjusted for moisture content.

Results and Discussion

This report will focus mostly on: (1) basic descriptions of soil nitrate-N (NO₃-N) status at the field plot sites in the immediate post-planting period each year; and (2) changes in soil nitrate profiles between the early season and post-harvest periods; with only a brief discussion of crop yield responses to applied plus residual nitrogen. More extensive discussions of the crop yield responses are available in previous papers (Hutmacher et al, 2001a, 2001b).

The soil NO₃-N levels found in the upper 2 feet of soil profile within a week post-planting covered a wide range of levels each year of the study (Table 1). Although not true in all cases, sites with relatively low residual soil NO₃-N in the upper 2 feet of soil profile generally were in cotton following either cotton, fallow or small grains, while high residual soil NO₃-N more typically were in cotton grown following field corn (for silage or grain), processing tomatoes, or forage alfalfa. It is recognized that there are other forms of soil nitrogen (total Kjeldahl N, NH₄-N), and in this study these forms of N were also determined for comparison purposes in a more limited number of field tests. NH₄-N data was also variable across soils, test sites and years, and NH₄-N levels were generally quite low relative to soil NO₃-N.

Soil N as NO₃-N was converted into lbs N/acre-foot of soil volume, and soil bulk density measured, allowing calculation of net changes in soil test N as NO₃-N during the planting to post-harvest period. Examples of individual site data as well as across-site averages are shown in Table 2. There are recognized limits in interpreting this type of data, since values change over time with processes such as mineralization and denitrification. However, these changes in soil NO₃-N over time still represent a general index of soil changes in N status resulting from crop uptake and other processes / losses. Data in general has indicated that most net depletion of soil NO₃-N was seen in the upper 4 feet of the soil profile (Table 2).

As levels of applied N increased at most sites, soil NO₃-N levels in the 4 to 8 foot zone of the soil profile generally increased. Average changes in soil NO₃-N between the Spring (planting time) and Fall (post-harvest) soil sample timings for 1997 can be used as an example of general findings (Table 2). Negative numbers indicate a net "loss" or a reduction in soil NO₃-N content for all the 0 to 4 foot depths in all N application treatments (50, 100, 150 and 200 lbs N/acre treatments. The positive numbers seen in the 4 to 8 foot zone of the soil profile in the higher applied N treatments potentially indicate there was more NO₃-N moved down into that deeper part of the soil profile during the course of the season. Again, other transformations can also account for part of the observed changes. If the cotton or subsequent crops cannot access this N source, it would be subject to leaching losses if moved further by water moving through the soil profile. Higher beginning soil NO₃-N prevailed in most sites during the 1996 trials, but similar trends were seen in the 1999 and 2000 data (not shown).

Due to soil surface infiltration characteristics, soil water storage capacity and timing of irrigations, half of the sites in this study (Shafter REC, Kern County, Tulare County, West Side REC) had relatively limited potential for significant leaching of NO₃-N into the lower profile. Other sites (data not shown) had soil types which allow significant downward water / solute movement under some crop, weather and management conditions. Careful attention to soil water storage capacity and irrigation timing and amounts could reduce potential downward solute movement beyond the 4 to 8 foot zone in many of these sites.

Irrigation water contributions to the N source available to the crop were monitored at all sites using monthly replicated water sampling and estimates of average water applications per irrigation. In general, most sites had relatively low irrigation water NO₃-N, as mountain snowmelt was a predominant irrigation water supply for many irrigation districts. Most of these sites had consistently less than 20 lbs N/ac as NO₃-N per summer growing season that could be attributed to irrigation water sources, however, there were some sites with higher contributions (in excess of 35 lbs/ac) from irrigation water N within each year.

A primary goal of this study was to develop some basis for use of soil residual NO₃-N levels as part of the decision process in estimating crop N application needs each year. The pre-plant or immediate post-planting soil samples from the upper 2 feet of soil profile were selected as a minimal amount of soil sampling that would be easily collected and inexpensive enough to be accepted by growers and consultants. In an effort to relate yield response data to general ranges of soil residual nitrogen, data were grouped according to soil NO₃-N levels in the upper 2 feet of soil at or within a short time period after planting. Three levels were chosen and the data partitioned into sites differing in likelihood (probability) of crop responses to increasing levels of applied N. These levels chosen were: (1) less than 65 lbs NO₃-N /acre 2 feet of soil; (2) between 65 and 110 lbs NO₃-N/acre 2 feet; and (3) over 110 lbs NO₃-N/acre 2 feet. Although there are several forms of soil N that could be measured, we chose to group the data using soil NO₃, since it is readily measured, thus analyses of soil NO₃ could be readily available to growers from commercial soil testing laboratories. Due to limits in length for this paper, these results are not reproduced here, but can be seen in Hutmacher et al (2001a, 2001b).

Some generalizations were observed with these groupings based on early-season soil NO₃-N, that are useful in assessing the likelihood of yield responses to applied N. When residual soil NO₃-N was less than 65 lbs NO₃-N/acre in the upper 2 feet of soil at planting, cotton yields increased significantly

with increasing N applications in 13 of the 16 sites ($P < 0.05$). When planting time soil residual $\text{NO}_3\text{-N}$ was between 65 and 110 lbs $\text{NO}_3\text{-N/acre}$ in the 2-foot soil depth, yields were significantly affected by increasing N applications in 7 out of 12 sites. Only 3 out of 11 sites showed significant yield increases to increasing applied N when residual soil $\text{NO}_3\text{-N}$ exceeded 110 lbs $\text{NO}_3\text{-N/acre}$ 2 feet.

Cotton yield response to N rates was also affected by environmental conditions among the years when tests were done. Lint yields in 1996 were moderate with a range of about 1000 to 1550 lbs lint/acre across sites. In all but one field site in 1996, there were no significant effects of N treatments on yields. (i.e., increasing N applications did not increase yields). Soil residual N in the upper two feet as well as the lower profile were generally higher than in other years of the five-year study. In 1997, there were more locations with significant yield reductions at the lowest two N application rates (50 and 100 lbs N/acre). In 1997, each location showing significant yield responses to increasing applied N had high lint yields (> 1500 lbs lint/acre), and planting-time soil $\text{NO}_3\text{-N}$ levels in sites with lint yield responses were not uniformly low. 1998 was a difficult cotton production year, with poor weather during much of the season resulting in low yield potentials. Under reduced yield potential, less nitrogen is required for growth and yield, resulting in the expectation that responses to applied N would be less than in years with moderate to high yields. In 1998, out of 8 field sites, only 2 showed significant yield responses to increases in applied N, and those yield responses were small. Yields at most sites in 1999 and 2000 were moderate to high in comparison with 1998, resulting in a higher N demand for growth and fruit production. In these final two years of the study, 4 out of 7 sites (1999) and 5 out of 8 (2000) showed significant yield responses to increasing applied N. However, only 3 of 7 (1999) and 2 out of 8 (2000) had significant yield responses to N applications in excess of 100 lbs N/acre. The largest yield responses were from low-N plots at sites where spring residual soil $\text{NO}_3\text{-N}$ was low (< 60 $\text{NO}_3\text{-N/acre}$ in the upper 2 feet of soil) due to repeated use of the same treatments over several consecutive years.

Growers trying to maximize yields and financial returns during difficult economic times are reluctant to reduce relatively inexpensive fertilizer applications and risk yield losses possible with N deficiencies. However, attempts to reduce applied N to make better use of residual N reserves in the soil will require growers to use more information concerning cropping history, soil N measurements, and even more in-season measurements of crop N status such as petiole nitrate analysis. Economically the cost of management time and analytical services may not represent a saving compared to at-planting applications of an additional increment of inorganic N fertilization. The extra costs may be warranted, however, to adjust application amounts to avoid negative impacts of excess applications on crop responses or soil and water contamination.

Plant nitrogen uptake data was collected at selected sites in three out of the five years in this study, and analyses indicated that with current SJV Acala cotton varieties, about 50 to 60 lbs total N are taken up by plants per bale of cotton produced. Some of that total N in plants will be returned as crop residue in root, shoot and leaf tissue, while some will be removed with harvest, primarily in cotton seed. These results are important in light of the lack of yield response noted in current studies across a wide range of applied N. The results of the current study do not indicate that only 50 or 100 lbs of N/acre are needed to produce high cotton yields under San Joaquin Valley conditions, but rather indicate that soil residual N (from various forms) can serve as a major source of N in addition to applied fertilizer N in meeting crop nitrogen requirements.

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Table 1. Average spring (early post-planting) residual nitrate-N in upper 2 feet of the soil profile by site and year.

Year	Location							
	Soil nitrate-N in upper 2 feet of soil (lbs nitrate-N /acre)							
	Shafter	West Side REC	Merced County	Madera County	Fresno County	Tulare County	Kings County	Kern County
1996	69	149	145	154	186	127	226	135
1997	56	43	141	76	48	87	109	47
1998	37	55	57	104	78	60	53	59
1999	46	36	110	245	-	63	55	76
2000	64	36	107	145	112	70	76	64

Table 2. Mean changes in soil NO₃-N shown as the post-harvest (Fall) sample results minus the post-planting (Spring) soil test NO₃-N as a function of N application treatments and depths (only 50, 100, 150 lbs treatments shown). Data for specific 1997 study sites are shown, while 1996 through 2000 averages were calculated across all study sites. Soil NO₃-N data are grouped as the soil surface to 0 to 4 feet depth versus the 4 to 8 feet depth. A negative number indicates a net reduction in soil NO₃-N during the period from planting through post-harvest.

Applied N Treatment (lbs N ac-1)	Depth in Soil Profile (feet)	Mean changes in soil NO ₃ -N (levels at post-harvest sampling minus values at post-planting timing) (in lb N ac ⁻¹ as NO ₃ -N)								
		1997 example sites				7 or 8 location averages by years				
		Shafter REC	Kern County	Tulare County	Kings County	1996 8 sites	1997 8 sites	1998 8 sites	1999 7 sites	2000 8 sites
50	0-4	-86	-78	-98	-100	-103	-92	-74	-84	-87
	4-8	-7	-2	4	-3	-5	-12	-16	-27	-13
100	0-4	-62	-59	-67	-103	-77	-78	-82	-72	-70
	4-8	2	-7	-1	-3	9	-8	9	-15	-9
150	0-4	-46	-37	-70	-56	-59	-50	-38	-53	-50
	4-8	0	-4	1	21	16	12	22	8	15

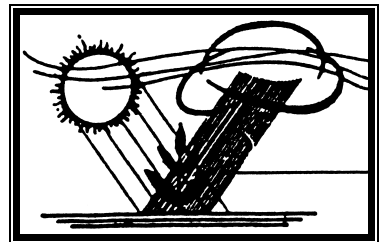
Session II
Impacts of Water Regulation
On
California Agriculture

Session Chairs:

Larry Schwankl, UC Davis, Dept. of Land, Air & Water Resources

Ben Nydam, Dellavalle Laboratory, Inc.

James Ayars, USDA-ARS



“Water Transfers” – Have We Learned Anything Lately?

Outline of Remarks by
Van Tenney
Glenn-Colusa Irrigation District
at the American Society of Agronomy Conference
February 3, 2004

A. Types of Water Transfers

- Short Term versus Long Term
- Conservation Transfers
- Land Idling Transfers
- Groundwater Transfer
 - Sustainable (Safe Yield) Transfers
 - Groundwater Mining
- Water Right Transfers

B. Purposes of Water Transfers

- To Provide for future growth of the State?
- To Improve water supply reliability
- To operate as an important strategic element of an integrated resource program that helps to avoid legislation that:
 - Forces adverse institutional changes
 - Forces an adverse definition of reasonable & beneficial use
 - Forces adverse groundwater regulations
 - Forces outright reductions in water rights

C. Rules that govern Water Transfers

- USBR and DWR Oversight to avoid injury to 3rd parties
- Stream Interaction
- The Delta Bottleneck
- Napa Proposal

D. Obstacles to Effective Water Transfers

- Third Party Impacts
 - Overall Economic Impact versus Individual Impacts
 - Potential Legislation
- Reasonable and Beneficial Use
 - What the Salton Sea & Giant Garter Snake have in common

Changes in Water Policy Motivate Land and Water Sales

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Introduction

Voluntary transfers of water among users have the potential to increase the values generated with limited water supplies by enabling water to be used where its incremental value is greatest. Many authors have examined the economic rationale for allowing water transfers from agriculture to urban areas and among agricultural users (Carter et al., 1994; Anderson and Landry, 2001; Tisdell and Ward, 2003). The opportunity to engage in water transfers increases the opportunity cost of current decisions regarding water use. Thus, the opportunity to sell water can motivate farmers and other water users to improve water management. Transfers enable potential buyers to enhance their water supply portfolio at a lower incremental cost than might be required to develop alternative water sources (Vaux and Howitt, 1984).

Several states in the American southwest are promoting water transfers to increase the values obtained with existing supplies and to reduce or delay the need to construct new dams and reservoirs. The city of Tucson, in southern Arizona, began purchasing farmland for the purpose of obtaining groundwater for municipal uses in the mid-1960s (Saliba and Bush, 1987). Several large cities in Arizona transfer both surface water and groundwater from agricultural lands that have been retired from production, in exchange for the sale of their water rights. Voluntary water transfers are considered a beneficial use of water in California, where there is considerable potential for enhancing economic values by moving water from agriculture to the cities. Values also can be enhanced by moving water from areas where it is used to produce field crops and pasture to areas where farmers produce fruits, vegetables, and other higher valued crops.

California has established a Water Transfers Office within its Department of Water Resources to assist individuals and public agencies seeking to purchase or sell water in market transactions. In general, the state supports voluntary water transfers, provided that third-party impacts are minimized (Water Transfer Workgroup, 2002; Johns, 2003). In a recent transaction involving the state's entitlement to water from the Colorado River, the San Diego County Water Authority has agreed to purchase water from the Imperial Irrigation District for an initial period of 45 years, with a renewal term of 30 years (SDCWA, 2003). Some of the issues raised during the negotiation of that agreement include the potential reductions in demand for agricultural labor and reduced purchases of supplies from merchants in the Imperial Valley, due to land fallowing. The San Diego County Water Authority has agreed to provide up to \$10 million to offset the potential regional economic impacts of temporary land fallowing (SDCWA, 2003).

The goal of this paper is to describe in detail one of the most recent water transfers to be proposed in California: the transfer of water from the Broadview Water District in the San Joaquin Valley to the Pajaro Valley Water Management Agency, located on the central coast of California. There are several characteristics of the transfer that motivate our analysis:

- 1) The transfer involves the movement of water from one agricultural district to another,
- 2) The water will be obtained by purchasing all of the land in Broadview and re-assigning the water supply contract to the Pajaro Valley Water Management Agency (PVWMA),
- 3) The PVWMA has negotiated individual purchase and sales agreements with all landowners in the Broadview Water District,
- 4) Irrigated agriculture largely will be discontinued in Broadview after the water is transferred, because the District does not have an alternative source of water, and
- 5) The issues motivating landowners in Broadview to sell their land and water supply to a prospective buyer are similar to issues facing many farmers in California's San Joaquin Valley.

We focus our analysis on the issues motivating landowners in the Broadview Water District to seek a buyer for their land and water. Those issues include changes in water allocation policy and water quality regulations that have occurred in California since the early 1990s. The Central Valley Project Improvement Act of 1992 requires the re-allocation of 987.2 million m³ (800,000 acre-feet) of CVP water supply from farms to environmental uses. The annual impacts of that re-allocation on farm-level water deliveries have been most notable in areas south of the delta formed by the Sacramento and San Joaquin Rivers. Issues regarding salt loads and selenium in agricultural drainage water have led to new restrictions on the volume of drainage water that can be discharged to the San Joaquin River. The combination of persistent reductions in irrigation water supplies and increasing restrictions on the discharge of drainage water have generated substantial concerns regarding the long-term viability of irrigated agriculture on the west side of the San Joaquin Valley. Those concerns, which we describe in this paper, have motivated landowners in the Broadview Water District to sell their land. If the land sale is completed, Broadview's water supply likely will be re-assigned to other agricultural lands within California.

Broadview's Motivation for Selling Land and Water

The 4,000-ha (10,000-acre) Broadview Water District is located on the west side of the San Joaquin Valley of California, approximately 80 km (50 miles) west of the city of Fresno. The District was formed in the mid-1950s for the purpose of obtaining a water supply contract from the U.S. Bureau of Reclamation. Farmers in the area had been using groundwater for many years, but the salinity of that water had increased to levels that were no longer suitable for crop production. Surface water stored in Lake Shasta in northern California is delivered to Broadview and other districts in the region via the Sacramento River and the Delta-Mendota Canal.

The major crops produced in Broadview include cotton, tomatoes for processing, cantaloupes, and seed alfalfa. In a typical year, with a full water supply, farmers plant about 1800 ha of cotton, 400 ha of processing tomatoes, 320 ha of cantaloupes, and 280 ha of seed alfalfa. Some land is left fallow when the annual water supply is not sufficient to irrigate all land in the District. Prior to 1990, land fallowing due to a limited water supply occurred only in 1977, when drought conditions resulted in a 75% reduction in the District's water supply. By comparison, land fallowing was required in three consecutive years in the 1990s, due to water supply reductions caused by persistent drought conditions and by public policies enacted to protect endangered species (Loomis, 1994).

Crop yields in Broadview have been higher than the average yields reported for Fresno County in most years since the District obtained its drainage water outlet in 1983. However, since 1998, the yields of cotton and tomatoes have declined with respect to the average yields reported for Fresno County (Wichelns et al., 2002). The causes of this apparent shift in productivity might include increasing soil salinity in the District, due to persistent recycling of saline drainage water in recent years. That strategy has been made necessary by reductions in surface water deliveries and restrictions on the volume of drainage water that can be discharged from the District. The prospect of continuing difficulties regarding water supply and drainage management likely have contributed to the desire of many land owners in the District to sell their land.

In January 2000, the Broadview Water District issued a Request for Bids to purchase all farmland in the District. The announcement was motivated by several considerations:

1. The District had been approached earlier by a consortium of individuals expressing an interest in purchasing lands within Broadview for the purpose of gaining access to the surface water supply contract associated with those lands,
2. The negotiations with that consortium ended without a successful sales agreement,
3. The District was considering major upgrades in its water delivery and drainage systems and the projects would have required substantial long-term financing and repayment, and
4. Several landowners in the District expressed an interest in selling their land, if an appropriate transaction could be arranged.

The Broadview Board of Directors chose to issue the Request for Bids to determine if a willing buyer was available, before moving forward with major upgrades of the District's facilities. A time dimension was described in the Request for Bids, so that the Board of Directors could proceed with its investment program in a timely fashion, if a willing and qualified buyer was not available.

The desire among landowners to sell their land in Broadview and to terminate their farming or leasing operations there developed over many years. Beginning in the mid-1980s, landowners and their tenant farmers in Broadview have been required to address several challenging issues regarding drainage water management and water supply. The adjustments that the District and the farmers have had to implement as a result of those issues have raised the cost of farming. In addition, the reliability of the District's water supply has been reduced by changes in water supply policies required by the Central Valley Project Improvement Act of 1992 and by implementation of several provisions of the Endangered Species Act of 1973. Those changes and new restrictions on the volume of drainage water that can be discharged from districts in the San Joaquin Valley have reduced the probability that irrigated agriculture will remain viable in the region.

Issues regarding the discharge of saline drainage water from Broadview and other districts in the region arose in the mid-1980s, when elevated concentrations of selenium at the Kesterson National Wildlife Refuge were attributed to agricultural drainage water that had been used as a source of water supply (Letey et al., 1986; California 1987; National Research Council, 1989). Subsurface drainage systems are installed beneath 3,035 ha (7,500 acres) in Broadview and, since 1983, most of the drain water has been discharged into ditches that carry commingled surface and subsurface drainage water from several irrigation and drainage districts into the San Joaquin River. The subsurface drain water contains boron, selenium, and other elements that occur naturally in the region's soils and are mobilized by the delivery of irrigation water.

The Broadview Water District began implementing economic incentive programs in 1989 to motivate farm-level improvements in water management practices that would reduce the volume of subsurface drain water generated in the District. Those programs have included increasing block-rate prices for irrigation water, farm-level allotments of the District's annual water supply, low-interest loans for investments in gated pipe and sprinkler irrigation systems, and restrictions on the discharge of surface runoff (Wichelns and Cone, 1992a, 1992b; Wichelns et al., 1996a; Ayars et al., 1998). The programs largely have been successful in motivating farmers to improve water management, resulting in smaller water deliveries per hectare, smaller volumes of surface runoff, and some reduction in the volume subsurface drain water.

Implementing some of the programs has raised the average cost of farming, as farmers have hired additional irrigators and invested in gated pipe and sprinkler systems (Wichelns et al., 1996b, 1997). Drainage service fees also have increased, over time, to pay for participation in a regional program in which drainage water from several districts is collected, transported, and discharged into a stream that enters the San Joaquin River. Water costs have increased also, particularly in years when water supplies to irrigation districts in the San Joaquin Valley are reduced due to persistent drought conditions or to new policies that require changes in the operation of water project facilities to enhance environmental benefits. The U.S. Bureau of Reclamation imposes a higher per-unit cost of water in years when the supply is reduced, in order to recover its fixed cost of water delivery operations. In addition, some farmers purchase water in market transactions at relatively high prices in years when supplies are not adequate to satisfy their irrigation requirements.

The persistent reductions in annual water deliveries, and the outlook for continuing pressure on water supplies in California, have added substantial uncertainty to near-term and long-term perspectives regarding the viability of agricultural production. Broadview farmers expect to receive, on average, only 60% of their annual contract supply of 8,843 m³ per ha (2.9 acre-feet per acre). That amount, 5,306 m³ per ha (1.74 acre-feet per acre), is not sufficient to maintain production on all land in the District every year, while also leaching salts from the soil profile in some years. As a result, farmers must leave some land fallow, resulting in a higher average cost of farming, as taxes and assessments must be paid on all of their land.

The future cost of addressing drainage issues also is uncertain. Despite implementing aggressive management strategies for many years at both the district and farm levels, the volume of drainage water and the loads of salt and selenium collected in Broadview drainage systems remain larger than the District will be allowed to discharge in future. California's Central Valley Regional Water Quality Control Board is preparing new rules that will require farmers and districts to make further reductions in the salt and selenium loads discharged into the San Joaquin River. Districts also will be required to implement more aggressive monitoring programs to generate better information regarding the source and movement of those constituents in watersheds. It is not yet clear that farmers will be able to sustain the higher costs required to implement the new programs or that they will be able to comply with the

tighter restrictions on discharges. If the costs are excessive, or if the allowable discharges are too small to accommodate leaching requirements, irrigated agriculture could lose its economic viability in the region.

Conclusions

The issues described above have impacts on both the current returns in farming and the asset values associated with agricultural land in the San Joaquin Valley. Current returns are reduced directly by higher costs of farming, while asset values are reduced by lowered expectations regarding long-term profitability. Tenant farmers will earn smaller net revenues if the rental rate for land remains the same, while their costs of production increase. Landowners will earn smaller annual revenues if they adjust their rental rates downward to reflect the higher prices that tenant farmers must pay for water and for inputs required to comply with drainage water management strategies.

Asset values are reduced in the region by the outlook for higher costs of farming and uncertainty regarding water supplies and drainage water discharges. The value of agricultural land in any region is determined by calculating the present value of the future stream of net revenues that a buyer can expect to earn from the land in agriculture. Higher production costs and increased uncertainty reduce those expected values.

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A Buyer's Perspective on the California Water Market

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Introduction

The state of California supports the voluntary transfer of water from willing sellers to buyers who seek to use the water for an alternative purpose or at a different point of delivery, provided that third-party impacts are minimized (Water Transfer Workgroup, 2002; Johns, 2003). Short-term leases of water enable farmers to obtain supplemental water supplies in some years, while the permanent sale of a water right or a delivery contract can enhance the long-term supply for a farmer or an agricultural district. Voluntary transfers also enable residential developers and municipalities to obtain the long-term water supply needed to support economic development in areas with increasing populations and commerce (Vaux and Howitt, 1984; Carter et al., 1994).

The Pajaro Valley Water Management Agency (PVWMA) is an agricultural district seeking to enhance its long-term water supply by permanently acquiring federal Central Valley Project (CVP) contract rights. This effort is one component of a comprehensive program to address problems of seawater intrusion and water quality degradation caused by persistent groundwater overdraft in the Pajaro Valley. Other components of the program include water recycling, conservation efforts, conjunctive water management, and water pricing strategies that reflect the increasing cost of obtaining water supplies (PVWMA, 2002).

The goal of this paper is to describe PVWMA's initial experience in the California water market. In cooperation with two other districts, the agency already has acquired a joint CVP contract assigned from Mercy Springs Water District, a small irrigation district on the west side of the San Joaquin Valley. The agency is now working with the same two districts to purchase lands within the Broadview Water District for the same purpose. These two transactions will enable the agency to enhance the reliability of its water supply, while also reducing pressure on groundwater resources.

Motivation for Seeking Additional Water

Located on Monterey Bay, the Pajaro Valley includes approximately 30,000 acres of strawberries, raspberries, lettuce, fresh market vegetables, apples, flowers, and other high-value crops. Agriculture is the main industry, with farm revenues totaling approximately \$500 million annually. About 80,000 people live in the Pajaro Valley, slightly more than half of them in and around the city of Watsonville, which lies at the approximate geographic center of the valley. More than 95 per cent of current water demand is supplied by pumped groundwater, with farmers, the city, and rural homeowners tapping the same coastal aquifer system. Conditions of groundwater overdraft and seawater intrusion have been documented in numerous studies, dating as far back as the early 1950's (California, 1953). While the fundamental problem has been repeatedly and well documented over time, it has proven possible until recently to avoid serious economic impacts by relocating wells further inland or in deeper aquifer strata (PVWMA, 2002).

The Pajaro Valley was one of three areas originally identified for inclusion in the San Felipe Division of the Central Valley Project. The other two areas, Santa Clara and San Benito Counties, constructed projects and began taking CVP deliveries in the 1980's, but local politics were such that the Pajaro Valley did not. As opinions continued to differ, PVWMA was formed by the legislature as a California special district in 1984 and approved by a local referendum. With explicit responsibility to manage surface and groundwater resources in the Pajaro Valley, PVWMA has pursued a fifteen-year public planning process to evaluate alternatives and develop a comprehensive "Basin Management Plan." The agency's finalized plan, adopted originally in 1993 and revised in 2002, sets forth a program for implementing a range of demand management strategies and supplemental supply projects, including an imported water project linked to the San Felipe Division (PVWMA, 2002).

Inaction in the Pajaro Valley on the import question had serious consequences. The original San Felipe authorization had reserved 19,900 acre-feet per year of CVP supply for the Pajaro Valley, but this potential supply is not presently available as a result of the Central Valley Project Improvement Act of 1992 (CVPIA). Among its many provisions, the CVPIA prohibits the U.S. Bureau of Reclamation (USBR) from entering into new CVP contracts – with PVWMA or other potential new contractors – until various environmental improvements are realized. Unwilling and unable to wait, PVWMA has entered the California water market to acquire its needed import supplies. To prepare for taking deliveries, PVWMA has certified an Environmental Impact Report on the Basin Management Plan, has worked with USBR to amend its CVP water rights to include the Pajaro Valley as an allowed place of use, and is in the process of working with USBR to complete an Environmental Impact Statement which will allow PVWMA to connect its import pipeline to the existing San Felipe Division facilities (USBR, 2003).

The Basin Management Plan recognizes a role for annual transfers, but implementation of the plan is predicated on acquisition of sufficient permanent supplies to justify capital facilities construction costs in excess of \$130 million. According to its current implementation schedule, PVWMA will complete construction of its 23-mile import pipeline, irrigation distribution system, wastewater recycling project, and related facilities by the end of 2006. Delivery of import supplies is scheduled to begin in 2007 (PVWMA, 2002).

Mercy Springs Contract Assignment

In 1999, PVWMA participated in one of the first successful CVP contract assignments, acquiring 6,260 acre-feet of annual CVP contract supply from willing seller landowners in Mercy Springs Water District, located in northern Fresno County. This was a joint acquisition by PVWMA, partnering with Santa Clara Valley Water District (Santa Clara) and Westlands Water District (Westlands). According to the terms of the deal, PVWMA retains options to buy out the other two district interests beginning in 2009. The Mercy Springs acquisition, subject to the same CVP shortages as other south-of-the-Delta contracts, represents about one-quarter of PVWMA's existing import supply need.

Broadview Contract Assignment

PVWMA is seeking to meet its remaining import supply need through a CVP contract assignment from Broadview Water District (Broadview), also located in northern Fresno County. Concerned with the long-term viability of continued farming in Broadview, the thirty landowners in the district collectively issued a Request for Bids in 2000, seeking a purchaser of their 10,000 acres of land and 27,000 acre-foot per year of CVP contract supply (Wichelns and Cone, 2004). Negotiations proceeded with varying intensity for more than two years, culminating in January 2003 with separate but parallel agreements between PVWMA and each of the Broadview landowners. Because Broadview's CVP contract amount exceeds PVWMA's current need, PVWMA subsequently entered

into a partnering agreement with its Mercy Springs collaborators, Santa Clara and Westlands. The three parties are further exploring the possibility of making some of the Broadview supply permanently available to the Environmental Water Account. In the meantime, PVWMA's contracts with the thirty Broadview landowners require PVWMA to complete the necessary environmental documentation and other terms of purchase by July 2004. Once escrow closes with the Broadview landowners and the CVP contract is assigned, PVWMA will be seeking to resell the Broadview lands, most likely for dryland farming or grazing.

Discussion

Pajaro Valley's venture into the California water market derives both from its critical import supply need and from its unusual ability, for an agricultural district, to compete with other potential purchasers. The yields and revenues obtained from farming in the Pajaro Valley are substantially greater than in most other areas of California. As a result, agricultural land values and the average value of water used in agriculture are correspondingly higher. Annual leases for agricultural land exceed \$2,500 per acre in much of the Pajaro Valley, while agricultural leases in the San Joaquin Valley generally are less than \$200 per acre. With implementation of the Basin Management Plan, annual water costs for strawberries in the Pajaro Valley are anticipated to increase to approximately \$900 per acre by 2007, but this water cost will represent less than three per cent of total farm production costs and should in time be offset by moderated future increases in land lease rates (USBR, 2003). On the other hand, failure to solve the long-standing seawater intrusion and overdraft problems could result in losses to the local economy exceeding \$350 million annually, including more than 9,000 lost jobs (USBR, 2003).

Based on PVWMA's experience, transactional costs and uncertainty remain serious impediments to permanent supply acquisition. Costs related to land conversion and resale, environmental documentation, mitigation of third-party impacts, public participation, and legal consultant fees will likely have added five to ten per cent to the overall purchase price by the close of escrow in the Broadview transaction. Moreover, these transactional costs must be incurred without secure knowledge that the deal will, in the end, result in a successful contract assignment.

Conclusions

Through a unique set of circumstances, Pajaro Valley Water Management Agency (PVWMA) finds itself dependent on the emerging California water market for a solution to long-term conditions of groundwater overdraft and seawater intrusion in the Pajaro Valley. The outcome for PVWMA at this point in time looks promising, but accessing the water market has proven challenging and expensive, even given a strongly motivated buyer and seller and favorable transactional circumstances.

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Watershed Coalition Approaches to Ag Discharge Regulation
California Plant and Soil Conference
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Background:

California Regional Water Quality Control Boards regulate discharges of waste under the authority of the Porter-Cologne Water Quality Control Act (Porter-Cologne Act)(California Water Code 13000 et seq) and the federal Clean Water Act (CWA). The federal CWA creates a complete exemption for irrigation return flows and agricultural storm water runoff. The passage of the Porter-Cologne Act in 1969 included an assumption that most agricultural discharges would be waived from requirements to file reports of waste discharge or be subject to direct regulation.

Consistent with Porter-Cologne, the California Regional Boards issued a waiver of waste discharge requirements for irrigation return water and storm water runoff in 1982. The waiver did not include any monitoring or reporting elements.

In 1999, Senate Bill 390 amended the California Water Code to terminate existing waivers effective December 31, 2002, and create a maximum term of five (5) years for all new waivers. This legislative action led to development by the California Regional Water Quality Control Board, Central Valley Region of new waivers, with conditions, for irrigation return flows and agricultural storm water runoff.

The Central Valley Regional Board took action in December 2002 to establish a Conditional Waiver (December Waiver) with a term of three (3) years. The December Waiver promoted development of watershed groups to represent individual dischargers within a watershed or sub-watershed. The December Waiver also required monitoring and reporting elements for the group. Similar conditions, although less extensive in scope, were established for individual dischargers not participating in these groups.

In July 2003, the Central Valley Regional Board rescinded the December Waiver and adopted a new Waiver (July Waiver). This action was taken upon consideration of public input and testimony from a broad array of agricultural, urban, and environmental interests. The July Waiver continues to promote Watershed Coalition Groups as well as an extensive monitoring and reporting program and expires in December 2005.

Formation of Coalition Groups:

At least eight (8) Coalition Groups have filed the Notice of Intent and General Report in compliance with a November 1, 2003 reporting obligation set forth in the July Waiver. These Groups are listed below:

California Rice Commission
Eastside San Joaquin Water Quality Coalition
Root Creek Water District
Sacramento Valley Water Quality Coalition
San Joaquin County and Delta Water Quality Coalition
Southern San Joaquin Valley Water Quality Coalition
Westlands Water District
Westside San Joaquin River Watershed Coalition

In most cases, local water agencies played a key role in the development of these coalitions, working with landowners, county Ag commissioners, and county farm bureau executives to form a collaborative approach to water quality monitoring and response for the irrigated Ag community. Many of the Coalition Groups were formed around watersheds or sub-watersheds, in recognition of the economic benefits of developing monitoring and response programs on a regional scale with emphasis on cultural practices unique to that area.

Coalition Deliverables:

The July Waiver requires each Coalition Group to submit a number of reports and documents, beginning with a Notice of Intent and General Report on November 1, 2003. The Notice of Intent and General Report must include basic contact information, a map of lands included in the Coalition, a general description of the watershed(s) included in the Coalition, a commitment to serve as coordinator for dischargers within the watershed(s), and must be certified under penalty of law by an authorized representative of the Coalition.

The July Waiver also required that each Coalition submit a Membership Document on November 1, 2003 containing information for each individual discharger who has knowingly elected to be part of the Coalition Group, including name of the owner or operator, assessor parcel number(s), Section, Township, Range, and the closest downstream water body. Contact information, including address and telephone number, is to be maintained by the Coalition Group and provided to the Regional Board upon request.

The Membership Document requirements were subsequently stayed by the State Water Resources Control Board (State Board) on October 27, 2003 in response to an appeal of certain aspects of the July Waiver by agricultural and environmental interests. On December 5, 2003, the State Board issued a draft order in response to the appeal, including proposed modifications of the Membership Document. These proposed modifications, which will be considered by the State Board in January 2004, appear to remove the “knowingly elect” provision of the Membership Document and require the Coalition Groups to maintain all information and provide it upon written request by the Regional Board if water quality standards are exceeded.

By April 1, 2004, Coalition Groups are required to submit a Watershed Evaluation Report and a Monitoring and Reporting Program (MRP) to the Regional Board. The Watershed Evaluation Report must contain map(s) of the watershed showing irrigated lands (including crop type) and drainage and discharge locations, information on crops grown, production practices, chemicals used and application methods, an inventory of management practices, historical water quality monitoring results, known water quality issues, and known programs addressing water quality issues within the

watershed.

The MRP must be designed to assess the impacts of discharges to surface water, the degree of management practices in place to reduce discharges that affect water quality, the effectiveness of management practices, the concentration and load of waste in discharges and the compliance with existing water quality objectives. The MRP is set forth in three (3) general phases. Phase 1 shall include analysis of physical parameters, drinking water constituents, pesticide use evaluation and toxicity testing. Phase 2 will include general physical parameters, pesticide use evaluation, and chemical analysis of pesticides, metals, inorganic constituents and nutrients. Phase 3 shall determine statistically significant changes in waste concentrations based on various management practices.

Phase 1 monitoring must begin no later than July 1, 2004. Phase 2 monitoring is expected to begin no later than two (2) years after the start of the first phase. Phase 3 monitoring shall begin no later than two (2) years from the start of Phase 2 monitoring. The first annual MRP report of Phase 1 monitoring results is due April 1, 2005.

The Coalition Approach:

Dischargers of irrigation return flows and storm water face three (3) general alternatives for compliance with state and federal law regulating waste discharges. A discharger may seek to comply with the Waiver as an individual, seek regulation under an individual Waste Discharge Requirement, or seek representation as a member of a Coalition Group.

Coalitions appear to be the most effective and efficient alternative facing individual dischargers at this time. Individual compliance requires preparation of a specific farm evaluation report and monitoring program similar in content, albeit slightly less comprehensive, to the Coalition requirements outlined above. Based on estimates developed by the California Farm Bureau Federation, costs to prepare the initial evaluation range from \$6,000 to \$10,000 per farm, followed by monitoring program costs that range from \$3,000 to \$6,000 per farm per year.

While the scope and cost of the monitoring at the watershed level increases for Coalitions, the ability to spread these watershed-based costs across a larger acreage significantly reduces the cost to the discharger. Most Coalitions are in the early stages of developing programs, which will ultimately require Regional Board approval, and can only provide general estimates as to cost at the farm level. At the present time, estimates of costs from various Coalition Groups throughout the state run from \$1 to \$10 per acre per year.

The Southern San Joaquin Valley Water Quality Coalition has established a Steering Committee to develop strategies and policies to guide development of local responses to the Ag Waiver. Within this Coalition, each river (Kings, Kaweah, Tule, and Kern) has developed a sub-watershed approach to implementation of the Ag Waiver. This sub-watershed approach allows each region within the Coalition to develop monitoring and response programs that are specific to the issues in that area.

To assist with the development and review of monitoring programs, and to implement response programs, each sub-watershed is developing a technical committee, consisting of representatives of stakeholders. This committee is expected to include representation from the county Ag commissioners, county farm bureaus, National Resource Conservation Service, water districts, and others.

As data is collected through the monitoring program, results will be evaluated to determine if response programs are necessary. Development of responses is expected to focus on promotion of

best management practices to alter the irrigation method and/or application of chemicals that have possibly contributed to the monitoring result. Promotion of these practices will be encouraged through the Ag commissioners, water districts, farm bureaus, and other local programs that are utilized by local farmers.

Conclusion:

Watershed Coalitions are actively engaged in developing a regional, watershed-based program to support agricultural irrigators affected by the Ag Waiver. These programs appear to provide a political and economic advantage over efforts to comply with the Waiver as an individual. The future success of Watershed Coalitions is dependent upon the outcome of the State Board appeal process and future actions of the Regional Water Quality Control Board. The outcomes of these processes could force Watershed Coalitions away from the Ag Waiver issue and leave an unmanageable result for the individual irrigator.

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California Animal Confinement Regulations in Chaos

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Introduction

At the present time there are several new significant statewide regulatory activities underway that will be impacting animal confinement facilities in California. Within the Central Valley, three (3) separate regulatory packages either have recently been adopted or will be adopted within the next few months. The regulatory packages are as follows:

1. On July 10, 2003, the Central Valley Regional Water Quality Control Board adopted regulations for irrigation return flows and storm water runoff from agricultural lands.
2. In March/April 2004, the Central Valley Regional Water Quality Control Board will be adopting new regulations for the management of manure from animal confinement facilities including new soil sampling and agronomic application requirements.
3. In March/April 2004, the San Joaquin Valley Air Pollution Control District will be adopting regulations for the control of particulates on animal confinement facilities. Later in 2004, the air district will be adopting regulations for volatile organic compounds (VOC's). As of January 1, 2004, new animal confinement facilities will require a permit from the air district if emissions exceed ½ of the major source threshold for particulates and volatile organic compounds (VOC's).

In addition, the Natural Resources Conservation Service is completing the “*California Comprehensive Nutrient Management Plan Technical Guidance Manual*”.

The convergence of these requirements and guidance documents provides the opportunity to implement them in a manner that does not duplicate regulatory resources and reduces the regulatory costs to the operator. This paper will discuss the major highlights of these new regulations and recommend options for implementation.

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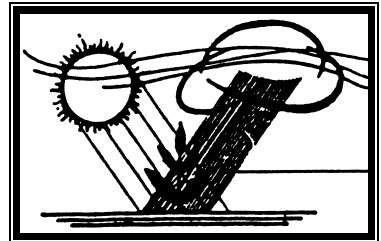
Session III
Irrigation
And
Water Management Issues

Session Chairs:

Larry Schwankl, UC Davis, Dept. of Land, Air & Water Resources

Ben Nydam, Dellavalle Laboratory, Inc.

James Ayars, USDA-ARS



Drip Irrigation Under Saline, Shallow Ground Water Conditions

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Introduction

Because no economically, technically, and environmentally feasible drain water disposal method exists for the San Joaquin Valley, the drainage problem must be addressed through options such as better management of irrigation water to reduce percolation below the root zone, increasing crop water use of the shallow groundwater without any yield reductions, and drainage water reuse for irrigation. One option to use drip irrigation instead of furrow or sprinkler irrigation. Drip irrigation can apply water both precisely and uniformly compared with furrow and sprinkler irrigation resulting in the potential to reduce subsurface drainage, control soil salinity, and increase yield. The main disadvantage of drip irrigation is its cost, about \$1,000/ac. For drip irrigation to be at least as profitable as the other irrigation methods, more revenue from higher yields and reduced irrigation and cultural costs must occur. Yet, several large-scale comparisons of furrow and drip irrigation of cotton revealed uncertainty in the economic benefits of drip irrigation. Thus, growers converting to drip irrigation face uncertainty about the economic risks involved, which might be minimized by growing high cash value crops such as processing tomatoes. Because processing tomato is a high cash value crop, a better potential for increased profitability with drip irrigation exists compared to cotton. However, tomato is much more sensitive to soil salinity, which could result in reduced crop yields in salt-affected soil.

Objectives

- 1) Determine the effect of subsurface drip irrigation on yield and quality of processing tomatoes under saline, shallow ground water conditions.
- 2) Determine the minimum amount of irrigation water that can be applied without reducing crop yield.
- 3) Determine patterns of soil salinity and soil moisture content around the drip lines.
- 4) Evaluate the effect of drip irrigation on depth to the water table.

Methods

Subsurface drip irrigation systems were installed in three fields of processing tomatoes, each about 50 miles, located in the Westlands Water District. Sites DI (80 ac of drip irrigation) and BR (40 ac ha) were installed in 1999, while DE (40 ac) was installed in 2000. Sprinkler irrigation was used for the rest of each field, the normal irrigation method of tomatoes in these soils. Westlands irrigation water was used at DI and BR, while well water was used at DE. Low-flow drip tape (about 0.22 gpm/100ft), 7/8" diameter, was buried about 8 in deep with one drip line per bed although two drip lines per bed were used for BR2001 (site/year). Emitter spacing ranged from 12 in to 18 in depending on the type of tape. Drip line lengths were about 1300 ft at all sites. Irrigations were twice per week during the period of maximum canopy size.

In addition, an experiment was conducted in the drip-irrigated field at each site to determine the minimum amount of water that can be applied under saline, shallow ground water conditions without reducing crop yield. This experiment consisted of applying different amounts of irrigation to small plots located in the drip-irrigated areas.

Measurements made at all sites were field-wide red fruit yield (machine harvested), yield quality, depth to the water table, irrigation water salinity, groundwater salinity, and applied water, soil moisture content, soil salinity, and canopy coverage.

Results

Field-wide Project

At each site, only one year of comparing drip-versus-sprinkler irrigation was possible (1999 for DI and BR; 2002 for DE). After the first year at each site, the rest of the field was converted to drip irrigation at BR and DE, while at DI, a different crop was planted. After the comparison year, yields of the drip-irrigated fields were monitored for several additional years.

Field-wide yields under drip irrigation were 5.4 tons/ac to 10.1 tons/ac more than those under sprinkler irrigation for the comparison year of each site (Table 1). Average yields were 41.8 tons/ac and 33.4 tons/ac for drip-and sprinkler-irrigation, respectively. Differences between the sprinkler-and drip-irrigation field wide yields were statistically significant using the t-test with a level of significance of 5%. Drip yields were considered to be high for these fine-textured, salt affected soils. After the first year, yields at DI and DE continued to be high (Table 1). Yields at BR for 2000 and 2001 were relatively low due to late plantings although these yields were higher than normally experienced for late plantings, but the 2002 yield was high. Soluble solids were acceptable for all years.

Small-plot Experiments

Results of the differential irrigation experiments showed that plot yield decreased with decreasing irrigation water applications for all sites and all years although differences in behavior occurred among the sites and years. Soluble solids increased with decreasing applied water for all sites and all years, but different magnitudes of changes occurred each year. Applied water had little effect on color and percent red fruit.

Depth to Water Table

There was little response of the water table to drip irrigations when water applications were about 100 percent of the potential crop evapotranspiration. In one case, however, the water table depth decreased to about 1.5 feet for water applications of about 10% more than the potential evapotranspiration. Decreasing the water applications to about 80 to 90 percent of the potential ET caused the water table depth to increase with time.

Soil Salinity

Soil salinity is normally expressed as the electrical conductivity (EC) of a solution extracted from a saturated soil sample, called the EC of a saturated extract paste or EC_e. Levels of soil salinity at these sites ranged from values less than the threshold EC_e (Site DI) to values exceeding the threshold EC_e throughout the soil profile (Site DE) (Figure 1). The threshold EC_e, 2.5 dS/m, is defined as the maximum root zone EC_e that will not reduce yield. (Note that the actual root zone salinity under drip irrigation is unknown because of spatially varying soil moisture, root density, and soil salinity around the drip line.) Soil salinity is the least near the drip line and increases with horizontal depth and depth below the drip line. Little correlation was found between soil salinity and crop yield.

Table 1. Summary of field-wide applied water and yield characteristics for all sites and years.

Irrigation System	Variety	Applied Water (inches)	Yield (tons/ac)	Soluble Solids (%)	Color
BR					
Sprinkler (1999)*	H8892	16.8	36.5	5.3	24.2
Drip (1999)*	H8892	16.0	46.3	6.0	21.1
Drip (2000)	Halley 3551	16.8	35.0	5.4	23.4
Drip (2001)	H9665	20.5	31.9	4.6	25.3
Drip (2002)	Peto303	**	48.9	4.8	24.1
DI					
Sprinkler (1999)*	H9557	**	35.2	5.2	24.8
Drip (1999)*	H9557	22.2	40.6	5.0	22.8
Drip (2000)	H9492	29.0	46.4	4.8	21.0
Drip (2001)	H9492	22.9	51.7	4.9	24.1
DE					
Sprinkler (2000)*	H9557	22.8	28.5	5.5	23.9
Drip (2000)*	H9557	28.0	38.6	5.6	23.7
Drip (2001)	H8892	22.1	45.8	5.2	23.6

* Comparison year

** Data not available

Economics

The benefits of converting to drip irrigation were increased revenue from higher yields and annual savings of cultural costs and energy costs of sprinkler irrigation. The costs of the conversion were the equivalent annualized capital cost of the drip system and its annual cultural costs and energy costs. The increase in annual net return for drip irrigation compared to sprinkler ranged from \$369/acre to \$604/acre for a 5% interest rate and from \$334/acre to \$569/acre for a 10% rate. Returns to land, farm management costs, taxes, and insurance costs (not available) were not included. Capital cost of the drip system was \$809/acre. The equivalent annual capital cost of the drip system was \$120/acre and \$155/acre for the 5% and 10% interest rates, respectively.

Summary

Subsurface drip irrigation of processing tomatoes in these fine-texture, salt-affected soils of the west side of the San Joaquin Valley is highly profitable. Over the range of soil salinities found at these experimental sites, crop yield was unaffected by the soil salinity. In addition, little or no response of the water table depth was found for properly managed drip systems. However, the long-term sustainability of processing tomato yield under subsurface drip irrigation in these salt-affected soils will require the following:

- Sufficient leaching must occur to maintain acceptable levels of soil salinity near the drip lines where the root density is probably the greatest.
- Periodic leaching of salt accumulated above the buried drip lines with sprinklers will be necessary for stand establishment if winter and spring rainfall is insufficient to leach the salts.

- Careful management of irrigation water will be required to apply sufficient water for crop evapotranspiration and leaching yet prevent excessive subsurface drainage.
- Periodic system maintenance must be performed to prevent clogging of drip lines. Clogging due to root intrusion was found to be a severe problem at one site where little or no chlorination occurred. Clogging will not only reduce the applied water needed for crop ET, but also reduce the leaching.

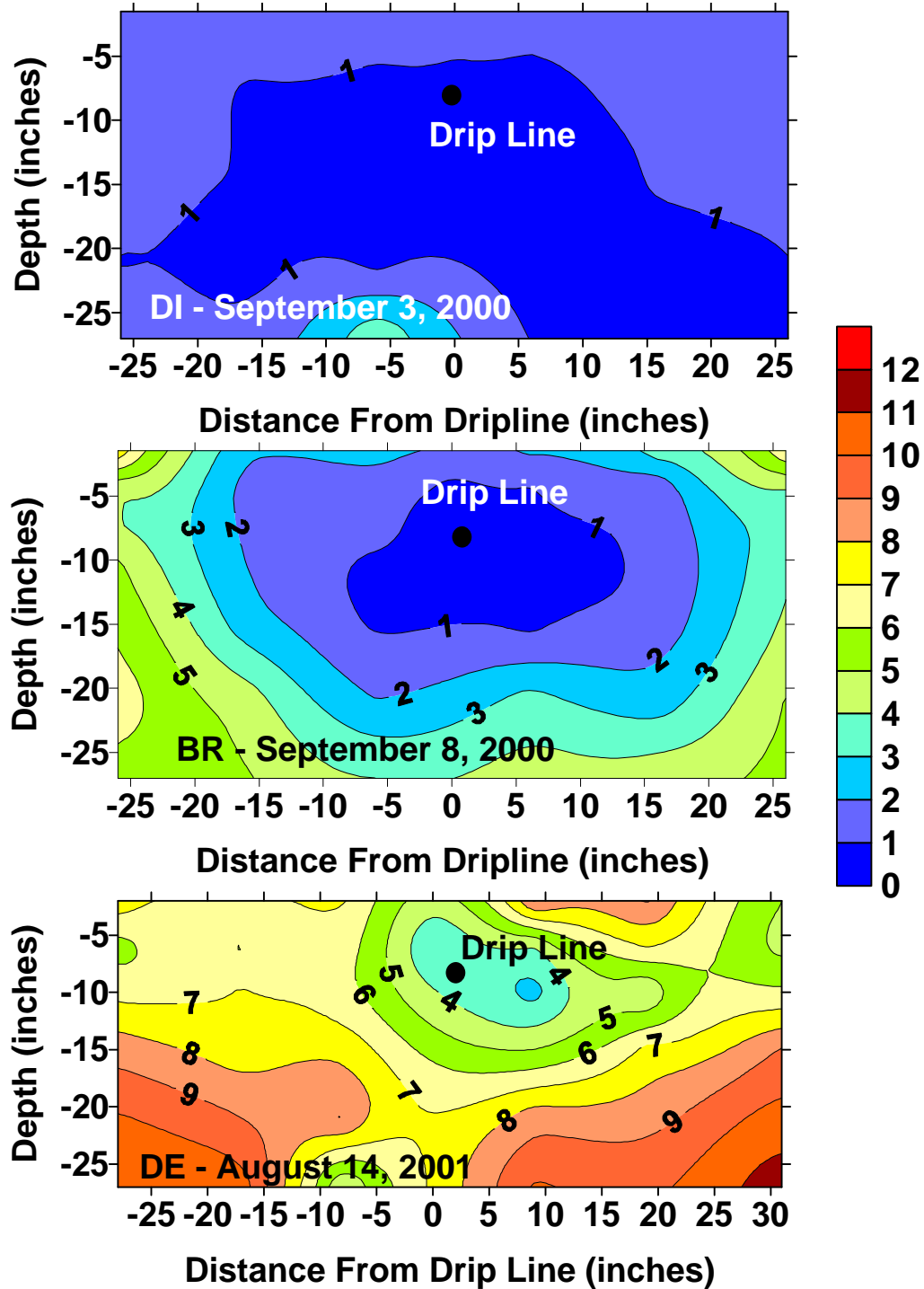


Figure 1. Patterns of soil salinity around drip lines for the three sites. Drip lines were eight inches deep. EC of the irrigation water was about 0.34 dS/m for Sites DI and BR and was 1.1 dS/m for Site DE.

Irrigation Water Requirements of Strawberries

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Introduction

Over 80% of the U.S. commercial strawberry crop is grown on 28,000 acres on the central and southern coast of California. These coastal areas have limited surface water supplies, are experiencing seawater intrusion due to groundwater overdraft and are facing increasing competition for water from growing populations. Where imported water is available, it is very expensive (\$300 - \$600 per ac-ft. on the southern coast). Consequently, even though strawberry is a very high valued crop (\$35,000/ac), efficient water use is critical.

Efficient water use requires an efficient and uniform irrigation system and correct scheduling of water applications. All California strawberries are grown on raised beds with drip irrigation. In most cases, the beds are covered with plastic sheeting (mulch). Thus, irrigation efficiency is potentially very high, although field measured irrigation distribution uniformities were below the potential (the low quarter distribution uniformity on 20 fields averaged 75% - author's unpublished data).

Strawberry growers schedule irrigations based on past experience, observation of weather conditions, and visual plant indicators of stress. Seasonal water application measurements on 10 strawberry fields indicated that growers overirrigated on 6 of the 10 fields (author's unpublished data).

Daily reference evapotranspiration (ET_o) in the strawberry-growing areas is available from California Irrigation Management Information System (CIMIS) weather stations. With proper crop coefficients (K_c), strawberry irrigation could be scheduled using CIMIS ET_o values. The CIMIS WEB site (<http://www.cimis.water.ca.gov/>) gives a strawberry midseason K_c value of 0.7 with adjustments up to 1.0 for low evaporative demand. Allen et al. (1998) lists basal crop coefficient values for strawberry as 0.15 during early season, 0.8 midseason, and 0.7 late season. The bed configuration or bed area-to-gross field area is not given in either case.

Gratten et al. (1998) measured strawberry ET_c with Bowen Ratio equipment in the Santa Maria, CA area with wide mulched beds (4 plant rows on 40" beds (65% of gross area)). They measured K_c nearly equal to midday canopy light interception (canopy cover) when canopy cover on the bed was near 100%. In early season when the canopy cover was about 50%, K_c exceeded cover by about 25%.

Evapotranspiration is a complex function of light interception; plant height, structure, and density; and surface soil exposure and wetness. In mulched strawberry, soil evaporation is small so the last factor can be ignored. Light interception can be estimated by canopy cover and information about plant height and row orientation (Allen et al. 1998). In raised bed strawberry, the bed and plant geometry is complex. California strawberry beds are about 12" high and vary from 25 - 40" wide. Narrow beds have 2 rows of berry plants on about 12" plant spacing, while wide beds have 4 rows of plants. The beds cover about 55% - 65% of the ground surface. Thus there are two scales of plant structure, the bed structure and the plant structure on the bed. Calculation of K_c based on this complex structure is difficult.

Strawberries in California are planted in the fall, grow slowly during the winter months and more rapidly in the spring. Harvest begins in January in the southern regions and ends in June. In the central coastal areas where this study was conducted, harvest begins in April and continues until August or September. Average yields are 45,000 lb/ac.

The objectives of this study are to determine the crop water requirement of strawberry in coastal California, calculate the crop coefficient based on canopy cover, and determine the impact of different irrigation amounts on strawberry production.

Experimental Procedures

Diamonte strawberries were planted in a fumigated silt loam soil on the central California coast near Watsonville, CA in November, 2002. The soil field capacity is about 25% and bulk densities were measured as 1.6 - 1.8 in the bed and 2.0 below 15". Rooting was not observed in the compacted soil below 15". The berries were planted in two rows on 28" wide beds on 52" bed spacing (54% bed area). Plant spacing was 14" resulting in 17,000 plants/ac. Beds were covered with black plastic mulch. Pre-plant broadcast, slow release banded, and water injected fertilizers were applied according to normal grower practice. The plot was irrigated with two drip tapes (0.67 gpm/100' flow rate) per bed placed 1" below the bed surface and 5" from the bed center and 4" from the plant row. The plants were sprinkler irrigated for approximately 2 weeks in the fall to "set in" the plants. Winter rains provided adequate water to maintain high soil water contents until early March when drip irrigation was initiated.

Five beds were subdivided into five irrigation treatments in a latin squares design with 5 replications. Plots were 20' long and contained 32 strawberry plants plus 2 border plants. Irrigation water was delivered to each plot from a manifold. Irrigations were applied 3 times per week based on calculated ET_o and estimated crop coefficients. All irrigation application amounts were based on bed area (54% of gross field area). Treatments were 70%, 85%, 100%, 125%, and 150% of estimated crop water requirements. Water applications were controlled and monitored with a Campbell Scientific CR-21X data logger. System pressure was maintained at 10 psi and monitored continuously. Water applications to each treatment were measured manually with turbine flow meters. Evapotranspiration was calculated from an on-site weather station using the Penman-Monteith equation.

Strawberry canopy area was calculated periodically from vertical digital photographs of 4' of each plot (approximately 8 plants). Either visual images were used to digitally planimeter plant canopies, or infrared photography was used to directly calculate vegetative area. The manual method tended to overestimate actively transpiring canopy area by about 5% relative to the IR method, likely because it was difficult to identify senescent vegetation and shaded leaves with visual images.

The literature and previous trials by the authors indicate that the crop coefficient for strawberries is somewhat greater than canopy cover. Consequently, irrigation applications for the 100% ET_c treatment were based on 1.2 times canopy cover (as a ratio) times ET_o since the last irrigation. Amounts for the remaining treatments were 0.7, 0.85, 1.25 and 1.5 times the 100% ET_c treatment. Irrigation times were based on calculated irrigation amount and the measured flow rate for the treatment. Flow meter readings confirmed irrigation amounts.

Soil water content was monitored continuously with WaterMark soil water sensors and a CR-10 data logger, and was measured periodically with gravimetric soil samples. The sensors were placed in the center of the bed at 6" and 15" depths. The gravimetric samples were collected in the plant row at 0 - 6", 6 - 12", and 12 - 18" depth increments. The sensors did not provide useful information except in the driest treatments, possibly because they were placed in the wettest portion of the bed. Detailed soil sampling in the beds at the end of the study confirmed that the in-row gravimetric samples were representative of the bed soil water content. Soil bulk density was measured with a Soil Moisture Corp. 200A bulk density probe.

Strawberry plant health was visually evaluated periodically. Plant growth and health were variable in two of the beds, possibly because of non-uniform pre-plant fumigation. Canopy size and soil water samples were collected from sections of the plots with the most vigorous plants. Strawberries were harvested weekly and divided into fresh market and total yields. Average berry size was measured alternate weeks. Yields were calculated based on the number of vigorous, productive plants in each plot.

Results and Discussion

Figure 1 shows the evolution of canopy cover through the season. Note that 100% canopy cover of the bed would be equal to 54% cover of the field. Even though strawberry harvest began in April and peak harvest occurred in June, the canopy cover continued to increase linearly until the plots were terminated in early August. It is assumed that the plants, if left longer, would reach nearly full cover on the bed. Similar canopy growth data has been measured in the Santa Maria area although rapid growth began about 40 days earlier in the warmer climate and full cover with the high plant density on the wide beds was achieved more quickly (personal communication from Blaine Hanson). The strawberry plants are not allowed to form runners, so the canopy increase was the result of continuing growth of the base plant. The data did not indicate an irrigation effect on canopy cover, so the one linear relationship was used to schedule all the treatments.

Figure 2 shows the ET_c calculated from the on-site weather station ET_o values times 1.2 x the canopy cover relationship (Fig 1), and the rainfall and irrigation applications for the 100% ET_c treatment. The ET_o during the March 1 to Aug 5 season was 470 mm. Daily ET_o averaged 2.5 mm/day and exceeded 4.5 mm only four days in the mild coastal climate. The ET_c increased with canopy cover, peaked at 3.3 mm/day, and totaled 298 mm for the March 1 - Aug 5 period. Twenty-five percent of the 120 mm of rainfall between March 1 and May 9 was considered effective by running into the planting holes in the mulch. Rainwater in the furrows is unlikely to be useful to the plants because the mulch extended 10 cm into the furrow soil and roots did not extend into the furrow. No rain occurred after May 9.

Figure 3 shows the cumulative irrigation and irrigation + effective rainfall for each of the 5 irrigation treatments. The spread in total water applications exceeded the targets with the actual applications being 62%, 90%, 108%, 139% and 161% of the 298 mm of ET_c . Irrigations early in the season tended to lag behind ET_c as we were attempting to dry down the plots and create soil water content differences. Late in the season, irrigation exceeded ET_c .

Measured (gravimetric) soil water content measured at 0 - 12" in the plant row prior to irrigation was uniform in all treatments in March (Fig. 4). By late May, irrigation treatment effect on soil water was evident. The water content varied from near field capacity (25%) down to 12 - 15% in the driest treatment. In the dry treatments, soil samples were difficult to collect below 12" due to the dry soil. The data indicate there should have been no soil water stress for the wettest two treatments, and stress was likely in the driest two treatments. Irrigation amounts that exceed crop water requirements should result in relatively uniform soil water contents since irrigation beyond requirements should deep percolate. Thus these data seem to indicate that no treatment less than the high treatment exceeded water requirements.

Figure 5 shows market yield as a function of treatment. The graph shows whole season, early season, and late season (before and after June 16) yields. Early season yield tended to decline slightly with irrigation treatment (not significant). Late season yield tended to increase with irrigation application. The trend indicates only a 25% yield decrease from the wettest two to the driest treatments. Only the 70% treatment yield was significantly different from the 125% and 150% treatment yields. Over 70% of the total yield was marketable, and total yields varied with treatment similar to market yield. Fruit size did not vary with treatment.

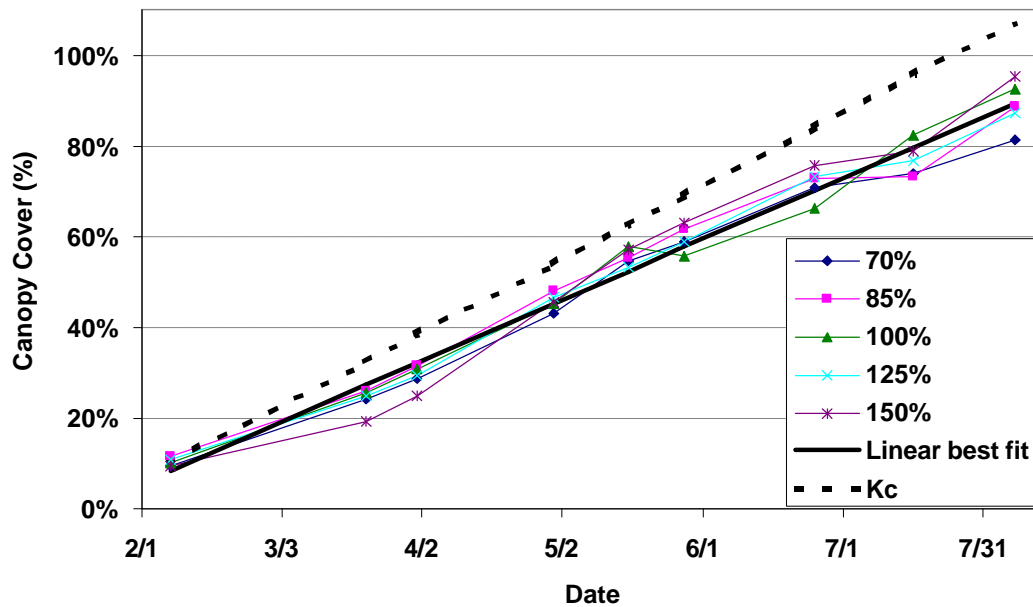
The weak response in yield to the wide range in irrigation amount and soil water content is unexpected. Growers believe that strawberry is very sensitive to soil water content. It is possible that the weak response in this trial was due to the high irrigation frequency and the relatively low evaporative demand.

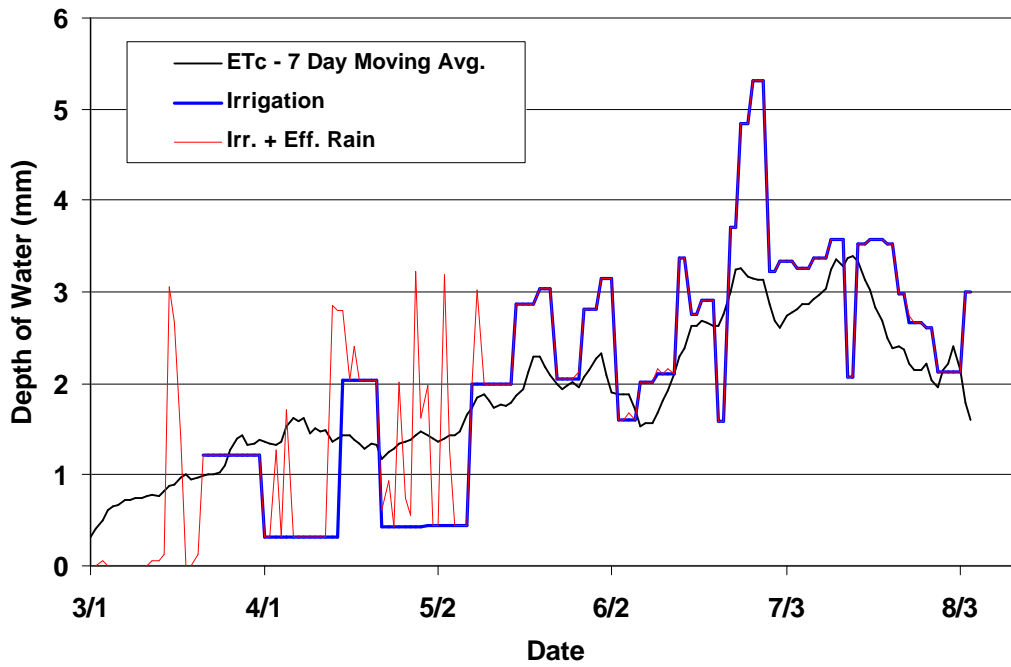
With the small yield response and the soil water content response to all treatments, it is not possible to determine the optimum K_c value from these data. The data indicates a possible yield plateau about the 125% treatment. Other indicators of adequate irrigation (canopy size and plant health) also indicated a slight trend but minimal response.

Previous strawberry water requirement studies at a different site also produced confounding results. In one year, yield responded to each of 5 levels of irrigation (70% - 130% of ET_c) while in another year, yield did not respond to similar treatments. This study will be repeated with the intent of determining a soil water content and strawberry yield response to water applications that would define a relationship between crop cover and K_c .

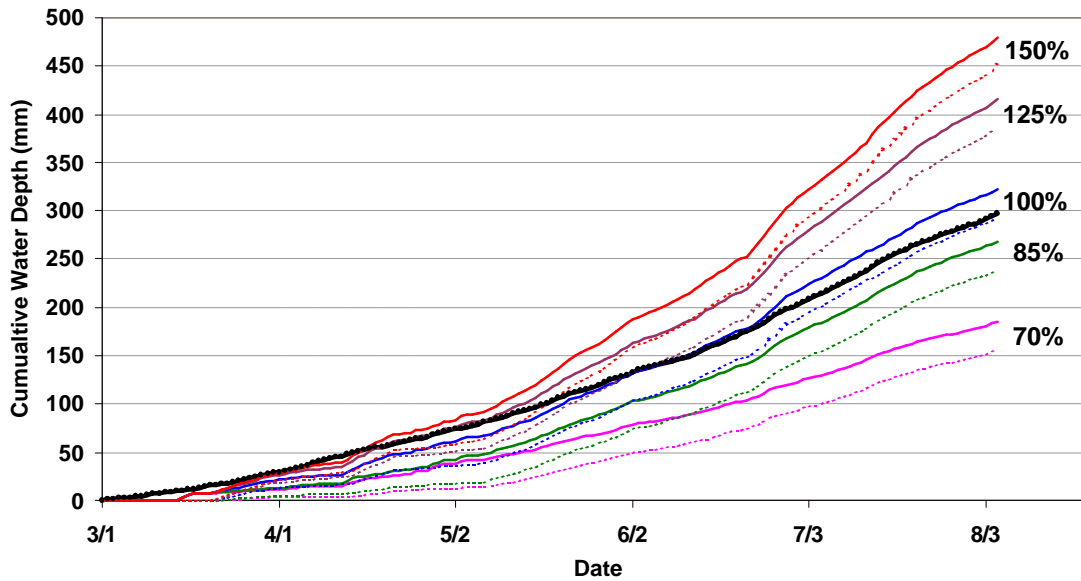
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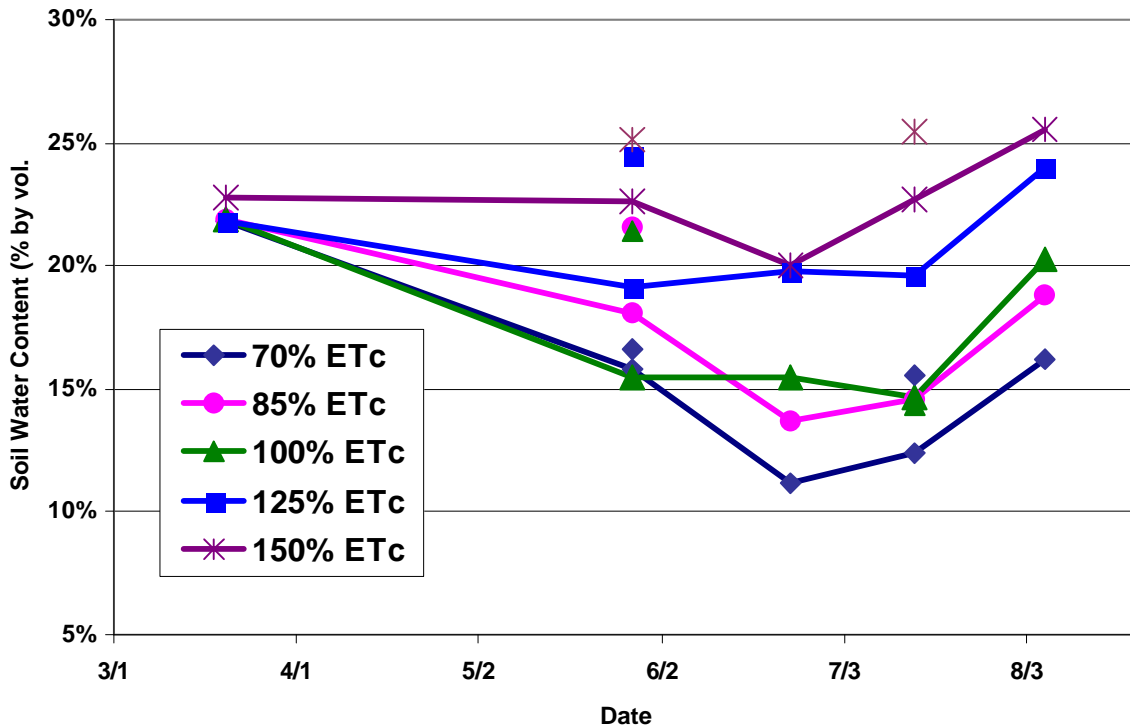




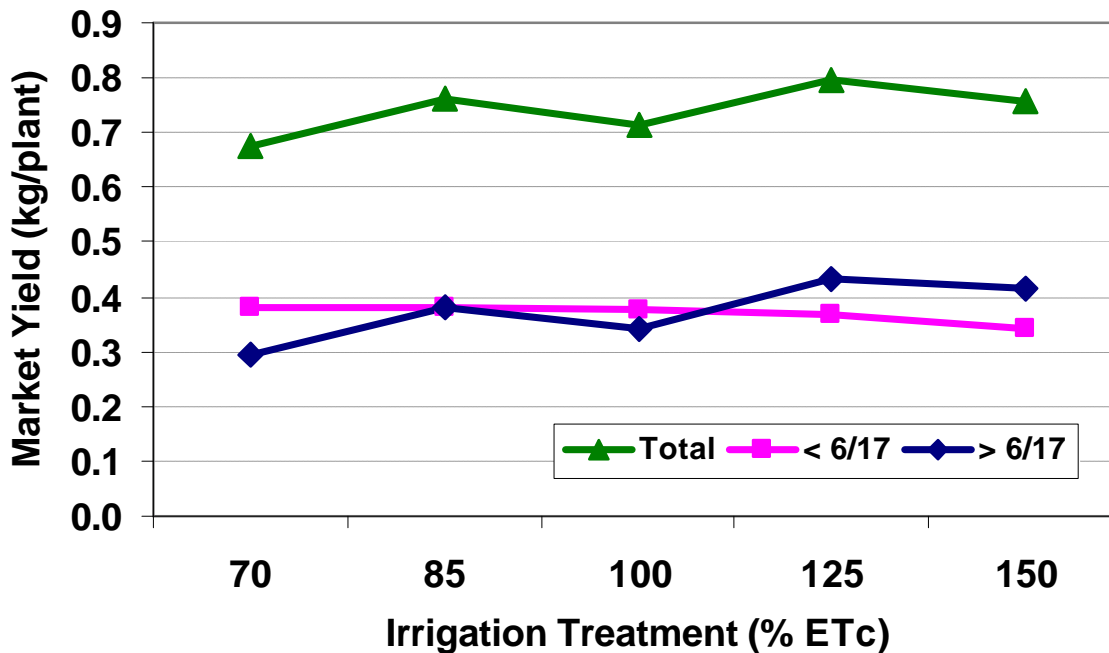
2. Daily crop water use, ET_c , irrigation application, and effective rainfall for the 100% ET_c treatment.



3. Cumulative ET_c (heavy line) and water application for the 5 treatments. Dashed lines are only irrigation applications. Solid lines include effective rainfall.



4. Volumetric soil water content (0 – 12” in the plant row) through the season based on gravimetric samples for the five treatments. Lines connect before-irrigation data. Individual points are after irrigation data.



5. Strawberry market yield for the five irrigation treatments, showing total yield, early season yield, and late season yield.

Regulated Deficit Irrigation in California's Orchards and Vineyards: Realizing the Potential

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Introduction

This paper discusses the role regulated deficit irrigation (RDI) can play in reducing the consumptive use of water in California agriculture. Currently in California, agriculture uses about 75% of all the developed water in California. The expanding population, predicted to grow by 17 million people within the next 25 years, and efforts to maintain or improve animal habitat and stream flows will require more water in the future. Coupled with little, if any, significant expansion of water supplies and, indeed, possible partial loss of existing resources, such as the Colorado River, agricultural water use is being eyed by many as a water source for competing interests.

The recent controversy in Imperial County over the transfer of water from agriculture to the city of San Diego illustrates this issue. Some maintain that growers there could free up the amount of water in question by improving their surface irrigation management, i.e., waste less water by reducing deep percolation below the crop root zone or end of field runoff. The growers argue that there are limits to how much water can be saved by reducing irrigation water losses (also called improving application efficiency) and point to reduced planting acreage increased salinity, and associated loss of production and agricultural jobs as likely affects.

Does improving application efficiency save water?

Statewide, California growers have steadily improved their application efficiency over the last couple decades. Moreover, deep percolation and runoff are usually only temporary losses on a small scale (the field being irrigated). Although it may be degraded by fertilizers and other agricultural chemicals, water lost to deep percolation eventually moves into the water tables where it can be pumped and reused. An exception to this is when it enters a salty, perched water table, usually making it unusable or when it flows to the ocean. Runoff is often collected and reused on another field on the farm. Thus, one field's or grower's loss is another field's or grower's source of supply. Recognizing this and the fact that most California growers have become highly efficient in their irrigation management shows that there is limited opportunity to free up net water by improving application efficiency.

The role of scientific irrigation scheduling in saving water

On farm water losses have also been reduced by growers using soil, plant, and atmospheric-based scientific irrigation methods. The goal of these different approaches to on-farm water management is the same: to meet the water needs of the plant without over irrigating. No single approach can be universally recommended. However, atmospheric (ET) approaches have greatly increased in popularity during the last three decades as crop water use information has become more readily available. The advent of internet-based sources of ET information, spearheaded by the CIMIS (California Information Management Information System) Program, has accelerated the use of water budget scheduling approaches, especially on orchard and vineyard crops in California.

Is it possible to reduce consumptive use (transpiration) in agriculture without reducing planted acreage?

The reason for this is that there's generally a near-linear relationship between ET and crop production. Why? Because transpiration, the movement of water vapor from the interior of the leaf to the surrounding atmosphere and the uptake of carbon dioxide, the basic building block required in the process of photosynthesis, both use the same plumbing at the leaf surface--the stomata. These are very small openings usually located on the undersides of leaves that regulate the movement of both water vapor and carbon dioxide. Indeed, it's often said that the plant trades water for carbon and if the goal is to maximize carbon uptake to achieve high yields, potential transpiration must be met. Thus, limiting transpiration (water stress) has usually been associated with production losses and lower grower profit.

While this is true for most field and row crops, it's not necessarily true for trees and vines. Lack of water (water stress) first reduces the vegetative growth of plants but that doesn't necessarily result in reduced fruit yield in trees and vines as it does with most field and row crops (cotton being an exception). Thus it is possible to trees and vines to reduce transpiration without a reduction in yield. Indeed, reduced vegetative growth in trees leads to better light penetration into the canopies that can improve certain aspects of fruit quality, such as color.

Regulated deficit irrigation

We now refer to strategies that purposely impose water stress in crops as regulated deficit irrigation (RDI). Water savings with RDI are true water savings--transpiration, the consumptive use of water, is reduced. This is fundamentally different than "saving water" by reducing the water losses to deep percolation and runoff since these aren't really losses to the basin or region as they can be eventually reused. Research with RDI in orchard crops began in the 1970s in Australia and New Zealand on peaches and pears. The primary goal of this work was to reduce vegetative growth and thus, summer pruning, in excessively vigorous trees. Associated water savings were of secondary importance. The researchers were successful when they stressed the trees only when the rate of fruit growth was relatively low. This concept formed that basis for the RDI work that followed here in California.

Take pistachio, for example. This tree, which has stomata located on both sides of the leaf, has the potential to use water at a faster rate than any other orchard tree grown in California--the peak crop coefficient is 1.19 versus 0.96 for almonds. The growth pattern of the pistachio fruit is unique. The nut grows rapidly from late April through mid May in the bulk of the growing acreage (southern San Joaquin Valley); this growth being almost entirely due to shell expansion. The kernel doesn't begin to grow rapidly until early July. Thus, the period between mid May and early July (what is referred to as Stage 2) seemed a prime candidate for stress in an RDI regime. This tactic was studied with the help of cooperating pistachio growers and the California Pistachio Industry Research Committee over many years. The results showed that indeed, a combination of stage 2 and postharvest deficit irrigation could reduce seasonal water use by 10 to 12 inches without any negative effects on crop yield or quality. In fact, while stage 1 stress resulted in smaller nuts, this was more than offset by improved shell splitting (desirable). We are currently investigating where stage 1 and stage 2 stress can be coupled to save water and improve grower profit due to fewer unsplit nuts.

Another successful example of RDI use in tree crops is with citrus. Working with a navel variety (Frost Nucellar) in the southern San Joaquin Valley, we investigated using RDI to lower the incidence of peel creasing; a defect that reduces fruit quality and thus, value, for growers. With the support of the Citrus Research Board, we imposed 14 RDI regimes in addition to a fully irrigated Control. The correlation between gross fruit yield (mean of three years) and applied water was fairly linear ($R^2=0.599$) but with a shallower slope than the 1:1 relationship (Fig. 1a). On the other hand, there was no relationship ($R^2=0.091$) between gross revenue (\$/acre) and applied water (Fig. 1b). Many of the

RDI regimes had appreciably higher gross revenue (\$600-700/acre, not included reduced water costs) than the fully irrigation Control while applying from 4 to 8 inches less water. This was due to significantly lower creasing (higher fruit quality), especially with early season stress. This illustrates a major difference between row/field crops and tree/vine crops--fruit quality (size, color, appearance, etc.) plays a much more important role in the later and can be influenced by stress management. In other words, lower gross yield doesn't always translate into lower revenue with trees and vines and its revenue (profit) that's most important.

Almond trees present possibly the best opportunity to couple RDI with adjusted horticultural management to not only reduce water consumption but to address two critical health issues facing the industry--agricultural burning and dust during harvest. Again working in the southern San Joaquin Valley and supported by the California Almond Board, we tested various RDI regimes ranging from water savings of 15 to almost 50% of potential orchard ET. We showed that mild stress over most of the season can be imposed with little negative influence on production and substantial water savings. However, a potentially more significant finding involved the RDI regimes that imposed moderate to severe preharvest (April-July) stress. These strategies reduced vegetative growth (canopy size) and individual kernel weight but had no influence on fruit load. In other words, the smaller, more compact trees had higher fruiting density (nuts per unit of canopy volume) than fully irrigated trees. Thus, one could increase the planting density (trees/acre), thereby increasing total nut production (number/acre) compared with conventionally planted and irrigated trees. For example, if 15% more trees were planted per acre with the same fruit load as a conventional tree but a higher fruiting density and fruit size was reduced by 10%, there would be a 5% increase in gross production. The downside is that fruit size would be lower, which may somewhat decrease the value of the nuts. On the other hand, the need to prune trees would be much less, reducing the amount of prunings and thus, burning.

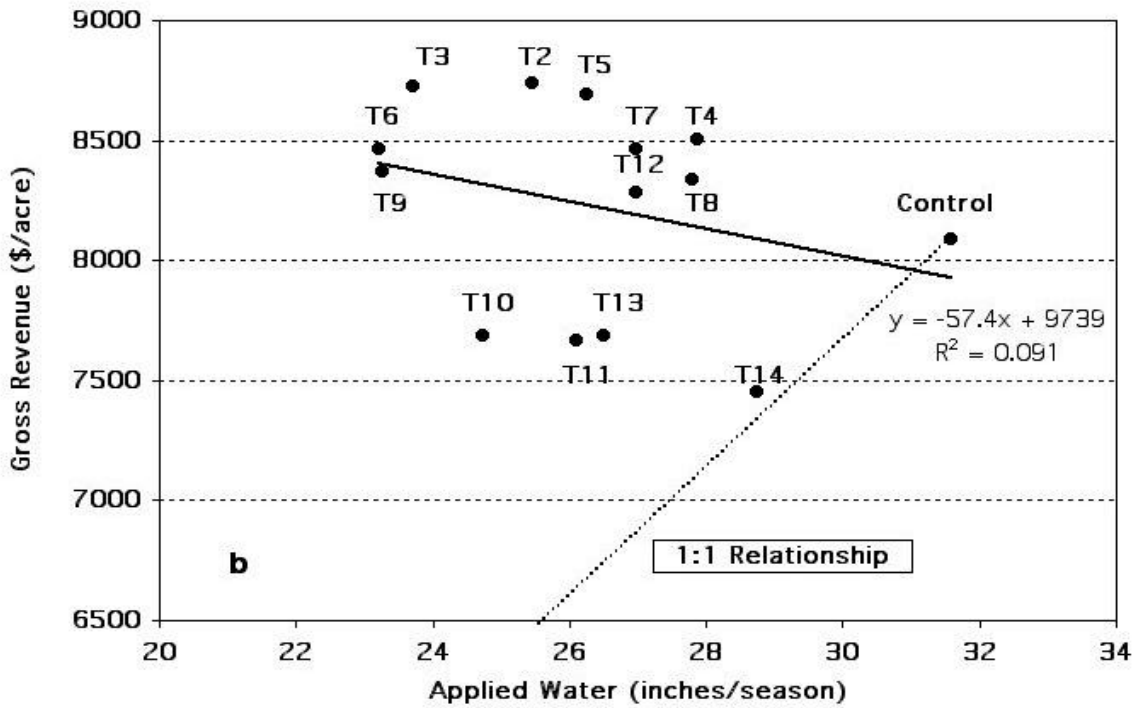
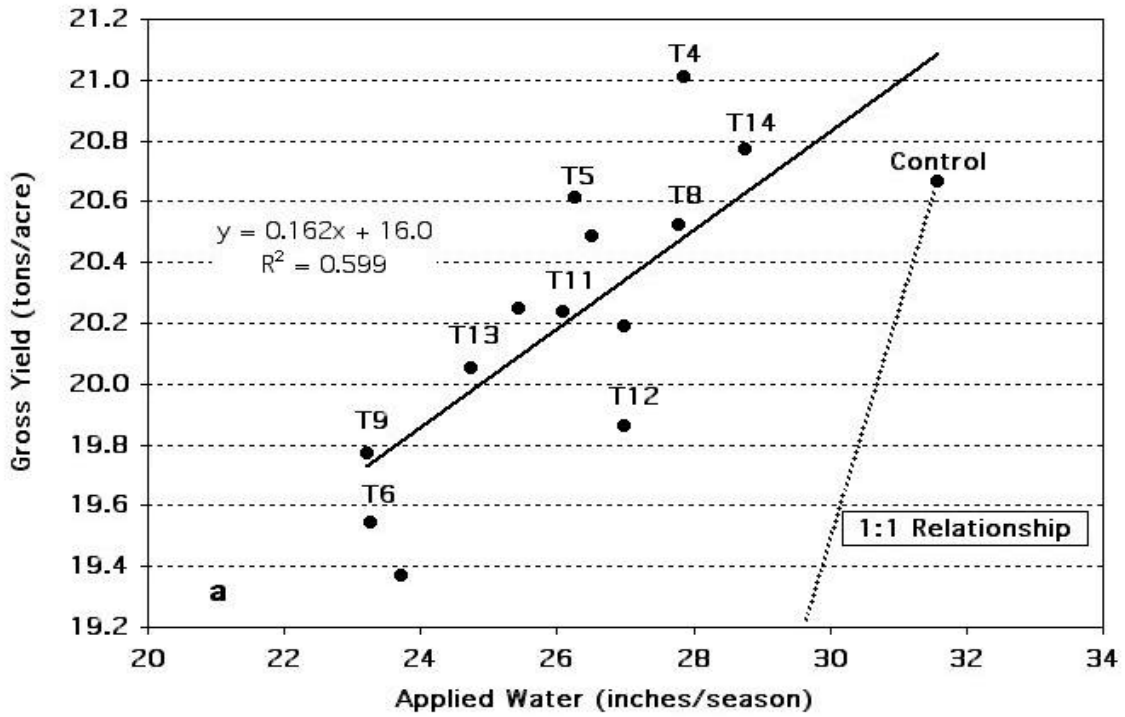


Figure 1. Production (a) and revenue (b) functions for applied water using mean 1998-2000 for navel oranges (Frost Nucellar) in the southern San Joaquin Valley.

Growers currently mechanically shake trees at harvest and leave the nuts on the ground to dry for 7-10 days before they are swept up. The sweeping and mechanical collection can create dust and there are PM-10 related health concerns. Our research showed that preharvest stress can accelerate hull splitting, allowing for an earlier harvest, which benefits growers in a number of ways. Moreover, earlier hull split allows the nuts to dry more completely on the tree prior to mechanical tree shaking. We believe that this presents the option of growers harvesting directly from the tree into nut catching machines, as is done currently in pistachio and prune orchards. This would eliminate the dust and other problems associated with nuts drying on the ground, such as ant damage and soil-borne bacteria infection.

Winegrapes is another crop where stress can substantially improve fruit quality. Indeed, the irrigation of winegrapes was against the law in some European countries, such as Spain, until quite recently. The reason presumably involved real or perceived negative irrigation-related impacts on wine quality. Some stress is indeed beneficial as it can reduce berry size, thereby increasing the ratio of skin to fruit volume. This is important to wine makers since the skin contains constituents important in wine color, taste, and chemical make up.

Estimates of water savings with RDI

Clearly, RDI can save water by reducing consumptive use without negatively affecting and perhaps, enhancing crop production. So how much water could be saved in California's orchards and winegrape vineyards if RDI were adopted on a wide scale? Using our research and that of others and conservative estimates of current practices in orchards and vineyards, we have calculated a range of water savings for the major tree crops and winegrapes in California. These estimates are based on RDI regimes that do not reduce grower profits. One tree crop, walnuts, is excluded since we have no data showing that RDI can be successful although further research is underway. Consumptive use reductions on the low end; those that we believe are currently achievable, total about 1 million acre-ft (Table 1). We believe that if RDI adoption is coupled with adjusted horticultural practices, such as the higher almond density plantings and improved, more precise methods of identifying tree stress, consumptive use can be reduced by 1.5 million acre-ft. We are currently conducting research on developing electronic sensors that can accurately detect tree stress thus allowing the management of RDI strategies with precision and with minimal risks.

Today's farming economy has resulted in the steady conversion of relatively low value row crop land into higher profit orchards and vineyards. This process only enhances the scale of potential RDI adoption. Achieving the promise of RDI depends on growers recognizing the benefits of managed water stress. This requires demonstrating on a large scale that RDI can be successful in their terms--profits are maintained or increased--and that the higher level of irrigation management required is within the ability of on-farm personnel. We believe that RDI in orchards and vineyards could be a key component in this state's effort to meet the growing demand for water and at the same time, preserve and protect permanent crop production.

Table 1. Range of estimated water savings relative to current practices using regulated deficit irrigation (RDI).

Crop	Bearing Acreage (acres)	Estimated Savings (inches)	Range of Water Savings (acre-ft)
Almonds	530,000	8 to 14	424,000 to 618,000
Winegrapes	480,000	8 to 12	320,000 to 480,000
Citrus	244,000	6 to 8	122,000 to 163,000
Pistachios	78,000	10 to 12	65,000 to 78,000
Prunes	76,000	6 to 12	38,000 to 76,000
Peaches	70,000	4 to 8	23,000 to 47,000
Olives	36,000	6 to 10	18,000 to 30,000
Apples and Pears	49,000	4 to 8	16,000 to 33,000
Walnuts	196,000	Unknown	Unknown
Total			1,026,000 to 1,525,000

A Web Based Model For Estimating Peach Tree Water Use

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Introduction

Over the past several years we have been developing a model for predicting peach tree water use. The model is based on data obtained from peach trees planted in a large weighing lysimeter at the Kearney Ag Center, near Fresno California (Phene et al., 1991). Originally, the purpose was to predict young tree water use (Johnson et al., 2002) since reliable information was lacking and grower practices are often wasteful. Since then, additional information has been gathered on mature trees, so the model can be expanded to include orchards of almost any age, planting configuration and irrigation system (Johnson et al., 2004). The next step is to post the model on the Internet to make it widely accessible to growers, consultants, extension agents and researchers.

Components of the Model

The details of the model have been published elsewhere (Johnson et al., 2002; Johnson et al., 2004) and only a brief summary will be presented here. Tree transpiration and soil evaporation are modeled separately. The transpiration component is driven by canopy light interception (Johnson et al., 2000), which is estimated from the shaded area under the tree or from tree dimensions of young, isolated trees. In addition, day-to-day fluctuations in vapor pressure deficit (VPD) have been shown to affect tree water use of the lysimeter trees. Therefore, a VPD factor has been added.

The soil evaporation component is modeled after the approach of Ritchie (1972) with two distinct stages. During stage I, which starts with an irrigation event, the wetted area in the sun evaporates at a rate equal to reference crop evapotranspiration (ET_o) and the shaded area at one third this rate. We have developed an equation to estimate the percent of the wetted area in the sun with different irrigation systems and canopy sizes. Once the soil has dried sufficiently, it initiates stage II, which follows an exponential decay rate over time. The transition from stage I to II is a function of soil type and daily ET_o. The soil evaporation component can be modeled with a minimum amount of input, including soil type, wetted area, irrigation frequency, canopy light interception and weather station ET_o.

Putting the Model on the Internet

The model will be included as an option on the weather page of the UCD Fruits and Nuts web page (<http://fruitsandnuts.ucdavis.edu>). We have set up the input screen with three columns of data. The first column asks for orchard information such as tree spacing, shaded area for mature trees or tree dimensions for young trees, soil type and harvest date. The second column asks for input on the irrigation system including emitter output, wetted area, frequency of irrigation and irrigation efficiency.

Finally, the third column deals with weather information. The closest CIMIS weather station is identified and a two-week time period needs to be specified. The model will only predict water use for a period of two weeks since canopy light interception can change significantly during that time.

The output page indicates the results of the model calculations in daily (or weekly) gallons of water per tree. Three separate scenarios are presented that give the user different options. The first scenario is called "Maximum Water Use" and is based on the maximum amount of water used by the lysimeter trees under non-limiting soil water conditions. This value can be quite large (Ayars et al., 2003). Based on our experience in the field, we have often found this amount of applied water to be less than optimum (and sometimes harmful) for the welfare of the trees. Problems such as iron chlorosis and root disease can arise from waterlogged conditions, especially with heavier soils. Therefore, we have identified the second scenario as "Horticulturally Optimum Water Use". This is generally about 20% less water than the first scenario but doesn't appear to have any negative effects on productivity or fruit quality. Finally, a third scenario, "Moderate Water Stress" is presented. Based on past research, we have found substantial savings of irrigation water can be achieved by imposing moderate stress during certain periods, especially post harvest (Johnson et al., 1992; 1994). Vegetative growth is decreased and certain fruit disorders can be increased (Handley and Johnson, 2000), but careful irrigation management can maintain productivity. Given these three scenarios, the end user can make decisions based on his/her goals, water availability, management level and risk tolerance.

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Can Mitigation Practices Provide Protection For Ground and Surface Waters?

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Introduction

The best solution to ground and surface water contamination is to prevent it from occurring. By assessing the risks of a pesticide application to water sources followed by the use of mitigation practices, water sources can be protected or the effects of the application minimized.

Nonpoint source ground water contamination, unlike point source contamination, occurs over wide areas and usually involves low concentrations. A nonpoint source problem could arise from repeated use of the same pesticide over many years, frequent use of the same material in a season, or high application rates in a single year. If pesticides travel downward through the soil, ground water can be contaminated. Ground water contamination depends on the rate at which the chemical moves through the soil, the rate at which it degrades into inactive materials, and the depth to ground water. Ground water also can be polluted by direct introduction of pesticides through sinkholes, poorly constructed wells, and back-siphoning into wells. Surface waters are directly affected when pesticides move off site either through runoff or with eroded soil.

Movement of pesticide residues from agricultural applications to ground water has been well documented (Hallberg, 1989). Ground water surveys conducted within the U.S. have shown that patterns of detection are related to cropping patterns (Kolpin et al, 1997). In the Mid-West, for example, detection of residues for parent and breakdown products of atrazine, alachlor, metolachlor and acetochlor have been related to use as pre-emergence herbicides in the production of corn and soybeans, the predominant Mid-Western crops. In contrast, residues for parent and breakdown products of simazine, diuron, and bromacil predominates detections in California. These pesticides are also pre-emergence herbicides, but they are widely used in grape and citrus production and for non-crop weed control (Guo et al, 2000).

Understanding Pesticide Movement

The pathway for movement of residues to ground/surface water are needed to determine if mitigation measures can be developed that allow continued use, but that are also protective of underground aquifers. This approach has been applied to regulation of pesticides detected in California's ground water because decisions made at the State level balance economic considerations with environmental protection. For example, on coarse-textured sandy soils, guidelines for irrigation management have been suggested to minimize movement of residues lost to deep percolation, whereas in hardpan soils with low infiltration rates, improved incorporation of pre-emergence herbicides is recommended to reduce concentrations in runoff water that eventually recharges ground water (Troiano et al, 2000).

These two scenarios are not representative of all geographical settings where residues have been detected in California's ground water, so further investigations were needed to determine movement of pesticides to ground water. A recently completed study investigated potential pathways for movement of hexazinone and diuron residues to ground water in an area dominated by cracking clay soils.

Residues of these pre-emergence herbicides were detected in wells sampled near the town of Tracy, California where the predominant cropping pattern was a rotation of alfalfa with corn and beans. The residues were related to agricultural applications, especially since hexazinone could only have been used on alfalfa. Although the soil is clayey, rapid water movement through cracks, termed macropore flow, has been identified as a potential pathway for rapid movement of solutes to lower layers of soil (Bouma et al., 1982; Lin et al., 1998). Investigation on soil distribution of atrazine had occurred for cracking clays soil condition in another area of California, but a definitive description of a pathway to ground water had yet to be determined (Graham et al., 1992).

Movement of Diuron and Hexazinone

Movement of diuron and hexazinone in this cracking clay soil was confined to the upper reaches of the soil profile even though water percolated past the deepest depths sampled (1 meter). Very little diuron was detected beneath the first 0 - 69 mm depth, whereas, concentrations of hexazinone in the deeper segment were equal to those measured in the first segment. Little to no residues was measured for either herbicide in the third segment, which represented the 271-339 mm depth. Based on a comparison of their physical-chemical properties, greater movement through soil would be expected for hexazinone, caused primarily by its lower soil adsorption value (Koc). After the second irrigation (June), the magnitude of the residues for both pesticides was reduced to levels that were similar to those measured in the background samples. The mass of diuron removed from the field in the runoff water as mean of treatments was 1.97 grams per hectare for the two irrigation events. Hexazinone was lower at 0.0615g/ha. The mass was carried in 84 cubic meters of runoff water per hectare.

Significant amounts of herbicide were delivered to the pond via the runoff waters then infiltrated over a 5 day period of time. The pond did not have a return system. The mass of residues infiltrated through the pond as a result of the 32-acre field for diuron was 10.13 grams while hexazinone was 0.79 grams as a result of the two irrigations. These values could have been larger or smaller depending on the runoff management. Ground water depth at the site was at 11 feet. Concentration of diuron measured in the groundwater at season's end declined with distance from the pond starting at 2.5 ppb with a linear decline with distance to non-detectable at 12 meters. Hexazinone, by virtue of its lower soil adsorption value (Koc), was constant from the pond water to the farthest distance measured (49m). Significant amounts of herbicide were moved by runoff to the pond then infiltrated over a 5 day period of time. Mitigation practices would obviously consist of a tail water return system to minimize the infiltrated water.

Mitigation Practices

A study conducted in 2003 in the same area suggests when runoff is consistently returned to the top of the field, a 96% reduction in the volume of infiltrated water is possible. The only water infiltrated occurred during the pond-filling phase and from water which remained in the pond which was below the pump intake. An evaluation of costs for installation and operational costs are currently under way. Since the runoff water contained the herbicide residue, a threat to surface water also exists if released to a surface water source. The use of a pond with a return system would completely eliminate the off-site moment to surface waters.

The production of food and fiber often requires complex strategies that must balance profitable and efficient farming with water quality and quantity concerns. At their most effective implementation, mitigation practices must be technically feasible; economically viable; socially acceptable; and scientifically sound. This mitigation study will provide the level of reduction of herbicide movement to the ground water and the associated costs to do so.

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Micro-Irrigation In Almonds – “To Bury or Not To Bury”

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Introduction

There is a continuing debate on which irrigation method and systems are the best for producing almonds. AlmendrosTwinland LLC (ATL) owns and operates a sub-surface drip irrigation system. ATL also operates orchards with micro-sprinkler systems, as well as flood irrigation systems. This work will attempt to shed some light on the debate about irrigation methods in almonds by analyzing the experiences of ATL and its irrigation systems. Various soil and water conditions will play into the process of selecting the right method and system for the almond grower.

Background

In 1998, ATL planted an eighty acre almond orchard on Milham-Sandy Loam soil in the Semitropic Water Storage District (SWSD). The well water on the property was not suited for almonds, since it was high in soluble salts. The water was also high in chloride. Using a flood irrigation system, the soil had a high absorption and leaching rate and used a lot of water to grow crops. It was evident that some kind of controlled irrigation system needed to be installed to maximize the efficiency of the water and make the ditch water go further for maximum production in drought years.

However, due to capital constraints, it was decided to delay the installation of any irrigation system, until after the third year. In that third growing season, the orchard used six acre-feet to grow the crop using the existing flood system. This result really confirmed that a system must be placed in this orchard foremost for water conservation. The land has a 3.25 ac. ft. contract allocation from SWSD. However, additional water can be purchased at times to supplement this amount, as well as adding a minimal amount of well water in drier years. A micro-system would insure that there would be enough water to produce future crops. The question was “Which system should be installed?”

Financial Analysis

Before making the final decision to install the irrigation system in this orchard a comprehensive financial analysis was completed. In summary of that analysis, the installation would provide substantial financial benefits to the farm. The annual costs for capital and operation of the system would be \$190 per acre, while the savings would be \$195 per acre. Additionally, there would be water saving which not only saved money but would allow the farm to make it through tough drought years. Another potential benefit kicker was that the increased efficiency would conservatively increase the yield by at least 100 pounds per acre. At \$1.05 per pound this would net approximately \$8,000 per year more in revenue. See Appendix A

Appendix A

Cost of System \$57,756

Operational Costs	Per Acre	Total Cost
Capital & Int.	\$ 116.87	\$ 8,998.99
Electricity	\$ 53.24	\$ 4,099.48
R & M	\$ 20.00	\$ 1,540.00
Total Addtl Costs	\$ 190.11	\$ 14,638.47

Savings	Per Acre	Total Savings
Fertilizer	\$ 15.00	\$ 1,155.00
Water	\$ 105.00	\$ 8,085.00
Labor	\$ 10.00	\$ 770.00
Fert. Appl.	\$ 30.00	\$ 2,310.00
Weed Control	\$ 35.00	\$ 2,695.00
Totals	\$ 195.00	\$ 15,015.00

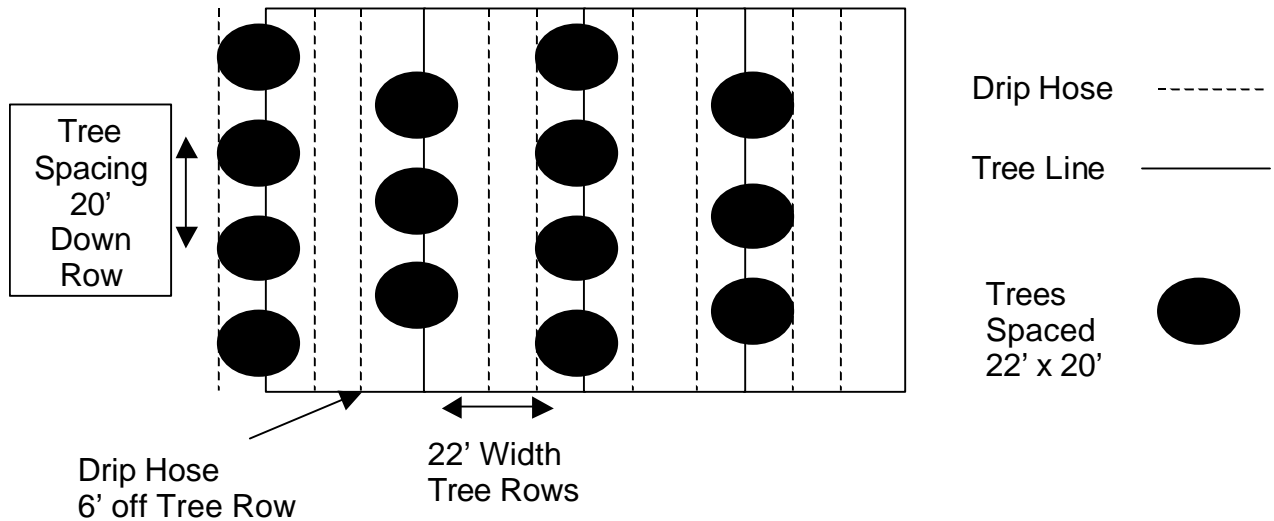
Increase In Production	100 lbs. /Acre	\$105/Per Acre
Added Annual Revenue	\$ 8,085.00	
Accum. Addtl Revenue	\$ 80,850.00	(Ten years)

The System

After researching with other growers, irrigation systems companies and consultants, it was decided to install a drip system in the orchard. The system selected was a one-set system using drip hoses with 1.05 GPH emitters space 52" apart in a double drip line configuration. This system required a 50 HP pressure pump to deliver approximately 830 GPM to the 75 acre orchard. The system was configured with shut-off valves on each line, so that during harvest irrigation could continue on the varieties not being harvested at the time. There were also main valves installed to separate each half of the field, if desired. The filter system installed was a three barrel 45" Lakos auto-flush sand media filter. A Mazzie chemical injector was installed to apply chemicals and fertilizers.

The irrigation system installer and specialist asked ATL if they wanted to bury the drip hose. ATL researched burying the hose with other growers in its farming area. The results of that survey were favorable for burying the hose. The hose was buried to a depth of 18-24. The reason it was buried this deep was to avoid the volcano effect of water coning up to the surface and below the level that gophers usually resided, to reduce damage. Due to the age and size of the trees, it took three passes with the ripper to achieve this depth, since only a small tractor could be used to shank the hose into the ground. The hose was placed approximately six feet from the tree line. Since the trees were planted in a 22' by 20' spacing, it was virtually a grid across the field. Additionally, special end caps were installed with red pop-out indicators to aid the irrigator in monitoring the system. See appendix B for layout.

Appendix B



ATL's Experience

ATL installed the system on the almond orchard in January of 2001. ATL had few problems in the first year of operation of this system. The efficiency of the system enabled ATL to make substantial savings on its water supply. The application of fertilizers including potassium, which is deficient in this soil, was a big boost to efficiency and enhancement of the production in this orchard. The soil, which this orchard is planted on, allows water to move laterally, as well as vertically. This enables the drip lines to be further from the tree line, yet provide moisture to the entire root zone.

In 2001, the fourth leaf, the orchard produced 1,280 pounds per acre. This was not an exceptional yield, but the growth and health of the trees had improved dramatically. This can largely be attributed to the injection of sulfuric acid in the water, thus lowering the pH and unlocking nutrients in the soil. Previous applications of saline well water had left the soil saturated with a certain amount of salts. Since there is plenty of free lime on this soil, the acid could be used to leach these salts.

In the fifth leaf year (2002) the orchard produced 2,010 pounds per acre. Again, this was not that exceptional, but the health of the orchard was much improved and the future production of this orchard looked bright. In the sixth leaf (2003), this orchard produced 2,581 pounds per acre. This was significant in a year, when most yields were down in the southern San Joaquin Valley.

ATL experienced less cost in weed control and orchard floor management due to the lack of moisture on top of the soil. There has been less mite control needed since mowers are in the field less than in flooding or micro-sprinkler systems. Being able to turn the water on in between the harvesting of the different varieties has enhanced harvest and tree health. Management at ATL views this to be the greatest value of any micro-irrigation system.

The only problem that ATL has encountered so far is as follows. There were some buried drip hoses with plugged emitters that were defective from the factory. These did not show up until 2003, since that was the first heavy crop and lateral movement of water provided sufficient moisture up until this point in time.

Comparisons To Other Systems

Micro-Sprinkler

Micro-sprinkler systems are widely used in the state to produce almonds. These systems are usually considered to run 80-95% in efficiency. Virtually all aspects of operation are similar to drip irrigation systems. One difference is that the wind can have an effect on application, where in drip this factor is absent.

These systems are more expensive to install, since there are more parts with the sprinkler heads and spaghetti hoses. On average these systems cost \$300 more per acre to install. These systems also require more maintenance than drip systems, since sprinklers can be damaged or clog partially or fully.

Another difference in micro-sprinkler systems versus drip irrigation is the circular pattern of irrigation, which creates a lush weed growth pattern. In ATL's experience this pattern has required either more mowing or herbicide control. Additionally, the outside ring created a wet zone that is right in the line of equipment traffic during the growing season. This can create rutting, which is a problem at harvest. This has not been the case with underground drip.

Aboveground Drip

ATL does not operate any aboveground drip orchards. However, the company performs various services such as spraying, harvesting and chipping for its customers. Through these processes the company has learned of some characteristics of aboveground drip systems. Generally, aboveground drip works just like underground drip. One main difference is that the hoses are kept close to the tree line. In some cases the lines are tied together, so that they do not move during harvest and other operations.

There is some evaporation, but this is minimal. Nutrients can be disbursed through the hoses as in the other systems. Weed control is reduced since the water is placed in strips down the tree lines. One disadvantage of drip irrigation is the instability of the soil at harvest, which may cause more dust at harvest. This is also true of underground drip.

Summary of Advantages and Disadvantages of Buried Drip

Advantages

One of the main advantages of buried drip is the efficiency of the use of water and nutrients. With this system these elements are placed directly into the feeder root zone for efficient uptake. The use of sulfuric acid through the system has enhanced the soil conditions and improved plant health and productivity. Although these things could be done with surface drip, there is a little more efficiency since there is no evaporation. This factor also plays into the water savings component of this system versus other systems.

Another advantage is that the hoses are out of the way of equipment and surface pests such as coyotes, dogs and the like. This minimizes the costs for repairs and replacement of the hoses. With surface hoses, during harvest and brush removal, hoses can be displaced and damaged.

There is a reduction in weed control due to the lack of excessive moisture on the surface of the soil. This reduces the need for additional mowing and herbicide applications, since the buried hoses are six feet away from the tree lines. This moves the weed pressure to the center of the middles.

Since hoses are buried, as soon as one variety is shooed, the entire orchard can be turned on prior to sweeping and picking up the almonds. This greatly reduces stress on the trees during harvest. It is widely believed that stress during this bud development stage is crucial in determining bud set for the

next year's crop.

Disadvantages

One of the most obvious disadvantages of this system is that the hose is underground and thus difficult to monitor for plugging of the in-line emitters. This disadvantage became apparent, when ATL discovered the faulty hose after two years of operation. If the hose had been above ground, it would have been easy to detect on the first irrigation.

Another disadvantage is the possibility of root intrusion into the hose lines. Roots can choke the hose if there is not a successful maintenance plan in place to impede such root intrusion. The injection of herbicides or sulfuric acid should take care of this. Other users of underground drip systems have been forced to purchase new hose lines and install them above ground to replace faulty hoses or root intruded sections. It is cost prohibitive as well as impractical to attempt to bury the replacement hose due to the underground root structure of healthy and older trees.

Another concern in underground drip irrigation is the potential for more unstable soil at harvest. This may become an issue, due to air pollution concerns. Fortunately for ATL, they have their flood system still in tact. One may want to consider this when installing systems in the future. The option to flood the orchard one in awhile may be necessary.

Conclusion

After three years of operation, the underground drip system has not posed any major problems. Furthermore, it has enhanced this orchard greatly, as any of the micro-systems for irrigation probably would have. ATL believes that this system for this soil is ideal. ATL will be planting another orchard in 2005 that is adjacent to this one. The company will have to decide which system to install. At this date it appears that ATL will duplicate its efforts on the new planting with a buried drip system in the new planting. "To Bury or Not to Bury?" The answer is "it depends". The water, soil conditions, soil structure and soil type must be considered prior to answering the question.

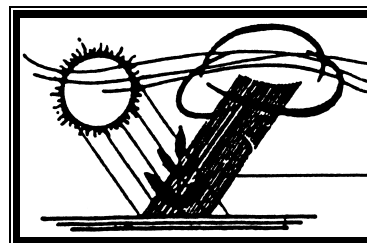
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Session IV
New Technologies
In
Pest Management

Session Chairs:

Tom Babb, California Dept. of Pesticide Regulations

Jim Gregory, Verdegaal Brothers



How the New Ground Water Regulations Affect Pest Management Practices

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Introduction

Historically, the Department of Pesticide Regulation (DPR) has regulated pesticides found in ground water mainly in the sections of land where they have been detected. At the 2002 Proceedings of the California Plant and Soil Conference, we described our investigations relating detections of pesticide residues in ground water to specific soil properties and to depth-to-ground water characteristics (Troiano, 2002). Where data are available, we have used this information to geographically locate sections of land with those same soil and depth-to-ground water characteristics and designated them, along with currently contaminated areas, as ground water protection areas (GWPA) (Troiano et. al., 2000). DPR is now proposing to regulate pesticides found in ground water in all GWPA, thus putting the focus both on preventing contamination before it occurs and on preventing continued movement of pesticides to ground water in areas already contaminated.

GWPA area designated as being either 'leaching' or 'runoff', which describes the predominant pathway for offsite movement of pesticide residues. This designation is important because management practices have been developed for each pathway; leaching management practices will apply to leaching GWPA and runoff management practices will apply to runoff GWPA. Information on the regulatory changes, proposed management practices, and supporting documents is available on DPR's Internet website at: http://www.cdpr.ca.gov/docs/empm/gwp_prog/gwp_prog.htm.

Pesticides regulated to protect ground water

Pesticides that are listed in section 6800(a) of Title 3 of the California Code of Regulations have been detected in California's ground water as a result of legal agricultural use (Troiano et. al., 2001). The active ingredients listed in 6800(a), product names, and their pesticide actions are given in Table 1.

Permitting system facilitates pesticide use

Under the provisions of the California Environmental Quality Act (CEQA), growers could be required to file cumbersome environmental impact reports (EIR) before each use of a pesticide found in ground water due to legal agricultural use. Fortunately, the permitting system used by DPR and the County Agricultural Commissioners has been approved as the equivalent of the CEQA review, greatly reducing the paperwork and time otherwise required to prepare an EIR. The proposed regulations would require end users to get a permit before applying pesticides listed in section 6800(a) only in GWPA.

Table 1. Pesticides regulated on the 6800(a) list as ground water contaminants.

Active Ingredient	Product Name	Pesticidal Action
Atrazine	Aatrex, Strike	Pre-emergence
Simazine	Simazine, Princep	Pre-emergence
Bromacil	Hyvar, Krovar	Pre-emergence
Diruon	Diuron, Karmex, Direx, Krovar	Pre-emergence
Norflurazon	Solicam, Predict, Zorial	Pre-emergence
Prometon	Pramitol	Pre-emergence
Bentazon	Basagran	Contact

Effect of ground water regulations on choice of pesticide and pest management practices

Pesticides currently regulated in Table 1 are herbicides so the new regulations relate primarily to weed control practices. ‘Leaching’ GWPA are characterized by coarse-textured soils where percolating water produced from irrigation moves pesticide residues below the crop root zone and, eventually, to ground water (Troiano et. al., 1993). The following management practices apply for six months after pesticide application in leaching GWPA:

1. Uncontrolled irrigation cannot be applied; **or**
2. Pesticide can only be applied to planting bed or berm above the level of furrow or basin irrigation water; **or**
3. Irrigation water applied to the treated area must not exceed 1.33 of the net irrigation requirement.

In some cases, existing management practices already comply with the new regulations and would not require any change. Some examples are:

- Pre-emergence herbicide applications made for winter weed control applied 6 months prior to crop irrigation.
- Applications of pre-emergence herbicides to raised beds so that the residue is located above the water level of a furrow irrigation system.
- Sites where irrigations are based on a measure of potential evapotranspiration (ET_o), such as those available from the California Irrigation Management Information System (CIMIS), and do not exceed 1.33 of net irrigation requirement.

Compliance may be problematic in some cases. For instance, restricting the amount of applied water to 133% of net irrigation requirement is difficult to achieve in furrow irrigation systems used on coarse, sandy soils.

Management practices differ in runoff GWPA because residues move offsite in runoff water to sensitive areas (Braun and Hawkins, 1991). The goal in runoff GWPA is either to move residues below the soil surface so they are less available for dissolution in runoff water, or to prevent runoff water from contacting and entering sensitive areas. Practices for runoff GWPA are:

1. Use a mechanical method to disturb soil before pesticide application; **or**
2. Incorporate the pesticide into soil within 48 hours after application either by mechanical or pressurized irrigation methods; **or**
3. Apply the pesticide in a band treatment to the crop row; **or**
4. Apply the pesticide between April 1 and July 31; **or**
5. Manage runoff water such that no runoff leaves the site; **or**
6. Store runoff water in a low permeable basin located offsite; **or**
7. Direct runoff to a fallow field.

As in leaching GWPA, some existing management practices in runoff GWPA may already comply with the new regulations. No change is necessary where pre-emergence herbicides are applied in band treatments to tree rows, a common practice used in almonds and other perennial tree and vine crops. But change will be required for growers who maintain clean row middles and rely on rainfall to incorporate residues into soil. Using one of the more effective incorporation methods, such as mechanical incorporation, would be a potential alternative management practice.

Although we have attempted to compile a comprehensive list of practices for use in leaching and runoff GWPA, we realize that they may not be appropriate for all crop uses. In this situation, the Director may approve an alternative management practice, if supported by data. In the absence of data the Director may also allow for a 3-year period of interim use when investigations would be conducted to develop an alternative management practice. The interim use option is conditional upon submission of a written request to the Director of DPR, a protocol that would be approved by DPR staff, and progress reports submitted every six months.

If none of the management practices or alternative options can be met, then use of a 6800(a) listed herbicide would not be allowed in a GWPA. What alternative herbicides should be used? DPR advises users not to substitute herbicides that have a similar potential to move to ground water. Properties of a pesticide that indicate potential for offsite movement are low attraction to soil constituents and longevity in the environment. Owing to their mode of action, many pre-emergence herbicides have low attraction to soil and have relatively long soil half-lives. Pre-emergence herbicides are applied before weed seeds germinate, so residues must long-lived in order to be available when seeds germinate and weeds begin to grow. Furthermore, the residues are taken-up by emerging plant roots and shoots so the residues must be available in soil solution rather than bound to soil. In Table 2, the physical-chemical properties are compared between those herbicides detected in California's ground water, as denoted with the superscript 'a', and some potential substitutes. Those with the superscript 'b' are listed as potential ground water contaminants because their physical-chemical properties are similar to known ground water contaminants (Clayton, 2002). Those without a superscript have high soil attraction compared to the known ground water contaminants. High soil attraction is a property that makes a pesticide much less susceptible to offsite movement as dissolved in water. The value for K_{oc} is a measure of the strength of adsorption between a pesticide and the organic carbon content of a soil. A higher value indicates greater attraction to organic carbon, which in turn decreases its dissolution in soil water and potential for offsite movement. Water solubility and aerobic half-life are properties that could modify the potential for offsite movement, but for the examples in Table 2, they generally fall within the range of the known ground water contaminants. Since contact herbicides such as glyphosate and oxyfluorfen are applied directly to plant tissue and have high soil adsorption, they would be good substitutes for known ground water contaminants because they would be tightly sorbed to plant material or soil, making them unavailable for movement in percolating or runoff water.

Effect of regulations on effectiveness of pesticides

Since the objective of each proposed management practice is to maintain residues at their

Table 2. Physical-chemical properties of selected herbicides.

Active Ingredient	Product Name	Action	Physical Chemical Properties		
			Mobility		Longevity
			Koc	Water Solubility	Aerobic 1/2-life
			---cm ³ /gm---	----mg/L----	----days----
Atrazine ^a	Aatrex	PRE ^c	93	32	146
Simazine ^a	Princep	PRE	340	6	110
Bromacil ^a	Hyvar	PRE	17	929	346
Diuron ^a	Karmex	PRE	499	36	372
Norflurazon ^a	Solicam	PRE	600	28	172
Hexazinone ^b	Velpar	PRE	640	29,800	222
Napropamide ^b	Devrinol	PRE	726	74	455
Oryzalin ^b	Surflan	PRE	848	3	63
Trifluralin	Treflan	PRE	9,900	1.8	180
Glyphosate	Roundup	Contact	24,000	900,000	47
Oxyfluorfen	Goal	Contact, PRE	100,000	0.1	180

^a Herbicides that are ground water contaminants in California.

^b Herbicides listed as potential ground water contaminants in section 6800(b) of Title 3 of the California code of regulations.

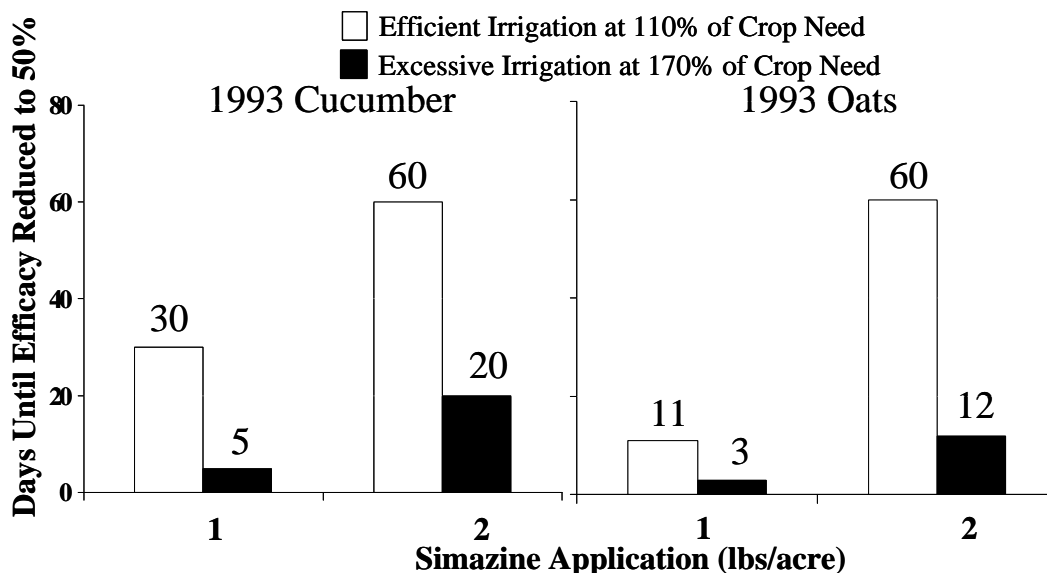
^c PRE = Pre-emergence herbicide.

Effect of regulations on effectiveness of pesticides

Since the objective of each proposed management practice is to maintain residues at their intended site of application, a greater portion of applied residues should be available to provide pesticidal action and subsequently, enhance performance. The potential for increased effectiveness was investigated in a study of simazine's efficacy under two different irrigation efficiencies (DaSilva et al., 2003). Simazine was applied at 0, 1, or 2 lb/acre to 3-year old nectarines. The nectarines were irrigated with micro-sprinklers. Irrigation water was applied at two levels of water management, one where water was applied efficiently at 110% of crop requirements and the other with excessive water applied at 175% of crop requirements. Simazine's effectiveness was measured as the survival rate of oats and cucumber planted at 0, 2, 4, and 8 weeks after simazine application. Based on these sequential survival data, the length of time was calculated for simazine's effectiveness to be reduced from 100% to 50% where longer time intervals indicated greater effectiveness. As anticipated, the 2-lb/acre rate of application was effective for a longer time interval than the 1-lb/acre rate, e.g. in cucumber reduction to 50% efficacy was measured at 20 vs 5 days, respectively (Figure 1). At each rate of application, time to loss of 50% efficacy was much greater in the efficient irrigation treatments. And comparing between rates, efficacy at the 1-lb/acre treatment in efficient irrigation was equivalent to that measured for the 2-lb/acre rate in the excessive water irrigation treatment. Historically, irrigation management and pesticide application decisions have been made independently. This study showed that linking these two decision-making areas together should result either in cost savings with respect to herbicide expenditures or in increased effectiveness of herbicide applications. For example, if a grower were to reduce percolating water through improved irrigation management, one might experience better product effectiveness when using standard rates. Alternatively, rates of application could be potentially lowered without reduction in efficacy.

The current list of management practices is not intended to be static. The regulations and management options can always be amended to reflect improvements in application technology, new methods to control offsite movement of residues, or even changes in philosophy of how pests should be managed. For example, chemigation of pesticides provides a number of benefits with respect to placement, timing, and management of pesticide residues. Since many of the pre-emergent herbicides listed in section 6800(a) are not labeled for application through low-volume irrigation systems, chemigation is currently not a management option. The DPR has contracted with the Center for

Figure 1. Effectiveness of simazine measured at two levels of water management in micro-sprinkler irrigation. Effectiveness was measured as the length of time in days for survival rate of emerged seedlings to be reduced from 100% to 50%.



Irrigation Technology (CIT), California State University, Fresno to conduct cooperative studies on the application of simazine and diuron through low-volume irrigation. Registrants are also participating in the project where the goal is to provide information that will enable chemigation to be added as a method of application to these products. Cooperating growers provide an opportunity to demonstrate the effectiveness and use of chemigation in their pest management system.

Summary

The goal of the new ground water regulations is to decrease offsite movement of residues in deep percolating water and in runoff water. Areas that are vulnerable to ground water contamination will be based on soil characteristics and depth-to-ground water data and denoted as ground water protection areas (GWPA). Based on the pathway of offsite movement of pesticide residues, GWPA are further designated as leaching or runoff areas. Management practices have been developed for each pathway so the effect of the new ground water regulations on pest management practices will depend on how much growers must change their current practices to meet the proposed management practices for each pathway.

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Reduced Tillage System Pink Bollworm Program

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Introduction

The pink bollworm (*Pectinophora gossypiella*) is considered one of the world's most destructive cotton insect pests. When its numbers build to high levels, pink bollworm can destroy 100 percent of a cotton crop. Pink bollworm has been a serious pest of cotton in Arizona and southern California since the mid-1960s. Insecticides used for control often facilitate secondary pest outbreaks of tobacco budworm, bollworm, cotton leaf perforator, and others.

Purpose

The purpose of the Pink Bollworm Program is to prevent the artificial spread of the pest to uninfested areas, to control emergent infestations of pink bollworm, and to minimize economic impact on California cotton growers.

Cotton is one of the most important crops grown in California. It is estimated that cotton accounts for over 150,000 jobs in California, a combination of direct employment and employment related to value added goods and services of cotton's domestic and export trade. The value of California's cotton exports including lint, cottonseed and other products makes the cotton crop worth nearly one billion dollars annually. Approximately 95 percent of California's cotton is produced in Fresno, Kern, Kings, Merced, and Tulare counties.

Background

The Pink Bollworm Program is an integrated pest control program that has been in continual operation since 1967. This cooperative Pink Bollworm Program is funded almost entirely by the cotton growers of California through an assessment on each bale of cotton ginned in the state. The United States Department of Agriculture contributes about 8 percent of the total funding. The Program uses a cotton industry advisory board known as the Cotton Pest Control Board to provide recommendations relative to program activities. For 36 years, program activities have successfully prevented incipient infestations of pink bollworm from becoming established in the cotton growing areas of the San Joaquin Valley. The Pink Bollworm Program uses an integrated pest control approach, relying on trapping, sterile insect release, cultural controls, and occasional pheromone treatments to keep infestations below economic impact levels. The Pink Bollworm Program is administered by the California Department of Food and Agriculture (CDFA).

If pink bollworm became established in the San Joaquin Valley, millions of pounds of pesticides would be introduced into the environment, annually, just to control pink bollworm. It is estimated that an additional seven pounds per acre of pesticides would have to be used every year to control pink bollworm and related secondary pests in the San Joaquin Valley. Establishment of pink bollworm in the San Joaquin Valley could increase cotton growers' pest control costs by \$90 to \$100 per acre each year.

Cultural controls target the number of larvae that survive between growing seasons. Since the initial inception of the Pink Bollworm Program, crop destruction has been a key component of the integrated pest control strategy and has significantly contributed toward the reduced use of pesticides. Post harvest shredding and plowdown practices kill overwintering insect populations and prevent wider infestations in the spring. When combined with required plowdown deadlines, delayed or restricted planting dates provide further overwintering population controls through the establishment of a host-free period. The host-free period can eliminate early spring fruit needed for egg laying. Early emerging females, searching for developing cotton plants, are denied suitable egg laying sites and perish within two to three weeks. Stub or regrowth cotton is extremely detrimental to effective pink bollworm cultural control, allowing insect populations to begin building earlier than would be possible in planted cotton.

Reduced Tillage Permit

The Pink Bollworm Program issued minimum tillage permits to Riverside County (2001) and Imperial County (2002) based in large part on the high ratios (95:5) of *Bt* (*Bacillus thuringiensis*) cotton plantings to conventional cotton. At their March 2003 meeting, the Cotton Pest Control Board received San Joaquin Valley grower requests to consider the implementation of a reduced tillage program as an alternative to current plow down regulations. Potential new air quality regulations and increased costs for fuel and other production activities were major reasons associated with the growers' request. A reduced tillage program for the San Joaquin Valley was strongly supported by the California Cotton Growers and Ginners Association. The Board recommended that the Pink Bollworm Program in conjunction with CDFA resources, work with the local County Agricultural Commissioners to develop a reduced tillage permit for the San Joaquin Valley.

There were several factors contributing to the consideration to allow some form of reduced tillage. These were: 1) a relatively low number of native pink bollworm moth finds in the San Joaquin Valley over the past several years; 2) the high percentage of *Bt* cotton being grown in southern California, and the subsequent infrequency of pink bollworm moths being "blown-in" from the southern desert cotton growing regions, 3) the overall low amount of cotton acreage in southern California; and 4) the Pink Bollworm Program's ability to successfully respond to an infestation using current detection and control methodologies.

The Cotton Pest Control Board appointed a subcommittee to develop a reduced tillage program proposal. Subcommittee members included representatives from the Cotton Pest Control Board, CDFA's Integrated Pest Control Branch, United States Department of Agriculture's Agricultural Research Service and Animal and Plant Health Inspection Service, University of California, Cooperative Extension and San Joaquin Valley Agricultural Commissioners.

On September 18, 2003 a reduced tillage permit was issued by the CDFA to the pink bollworm regulated districts in the San Joaquin Valley. The permit had several key requirements including grower notification to the local County Agricultural Commissioner, post harvest cotton plant shredding, tillage, regulatory inspection of cotton fields, and prohibited or restricted areas based on pink bollworm native finds. The most significant change was **not requiring** that roots, plant stubs, shredding debris and trash remaining from harvesting or clean-up operations be mixed with surface soil. The plowdown and planting date requirements remained the same.

The language stated in CDFA Permit Number 1084 is as follows:

1. *A native pink bollworm (PBW) cannot have been detected within the described boundary of a government section (township-range) and the immediate adjoining sections (a total of nine square miles) during the previous crop year or during the current crop year. Except: If a moth were detected after September 1 of the current crop year, reduced tillage would be allowed in the current crop year, but not in the next crop year.*
2. *The requirements in Section 3595(e)(1) for cotton destruction by shredding shall be complied with in full: "All cotton stalks and debris shall be shredded by a power-driven shredding device in a manner which effectively reduces stalks to a particle size permitting burial and decomposition and assures that the bolls remaining in the field are broken open and the parts scattered."*
3. *The authorized cotton grower shall notify the county Agricultural Commissioner a minimum of ten (10) days prior to beginning use of the reduced tillage system.*
4. *Following shredding as required above, the land on which any cotton plants were growing during the preceding season shall be tilled in a manner that dislodges the cotton plant roots from the soil which insures that cotton plant re-growth will not occur (reduced tillage system).*
5. *Without prior notice and during reasonable hours, authorized state or county regulatory officials shall be allowed to inspect the condition of said cotton fields and the reduced tillage system operations.*
6. *Roots, plant stubs, shredding debris and trash remaining from harvesting or clean-up operations are not required to be mixed with surface soil.*
7. *All cotton plants in Districts 2 and 3 shall be destroyed in a manner described in Section 3595(e) or this permit by December 20, and all cotton plants in District 4 shall be destroyed in a manner described in Section 3595(e) or this permit by December 31 of each year, unless a variance is issued by the California Department of Food and Agriculture.*
8. *Nothing contained herein shall in any way preclude the County Agricultural Commissioner or the California Department of Food and Agriculture from taking appropriate action under applicable provisions of the California Food and Agricultural Code, including Section 5784.*

This reduced tillage permit is an annual permit and expires December 31, 2003. The use of an annual permit (as opposed to a "regulation change") provides the ability to quickly and easily revoke and/or modify the Reduced Tillage System/Program Permit in the event of a pink bollworm "outbreak" or dissatisfaction by the grower community.

Grower informational seminars have been conducted in conjunction with the University of California, Cooperative Extension and local County Agricultural Commissioners in various locations through out the San Joaquin Valley. These informational meetings have stressed the requirements and restrictions of the new reduced tillage permit including detailed maps and township-range-section descriptions of the precise prohibited areas.

Monitoring will be conducted throughout the 2003-growing season and into the following 2004 crop year to assess reduced tillage program impacts and effectiveness.

Robotic Weed Sprayers in Production Agriculture

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Introduction

Weeds in close proximity to crop plants compete for light, water and nutrients and may significantly reduce yield and quality of the crop. Hand weeding, requiring human labor, can be costly and unreliable. Precision, targeted treatment of these weeds can reduce or eliminate the need for hand weeding and selective herbicides. Automation of the in-row weed control process requires development of sensing and actuation systems.

The spray actuator system used in this study was originally described by Lee *et al.* (1999) for tomatoes and Lamb *et al.* (2002) for cotton. Lee *et al.* (1999) developed a machine vision weed detection system for the seedlines in tomatoes. Ground speed was 1.2 km/h and image processing rates were 3 Hz. Lee *et al.* reported that 24.2 % of tomatoes were identified incorrectly and sprayed while 52.4 % of weeds were not sprayed. Lamm *et al.* (2002) adapted Lee's work for cotton identification and developed a non-morphological machine vision technique to identify occluded plants in addition to discriminating between narrow leaf and broadleaf plants. The system correctly sprayed 88.8 % of the weeds during in-row seedline image analysis from a moving vehicle in the field.

Objectives

The objectives for this work were to determine the biological efficacy of a micro-dosing system against weeds in field grown processing tomatoes, the concurrent phytotoxicity to the crop plants and the crop biomass under field conditions.

Methods and Materials

The initial field system (Lee, *et al.* 1999) was constructed as a linear array of Type 304W stainless steel hypodermic tubes, 1.25 cm long x 0.27 mm i.d. and inside chamfered on each end. Five tubes were placed 0.125 cm apart to create a linear array covering the 0.65 cm width. Eight, individually-controlled arrays provided the 10 cm treatment width along the row centerline. Flow to each tube array was controlled by a direct-acting, DC solenoid valve with 12 Vdc, 6 W coil and 0.65 cm internal flow orifice. Minimum cycle time for the valve was measured as 6 ms; therefore a minimum duty cycle of 20% could be achieved at 34 Hz operation.

The physical performance of the microsprayer and the liquid adjuvants guided the design of a field assessment of micro-dosing a herbicide to weeds within the seedline of field-grown processing tomatoes. Physical performance of the fluids selected for testing were reported by Downey *et al.*, (2003). Weeds and crop plants were in their naturally-occurring positions and experienced typical crop growing conditions in the Sacramento Valley of California, USA.

Efficacy and phytotoxicity of micro-dosing applications were investigated using the nonselective herbicide (glyphosate). The experiment was conducted as a factorial design with three concentrations of glyphosate, viz., 0.25, 0.375 and 0.50% (active ingredient) and two concentrations of a polymer splash inhibitor (polyethylene oxide, PEO): 0.0 (absence) and 0.03% w/w (presence). The application rate of spray mix applied by the micro-dosing jet was 37.0 µl per spray cell of 0.63 x 1.25 cm for an equivalent application rate of 4698 l/ha. The spray cell size was equivalent to the spray cell size used the machine vision weed detection system (Lamm *et al.*, 2002). A transparent grid with the arrays of cells was used to estimate the weed size and number of distinct jet doses to apply. Applications were made manually, that is, by holding the jet tube 5 cm above the weed and pulsing the jet control valve for 6 ms. A treatment of the commonly-used, post-emergent, selective herbicide (rimsulfuron) was also included in the test. The selective herbicide was broadcast over the crop beds at a rate of 33 g active ingredient/ha. The design also included untreated control plots.

Processing tomatoes were seeded on 8 July 2002 and treated 16, 23 and 30 days afterward. The weeds present in the test area and used in the study were: pigweed (*Amaranthus albus*, *A. blitoides*), spotted spurge (*Euphorbia maculata*) and black nightshade (*Solanum nigrum*). Weed mortality was determined by manual counting at 5, 10 and 15 days post application. Efficacy of the post-emergent treatment was estimated by a visual rating of weed control relative to the untreated, control plots. Phytotoxicity to the tomatoes was determined by counting dead and chlorotic plants at 5, 10, 15 and 20 days post application. Biomass data were collected by harvesting tomato biomass on 1 October and oven drying to determine dry mass.

Results

For the three weed species tested, all the glyphosate treatments effectively controlled the weeds; the least efficacious situation was with the spurge, therefore those results are shown as an example (Table 1). There were no significant differences between the glyphosate treatments; however, they all provided control superior to that from the standard, selective herbicide. The relatively high specific dose rate (approximately 4700 l/ha) on the leaves and the generally high efficacy of the active ingredient combined to provide a high dose delivery and very effective control.

Results of phytotoxicity to the surrounding tomato plants (Fig. 1) showed that the broadcast application of selective herbicide caused significantly more damage than the micro-dosing of a non-selective herbicide. Comparison of the results for the glyphosate treatments to the results in the untreated plots indicated that the damage was due to inadvertent deposition (or perhaps soil transport) of the active ingredient. Many of the plants that showed chlorotic symptoms shortly after treatment eventually died during the 20 days post application. A positive correlation between application rate of glyphosate and resulting crop phytotoxicity was observed. Addition of the PEO anti-splash polymer reduced phytotoxicity. While traditional multiple range tests for all treatments did not find the effect to be statistically significant, analysis of the polymer effects within blocks of active ingredient rates found the effect to be highly significant. For the mid range concentration (0.375% a.i.), the effect of polymer was distinct.

Biomass data are shown in Table 2. All glyphosate herbicide treatments resulted in higher biomass yields than untreated controls. The effect was numerically large, that is, 20-30 fold higher. Several of the highest herbicide treatment yields were from the lower doses of active ingredients, suggesting that avoiding phytotoxicity provides more marginal benefits than increasing weed control and reducing competition. This finding would have implications for design of machine vision and treatment algorithms; a bias toward conservative protection of the crop over complete weed control would be optimal.

Table 1. Control of spotted spurge (*Euphorbia maculata*) in tomatoes after micro-dosing at 37.0 μ l per spray cell of 0.63 x 1.25 cm.

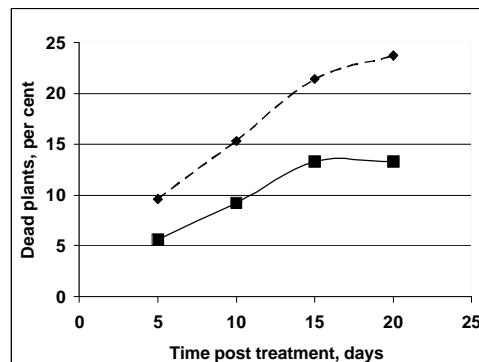
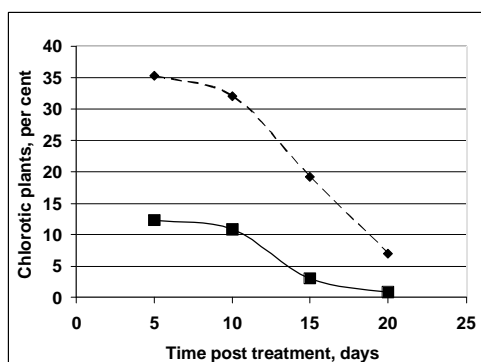
Active ingredient and rate	Polymer concentration	Mortality @ 5 days	Mortality @ 10 days	Mortality @ 15 days
-	per cent	per cent	per cent	per cent
glyphosate 0.5%	0.00	91.3 a	98.3 a	98.3 a
glyphosate 0.5%	0.03	90.1 a	97.8 a	98.7 a
glyphosate 0.375%	0.00	86.5 a	93.8 a	95.5 a
glyphosate 0.375%	0.03	84.9 a	94.4 a	96.2 a
glyphosate 0.25%	0.00	82.4 a	86.8 a	87.5 a
glyphosate 0.25%	0.03	78.7 a	87.4 a	88.0 a
rimsulfuron 35g/ha	-	5.0 b	25.0 b	11.7 b
control	-	0 b	0 c	0 c

Letters = significant differences in a column at $\alpha = 0.05$ by Duncan's New Multiple Range Test.

Table 2. Tomato dry biomass after micro-dosing at 37.0 μ l per spray cell of 0.63 x 1.25 cm.

Active ingredient and rate	Polymer concentration	Application 24 July	Application 31 July	Application 7 August
-	per cent	g/m	g/m	g/m
glyphosate 0.5%	0.00	211.9 a	224.2 ab	74.4 a
glyphosate 0.5%	0.03	287.9 a	263.2 ab	105.0 a
glyphosate 0.375%	0.00	178.8 a	287.9 ab	81.7 a
glyphosate 0.375%	0.03	307.6 a	372.1 ab	111.0 a
glyphosate 0.25%	0.00	253.2 a	269.2 ab	154.4 a
glyphosate 0.25%	0.03	327.3 a	379.3 a	132.4 a
rimsulfuron 35g/ha	-	159.7 ab	159.7 b	52.2 a
control	-	10.0 b	10.4 c	5.5 b

Letters = significant differences in a column at $\alpha = 0.05$ by Duncan's New Multiple Range Test.



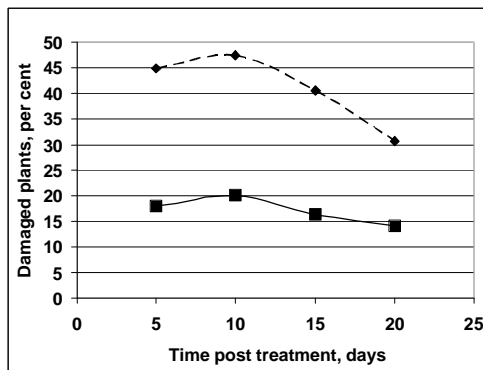


Fig. 1. Effect of polyethylene oxide anti-misting polymer (PEO) addition on chlorotic, dead and total damaged tomato plants from glyphosate at 0.375% a.i. 0% PEO (♦), 0.03% PEO (◻).

Discussion

The physical (Downey *et al.*, 2003) and biological performance (this report) of the micro-dosing system, consisting of pulsed jets and selected fluid adjuvants showed consistency. The effectiveness of combining surfactants to reduce surface tension and improve spread of deposit on weeds and anti-misting polymers to inhibit splash and inadvertent deposit on nearby crop plants was confirmed in both physical and biological assessments.

The emitted, pulsed jets from the micro-dosing system were governed by Rayleigh break up, indicating stable jets and large, if any droplet formation. Jet velocities were found to be high in relation to vehicle travel speeds that are limited by time delays characteristic of image acquisition and processing for weed vs. crop discrimination.

For the concentrations of non-selective herbicide tested, i.e., 0.25 to 0.50% a.i., weed control was virtually complete and independent of dose, suggesting that doses can be lowered without sacrificing efficacy. This is perhaps a consequence of the relatively high (4700 l/ha) specific application rate of liquid.

Phytotoxicity of the crop plants as a result of micro-dosing nonselective herbicide to adjacent weeds was reduced by addition of an anti-misting polymer to the liquid mix. The polymer had no significant effect on weed control efficacy. Tomato biomass yield was significantly increased by weed control within the seedline; lower doses of herbicide provided highest yields suggesting that avoidance of phytotoxicity may be more important than extremely high weed control rates when selective micro-dosing is used in field conditions.

Acknowledgements

The authors acknowledge the Agricultural Experiment Station of the University of California, the U.S. Dept. of Agriculture, the University of California Buy California Specialty Crops Research Program and the California Department of Food and Agriculture Buy California Grants Program for financial support of this project.

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Session V

Emerging Field Technologies

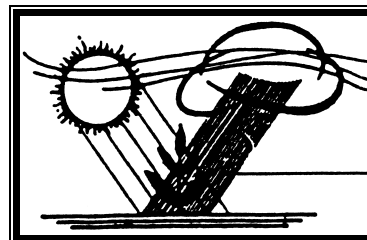
In

California Agriculture

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A New Approach for Monitoring Soil Moisture

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Introduction

Monitoring soil moisture is recommended as part of managing irrigation water. Soil moisture measurements can help determine when to irrigate, crop water use, depth of wetting, trends with time which might indicate over-or-under irrigation, and moisture extraction patterns.

Many sensors exist for monitoring soil moisture content. Some devices are designed to measure soil moisture tension, which is the tenacity at which soil moisture is retained in the soil. Others measure soil moisture content. Methods that measure soil moisture tension can be used to determine when to irrigate, but they require calibration to relate soil moisture tension to soil moisture content. Even though reliable calibrations may be unavailable, monitoring soil moisture tension provides useful information on trends of soil moisture content with time, patterns of soil moisture uptake by roots, and depths of wetting. Also, simple observations correlating soil moisture content determined by soil sampling and the instrument's reading could help to determine those readings that indicate a need to irrigate.

Methods for Monitoring Soil Moisture

Soil moisture sensors appropriate for growers are summarized as follows.

Soil probe/soil sampling. Soil samples are obtained using a soil probe or auger. Appearance and feel of the soil is related to soil moisture using an appropriate chart.

Tensiometers. Tensiometers measure soil moisture tension. A tensiometer is a plastic tube with a porous cup attached to one end and a vacuum gauge attached to the other end. The porous cup is inserted into the soil, and the vacuum gauge measures the soil moisture tension. Tensiometers are limited to about 80 centibars of soil moisture tension because of the vapor pressure of water.

Electrical resistance blocks. These devices, which are used to measure soil moisture tension, are two electrodes embedded in gypsum or a gypsum-ceramic mixture. Changes in soil moisture content cause changes in the water content of the block, which in turn changes its electrical resistance. An appropriate instrument is used to read the electrical resistance or conductance of the block depending on the manufacturer. Readings of resistance blocks are related to soil moisture tension.

The response of resistance blocks to changes in soil moisture content depends on their design. The blocks measure the electrical resistance of the water in their pores, which are very small voids in the porous block material. Water flowing in and out of the pores as soil moisture content changes causes changes in the electrical resistance. Blocks that contain a relatively uniform range of pore sizes respond poorly to changes in soil moisture in wet soil because the block reading will not change until the block desaturates. Desaturation will occur only when a threshold block water tension is reached. This threshold tension depends on the sizes of the largest pores. For blocks with a small range of relatively small pore sizes, substantial drying of soil must occur before desaturation occurs. Once desaturation occurs, block readings will change rapidly with small changes in soil moisture content. For blocks with a wide range of pore sizes, desaturation of the larger pores will occur at relatively small block water tensions such as occur in wet soil. Also, because of the wide range of pore sizes, block readings will change more gradually with changes in soil moisture compared to blocks with a small range of sizes. Blocks with a wide range of pore sizes are preferred for monitoring soil moisture content.

Dielectric Sensors

There are many types of dielectric sensors available for soil moisture monitoring. These sensors measure soil moisture contents by measuring the dielectric constant of soil, an electrical characteristic of soil that is highly dependent on moisture content. The constant of dry soil is between 3 and 5, about one for air, and is about 80 for water. Thus, changes in the soil moisture content changes the dielectric constant of soil. Calibration equations have been developed correlating volumetric soil moisture content and dielectric constant. The most common dielectric methods are frequency-domain-reflectometry (FDR) or capacitance sensors and time-domain-reflectometry (TDR) sensors.

The zone of influence appears to be very small for TDR sensors. Also, an air gap between the waveguide and the soil can adversely affect its measurements. Careful installation of these sensors is needed to prevent air gaps. A grower can easily install some types of sensor, while other types require technical support from the manufacturer or dealer.

Numerous field evaluations and observations of the performance of dielectric soil moisture sensors have shown mixed results. In sandy soil, the sensors perform reasonably well using the manufacturers' calibration curve. For clayey soil (silty clay loam, clay loam, clay), the sensors may not be very accurate using the manufacturers' curve, and thus field calibration will be required for soil moisture content measurements. Capacitance sensors are particularly susceptible to inaccurate readings in fine-textured soil, and may give readings as high as 80% soil moisture content, a reading that can only happen in organic soils.

Sensor cost may range about \$100 to more than \$1000. Other costs include readout devices, data loggers, and computer software. .

Continuous Monitoring of Soil Moisture Content

A common practice is to read the soil moisture sensors once or twice per week. Manually reading the sensors at a higher frequency is not practical in many cases. However, a new approach to soil moisture monitoring is to use relatively low cost data loggers connected to the sensors. The loggers can be programmed to read the sensors at intervals ranging from a few minutes to a few hours, depending on grower preference. The advantage of this approach is that behavior in the data that might be related to irrigation water management, soil, and crop type can readily be seen, whereas such behavior might be difficult to identify from infrequent measurements.

There are a number of low cost data loggers available for electrical resistance blocks and dielectric sensors. Costs range from about \$200 to about \$500. Some loggers are weatherproof while others are not. Some loggers contain a LCD display that shows the actual soil moisture tension or moisture content data. One logger uses a LCD display to show the soil moisture tension data of the previous five weeks. For some of the loggers, a portable computer is required to download and display the data. Others use a portable storage device called a shuttle, which downloads the data from the data logger and then is used to transfer the data into a computer at some other time. Several loggers can use a temperature probe to adjust soil moisture sensor readings for soil temperature. In one case, a pressure sensor can also be connected to the logger, which allows the irrigation operation times to be recorded and compared with the soil moisture data.

Examples of Continuous Measurements of Soil Moisture

Soil moisture tension was measured in a flood-irrigated orchard using Watermark resistance blocks (Fig. 1). The data of the 1-foot depth clearly show the irrigation events, which resulted in readings nearly equal to zero. Between irrigations, soil moisture tension increased (drying soil) to values between about 80 to 120 centibars. At the deeper depths, little change in soil moisture tension occurred with time

until about day of year(DOY) 160. Thereafter, soil moisture tension increased with time. No response of soil moisture tension with irrigation was found for the deeper sensors indicating that little or no irrigation water was infiltrating down to those depths.

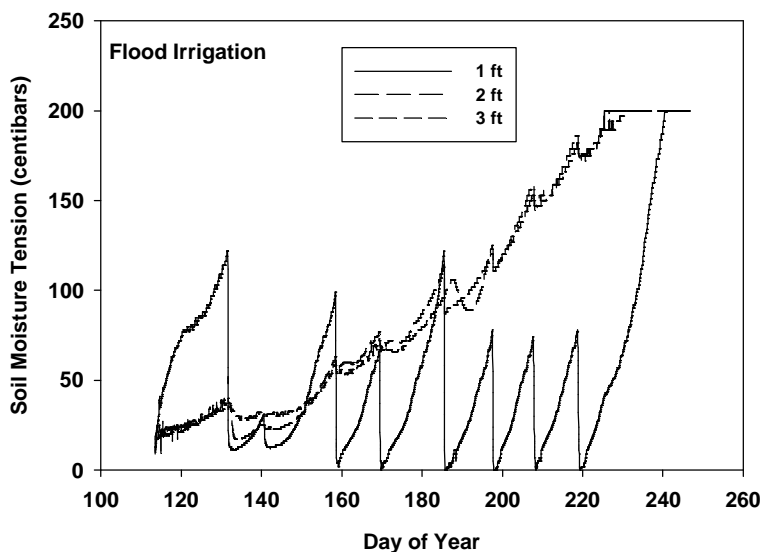
The response of soil moisture tension, measured with Watermark resistance blocks, with time is shown for a drip-irrigated field (Fig. 2). The drip line was buried at 12 inches deep. The irrigation operation times were also monitored (black bars). Only the measurements at 6 and 12 inches deep are shown. At 6-inches deep, little response with irrigation was found. After DOY170, soil moisture tension continued to increase (drying soil) with time. At 12 deep, however, soil moisture tension data showed a strong response to the intervals between irrigations. Larger intervals resulted in larger values of soil moisture tension.

Fig. 3 also shows soil moisture tension with time for a buried drip irrigation system. Drip line depth was about 14 inches. Moisture tension increased with time up to about DOY180 to DOY190 to very high values. This behavior was caused by emitter clogging. After about DOY175, a surface drip system was installed which reduced tension values to about 20 to 30 centibars.

Fig. 4 shows the results of too-frequent irrigations and too much water applied to a drip irrigated field. Drip line depth was about 8 inches. Watermark blocks were located about 6 inches from the drip line at a depth of about 6 inches. The irrigation times (black bars) show daily irrigations. Block readings remained at zero for most of the irrigation season, thus indicating near saturated conditions most of the time. Crop growth also suggested very wet soil with a maximum canopy size of about 50%.

The effect of irrigation and alfalfa harvests on soil moisture tension is shown in Fig. 5. These measurements were made to determine if any changes in the irrigation schedule could be made. Alfalfa harvests occurred just before an irrigation, which resulted in a large decrease in the soil moisture tension. Soil moisture tensions become relatively high between irrigations exceeding 100 centibars just before an irrigation with only one irrigation between cuttings. Two irrigations between cuttings was not possible of insufficient time for the soil to dry sufficiently for the harvesting equipment.

Figure 1. Soil moisture tension measurements in a flood-irrigated field. No water infiltrated down to the 2 ft depth.



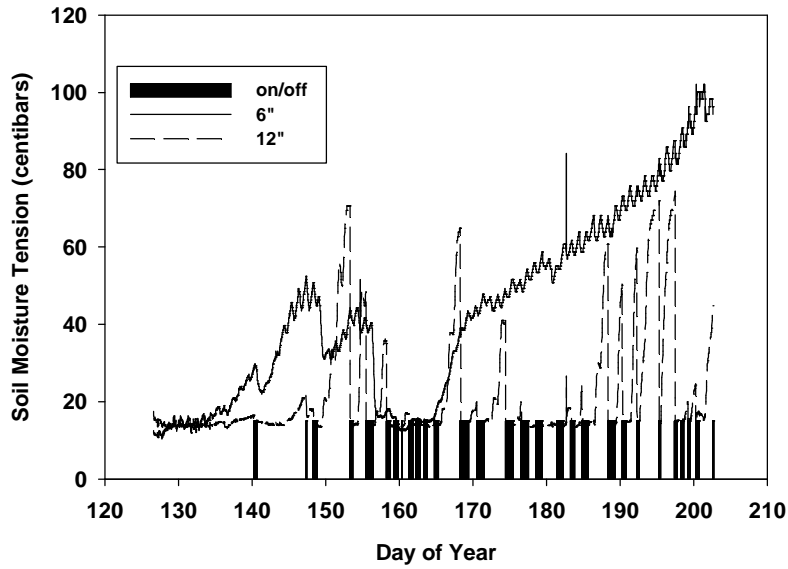


Figure 2. Soil moisture tension measurements in a drip-irrigated field. A strong response of soil moisture tension to irrigation interval was found for the 12 in depth.

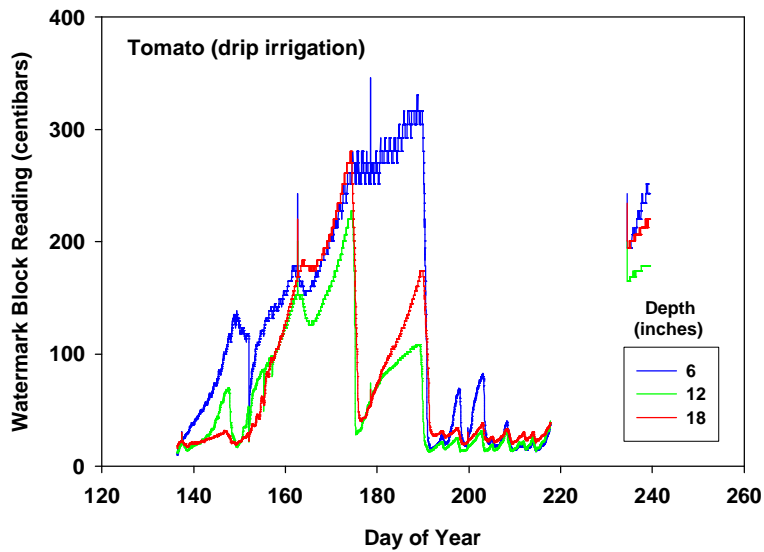


Figure 3. Response of soil moisture tension to clogging of drip line and subsequent replacement.

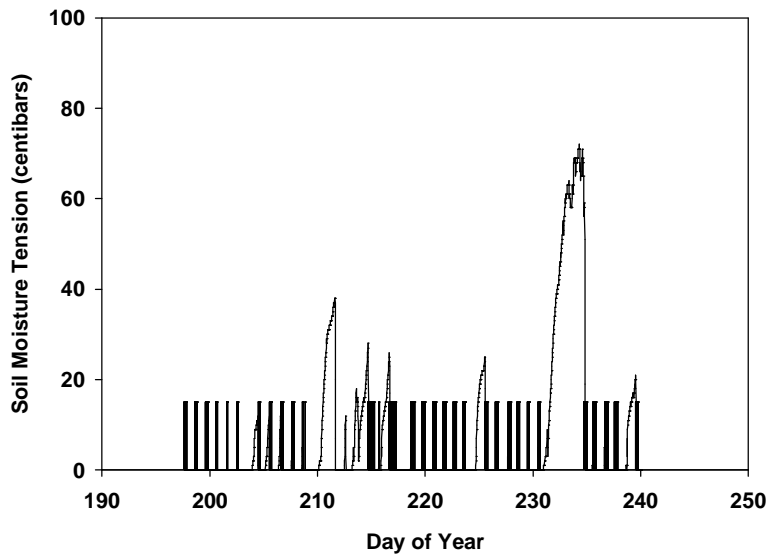


Figure 4. Response of soil moisture tension to drip-irrigated field irrigated that was apparently irrigated too frequently with too much water.

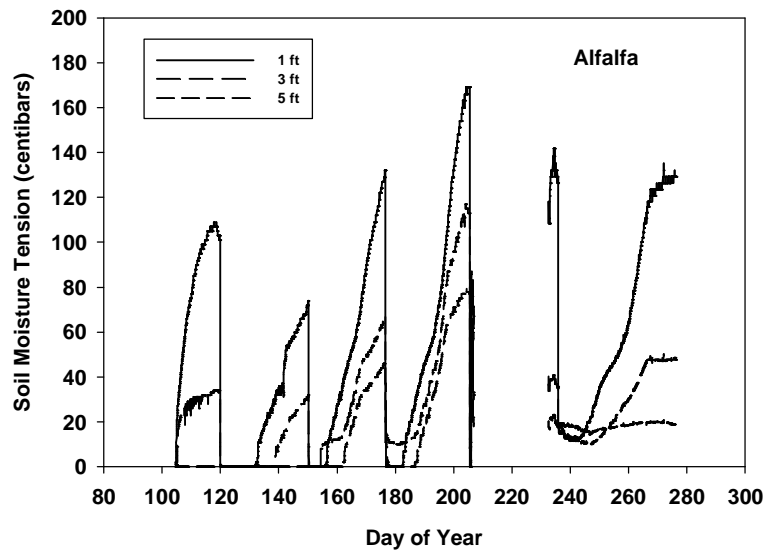


Figure 5. Soil moisture tension readings in a flood irrigated alfalfa field. Measurements showed little opportunity for improving the irrigation schedule due to the harvest schedule. Alfalfa harvests occurred just before an irrigation.

Update on Specialty Crops Research for the San Joaquin Valley of California

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Introduction

The economy for San Joaquin Valley growers is somber. Market prices for most crops have been depressed for several years resulting in removal of thousands of acres of citrus, stone fruits, grapes and olives. More than ever growers are seeking new crops to plant and many are focusing their attention on specialty vegetable and berry crops for alternatives. Historically, small acreage growers have been extremely successful growing numerous specialty crops, many of which have become mainstream commodities. The new competition is generating concerns among small acreage farmers. They are desperately seeking new niche crops to maintain their competitiveness in the market place. This project was undertaken the task to identify potential new crops and market opportunities. This specialty crop research is essential for their economic viability of many small acreage farmers in the San Joaquin Valley.

What is a specialty crop?

Specialty crops typically include crops unfamiliar to us such as ethnic fruits and vegetables, unique high quality, high value vegetable crops grown out of season, crops difficult to grow i.e. organic fruits and vegetables, heirloom fruits and vegetables, and exotics.

The following are examples of specialty crops:

- § **Ethnic fruits and vegetables:** bitter melon, bok choy, diakon, nopalitos (cactus leaves), tunas (cactus fruit), jicama, tomatillo, cilantro etc.
- § **Unique high quality fruits and vegetables:** miniature vegetables, gourmet vegetable i.e. specialty mild peppers (gringo peppers), specialty lettuce or lettuce mixes, high sugar/high acid tomatoes and other fruit, high quality sweet corn for direct marketing.
- § **Crops grown out of season:** greenhouse tomatoes; blackberries, raspberries, blueberries, strawberries or any crop grown in hoop houses for early production; all warm season vegetables grown under hot caps and plastic tunnels for early production; crops grown under specialized covers to delay maturity.
- § **Crops difficult to grow or not normally grown in a region:** blueberries, papaya.
- § **Heirloom crops:** old fruit and vegetable varieties recognized by good taste.
- § **Exotics:** zapote, guava, mango, tamarillo, green papaya.

A specialty crop can simply have an unusual color or shape. Cauliflower and eggplant are excellent examples. Although white cauliflower is traditional, *Graffiti* is a bright neon purple, *Panther* is lime green and *Citrus orange* is yellow/orange colored. *Romanesco* cauliflower has beautiful and unusual spiraled heads. Eggplant species have even greater diversity in colors and shapes. Many cultivars grown and consumed in Europe, North America, Asia and the Middle East have little likeness. Most of us are familiar with American eggplant, a large round or oval shaped fruit usually black but really dark purple. These large fruit are also available in shades of white, green and pink. Japanese eggplant long and cylindrical used to be considered a specialty but today is just another mainstream eggplant. The designation of specialty eggplant is awarded to the Hmong eggplant which resembles a flat green bell pepper. Thai eggplant (*Kermit*) is a small round green and white variegated fruit, *Turkish Orange* is a round ribbed light green fruit which become bright orange when over mature. Other unusual varieties include *Neon Fl* a bright deep pink fruit with a green calyx, *Zebra* a variegated maroon colored fruit and *Comprido Verde Claro* a green to orange ribbed fruit.

Project Objectives

1. Identify potential new crops.
2. Identify new markets for old crops.
3. Identify unique attributes of common crops and develop new marketing strategies.
4. Identify alternative production methods to increase profitability of current crops being grown.

Methods

Before initiating field research trials considerable time was spent speaking with growers, conducting literature search, identifying potential crops, studying market trends and determining if our climatic and soil conditions were adequate or adaptable .

Several trials were established at the University of California, Kearney Research and Extension Center in Parlier. We evaluated numerous vegetable crops, blueberries, blackberries, fresh cut flowers and exotics. In the initial stage of each trial, we took the *Ashot gun@* approach, planting many varieties and made cursory evaluations. Once we identified a potential area of research, we concentrated our information search, and dedicated more time and resources to refining our observational evaluations. Grower meetings were organized to view the observational trials. If growers indicated in specific crops we then established replicated trials.

Results

❖ **Blueberries:** Our inquiry indicated that an excellent market window existed if we could produce blueberries during the month of May. Since 1997 we have planted forty one (41) blueberry varieties including eight (8) northern highbush varieties, twenty seven (27) southern highbush varieties and six (6) rabbit varieties. The two major obstacles were that blueberries require acidic soil conditions and require considerable chilling for fruit set. We identified several southern highbush varieties which demonstrated good potential. We also demonstrated soil acidification techniques that lowered soil pH to acceptable levels. The most promising varieties include *Misty*, *Jewel*, *O=Neal* and *Star* for early production, *Legacy* and *Ozark Blue* for late production and *Reveille* and *Southmoon* for direct marketing. Growers in the region have recognized the profit potential of blueberries and planted more than one thousand acres of blueberries in the San Joaquin Valley.

- ❖ **Blackberries and Raspberries:** We found that there was good demand for blackberries and raspberries through direct marketing venues. Although we have grown blackberries and boysenberries for many years these varieties are thorned and difficult to harvest and are costly to prune and train. Since 1997 we have evaluated six (6) raspberry varieties and twenty four (24) blackberry varieties. The blackberries included trailing, semi-erect and erect selections and among them were thorned and thornless varieties. We identified some unique varieties including Kiowa an erect, highly thorned variety which produces extremely large fruit and Arapaho a thornless variety which produces fruit mid season. Because of there later season maturity these varieties are still prone to sun scald when temperatures exceed 100 degree F.
- ❖ **Specialty vegetables:** Small acreage growers in the region would benefit from any improvements in vegetable species. We have made a strong effort to identify new, improved and specialty varieties that could be planted as niche crops by growers. During 2001 to 2003 we have planted two hundred and eighty (280) specialty tomato varieties, more than three hundred (> 300) chili pepper varieties, more than three hundred (> 300) squash and pumpkin varieties and numerous exotic vegetables. Many growers are currently growing cultivars that were initially demonstrated at our field trials.
- ❖ **Sub Tropical Fruits:** Growers have indicated they would like to be able to grow some sub tropical crops. We reviewed the market for several potential crops and identified papaya for green papaya salad as one that we might be able to produce. In 2002 we planted six varieties. In 2003 we planted twelve varieties including six Hawaiian varieties, three Chinese varieties, two Indian, and one Mexican variety. In 2003 we successfully harvested green papaya and are conducting post harvest evaluations at the University of California, Davis
- ❖ **Growing Vegetables Out of Season:** One method of increasing profitability is to grow crops when supplies are low. Usually that means growing crops under some form of plastic culture to enhance maturity. We have demonstrated the use of various growing systems to advance maturity including hot caps, plastic mulch poor man tunnel, large vegetable tunnel and hoop houses (large mobile greenhouse). All these system only work if the best early producing vegetable cultivars are utilized. We've also demonstrated the use of shade cloth to delay maturity on late blueberry varieties.

Conclusions

Identification of profitable specialty crops is elusive. As soon as someone makes money growing a new or improved crop many other growers follow. Soon what was a unique crop is over produced or it becomes a mainstream crop. What becomes a mainstream crop is eventually grown more efficiently and the economies of scale take over. The original grower who discovered the crop can no longer compete. Therefore he must find new crop opportunities. The University of California Cooperative Extension then has the task of working growers to continue their search for market niche crops to sustain their economic viability.

Marker-Assisted Selection For Disease Resistance in Wheat

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The information that follows is from a research project titled “Bringing genomics to wheat fields” funded by IFAFS (Initiative for the Future of Agriculture and Food Systems) through USDA-CREES for 4 years (2001/04) for \$3,250,000. The overall goal of the project is to transfer new developments in wheat genomics and biotechnology to wheat production through the development of a National wheat Marker Assisted Selection (MAS) consortium of 12 wheat-breeding and research programs from across the U.S. The lead PI is Jorge Dubcovsky, wheat geneticist and breeder at UC Davis.

Participants:

University of California, Davis: Jorge Dubcovsky and Lee Jackson

Colorado State University: Nora Lapitan and Scott Haley

Cornell University: Mark Sorrells

Kansas State University: Allan Fritz, Bikram S. Gill

Montana State University: Luther Talbert

North Dakota State University: Shahryar F. Kianian; Elias Elias, and Dr. Micheal Peel

Purdue University: Herbert Ohm

University of Idaho: Ed Souza

University of Minnesota: Jim A. Anderson

University of Nebraska: Kulvinder S. Gill, Stephen Baenziger, and Don Lee

USDA-ARS Genotyping laboratory: Gina Brown

Washington State University: Kim Campbell, Kim Kidwell, Camille Steber, X. Chen

The goal of wheat breeding is to combine desirable genes from different parent lines into new cultivars of distinct market classes adapted to specific growing regions. However, it is often difficult to monitor for the presence of multiple desirable genes during the selection process. Biotechnology has revolutionized plant breeding efforts by providing tools, such as DNA tags, which can be used in MAS strategies for cultivar development. These molecular markers are particularly useful for incorporating genes that are highly affected by the environment (e.g. high grain protein content), genes for resistance to diseases that cannot be easily screened for, and to accumulate multiple genes for resistance to specific pathogens and pests within the same cultivar, a process called gene pyramiding. Gene pyramiding is an effective mechanism for creating durable resistance but has been difficult to accomplish because once an effective resistance gene is present in a breeding line, it is very hard to screen for the incorporation of additional resistance genes. Fortunately, molecular markers can be used to pyramid different resistance genes into elite lines or cultivars while maintaining preexisting, effective resistance genes.

Available molecular markers were used in this project to transfer 23 genes for resistance to fungal diseases, viruses, and insect pests, and 21 genes related to bread, pasta, and noodle quality into adapted cultivars or breeding lines belonging to all major market classes of U.S. wheat. For host resistance, the emphasis was on the fungal diseases stripe rust leaf rust, *Septoria tritici* blotch, Karnal bunt, Fusarium, and Eyespot; viruses BYDV, WSMV, and WSSMV; and insects Russian wheat aphid and Hessian fly. The resistance alleles used are present within the wheat gene pool and were originally transferred by meiotic chromosome recombination. Since these genes are transferred to their natural chromosomal locations, the possibility of gene silencing is minimized. Also, cultivars developed by

MAS are not transgenic and therefore, do not face the public resistance observed against transgenic crops.

A relatively large investment has been made in wheat molecular genetics and wheat genomics. Many of the participants in the project were funded over the last ten years to construct detailed molecular maps of wheat including more than 3000 molecular markers. This number of markers will triple with the incorporation of the 10,000 genes from the current NSF project "The Structure and Function of the Expressed Portion of the Wheat Genomes". In addition to mapping projects, U.S. federal agencies have funded the construction of wheat Bacterial Artificial Chromosome (BAC) libraries, the assembly of these BACs into physical contigs, and sequencing of large segments of wheat DNA. This abundant genetic information was used by the participants of the project to develop molecular markers for numerous genes related to wheat quality and disease and pest resistance.

An advantage of the incorporation of MAS into breeding programs is that a disease resistance gene or a gene to increase grain protein content can be manipulated using the same technology. In addition, marker technologies are continuously evolving. Research laboratories are working in parallel with the breeding programs to convert current molecular markers into PCR-based markers and SNPs (single nucleotide polymorphisms), a new generation of molecular markers whose use has resulted in huge technological advances. Different SNP detection and multiplexing technologies were tested to develop a simple and cost effective technological platform for future MAS in wheat. Assays developed for the detection of SNPs include allele-specific PCR, cleaved amplification polymorphic sites (CAPS), degenerate CAPS (dCAPS), allele specific oligonucleotide hybridization, dynamic allele-specific hybridization, oligonucleotide ligation assay, single base extension, base excision sequence scanning, and others. The objective of this portion of the National MAS program is to determine which of these technologies is better adapted to the hexaploid genome of wheat.

The majority of the targeted genes are from wheat and are located on chromosome segments that recombine normally in wheat. If the available marker is not completely linked to the target, two flanking markers are used in MAS to greatly reduce the possibility of losing the targeted gene by recombination. Five of the selected targeted genes (*Bdv2*, *Wsm1*, *Lr37-Yr17-Sr38*, *Lr47*, *pinB-A^m1a*) are in homoeologous chromosome segments incorporated into wheat from closely related wild relatives. These segments show a high level of polymorphism with wheat and are easier to convert into PCR markers. A single molecular marker is enough for MAS because the *Ph1* gene prevents recombination with the wheat chromosomes. An alien chromosome segment will not recombine with the wheat homeolog even if it is interstitial and flanked by homologous chromatin.

Most of the selected genes or chromosome segments were incorporated into adapted wheat lines using six backcross (BC) generations and using markers to select for the targeted gene from the BC₂ generation. More than 99% recovery of the recurrent parent is theoretically expected after this process. Seven BC plants per generation are adequate to have a probability higher than 0.99 of recovering a BC plant with the desired genotype. However, 12 plants were used in each BC to simultaneously select for minimum linkage drag. The number of selected plants was increased when more than one trait was introduced simultaneously in the same recurrent parent. The heterozygous BC plants were used as male parents to eliminate the risk of self-pollination. The heterozygous BC₆ plants were self-pollinated and homozygous plants for the targeted molecular markers were selected in the last generation. In the last cycle of backcrossing several plants of the recurrent parent were used to maintain whatever beneficial heterogeneity was present in the recurrent cultivar. To minimize the introgression of large flanking regions from the parental gene donor, microsatellite markers outside the targeted region were tested during the backcrossing program. Recombinants between those microsatellites and the targeted markers were selected. The objective of this strategy is to reduce the "dead genome space" caused by linkage drag. An average of 28 cM from the donor parent is retained around the targeted gene after BC₇ without MAS. Alien chromosome segments recombine poorly with wheat chromosomes, but the length of the selected segments has been reduced by two cycles of *Ph*- recombination before the initial introgression.

In this project, markers closer to the targeted genes were developed to minimize the dead space created by the backcrossing process.

The backcrossing process can be accelerated three generations by the use of molecular markers across the complete genome. The recently developed highly polymorphic microsatellite map of wheat has given wheat breeders a valuable tool for optimizing MAS. The identification of polymorphisms between a recurrent and a donor parent for each chromosomal arm of wheat increases the probability of early generation recovery of the recurrent parent genotype using a recurrent-enriched MAS backcross breeding strategy. Recurrent-enriched backcrossing involves screening BC₁ and subsequent backcross progeny for markers across the complete genome for selection of disproportionate inheritance of recurrent parent chromatin. Based on theoretical expectations, a recurrent-enriched backcross breeding strategy will identify BC₃ plants with minimized linkage drag and approximately 95 percent of the recurrent parent genotype 95 percent of the time. Although this process can accelerate the backcrossing process three generations, it has a larger cost and requires more greenhouse space and resources.

The MAS selection programs are integrated into existing breeding programs. The existing breeding programs provide recurrent parents from the highest-yielding, elite germplasm from each region. Intermediate products of MAS are returned to the breeding programs for evaluation and crossing purposes. After each of the first three generations of backcrossing, the selected heterozygous plants are self-pollinated and the BC₁₋₃ F₂ seeds planted as additional segregating populations. This generates variability for selection in the breeding program. Finally, products of the advanced BC₄₋₆ generations are used as parental lines in the crossing blocks of the existing breeding program. One of the most challenging aspects of wheat breeding is the introgression of genes from non-adapted germplasm into regional germplasm. The improved germplasm developed through this research facilitates the rapid recovery of superior, elite lines from forward breeding efforts and will make the targeted genes available in adapted backgrounds for future crosses.

A strict backcrossing strategy will not increase yield potential, except for the reduction of yield losses due to pathogens. Therefore, this backcrossing strategy should be used only as a complement of active "forward breeding" programs. For this reason, all the participants in the project also have active programs with hundreds of crosses made each year and tens of thousands of segregating lines evaluated by classical methods based on phenotype. The traits selected by each program are indicated in the WEB site: (<http://agronomy.ucdavis.edu/Dubcovsky/IFAFS/IFAFS.htm>, Username: IFAFS, Password: Genomic\$). The same WEB site includes a link to "[Tables of selected recurrent parents: backcrossing progress](#)".

At UC Davis we focused on the diseases stripe rust, leaf rust, and Septoria tritici blotch. Stripe rust, caused by the fungus *Puccinia striiformis*, devastated the California wheat crop in 2003. In fields where stripe rust was most severe, highly susceptible cultivars suffered 75% or more loss; susceptible cultivars, 50-70% loss; moderately susceptible cultivars, 20-40% loss; and moderately resistant cultivars, 5-15% loss. Statewide, yield losses were at least 25%. New races of *P. striiformis* appeared in California and throughout the country during the last two years: 12 races were identified in California in 2002 and additional races became established in 2003. These races are virulent to many of the previously resistant cultivars so new resistance genes are required to maintain adequate resistance levels. Fortunately, new resistance genes to stripe rust and other diseases have been identified and have been or will be introgressed into hexaploid wheat. These genes include stripe rust resistance genes *Yr5*, *Yr8*, *Yr15*, and *Yr17* and the high temperature adult plant (HTAP) resistance identified in 'Stephens'. This resistance has been durable for over 20 years in the Pacific Northwest. Resistance gene-analog markers are available for *Yr5*, *Yr8*, and the HTAP resistance gene and were used for pyramiding multiple resistance genes within selected cultivars. We developed new PCR markers for *Yr5* and *Yr17* and a marker for *Yr15*. *Yr5* from spelt wheat and *Yr15* from *T. dicoccoides* are resistant to the current stripe rust races in California. Microsatellite markers *Xgwm18* and *Xgwm264* flank *Yr15*. *Yr17* is linked to the leaf rust resistance gene *Lr37*. Leaf rust resistance genes include *Lr21*, *Lr39* and *Lr40* from *T. tauschii*,

Lr37 from *T. ventricosum*, *Lr47* from *T. speltoides*, and *LrArm* from *T. timopheevi* subsp. *Armeniacum*. *Lr47* is resistant to the current races of leaf rust present in California. Resistance genes *Lr37-Yr17-Sr38* are completely linked so can be transferred together. PCR-specific markers are available for *Lr21*, *Lr40*, *Lr47* and the linked group of resistance genes *Lr37-Yr17-Sr38*. CAPs markers are available for the last two loci to select homozygous resistant plants in the last BC₆F₂ generation. Microsatellite markers *Xgwm210* and *Xgwm382* are linked to *Lr39* and *LrArm*, respectively.

We have completed the introgression of *Yr17* into Hard Red Spring (HRS) wheat cultivars/breeding lines Yecora Rojo, Anza, RSI5, Express, UC1041, Kern, UC1037 and are moving it into Hard White Spring (HWS) wheat lines UC896, UC1107, and UC1110. We are in the final stages of selection for *Yr15* in HRS cultivars/breeding lines RSI5, Express, UC1041, Kern, UC1037 and are moving it into HWS lines UC1107, UC1128, and UC1110. We currently are pyramiding *Yr17* and *Yr15* in UC1041 and Express. We are in the 3-4 generation of backcrossing *Yr5* into RSI5, UC1041, Kern, UC1037, UC896, UC1128, and UC1110.

Most of the backcrossing for leaf rust resistance in the HRS program has been completed. Field evaluation of lines carrying *Lr47* (5 cultivars) and *Lr37* (3 cultivars) showed no negative effects on agronomic characteristics and quality. *Lr37* and *Lr47* were pyramided in Yecora Rojo, Kern and UC1037. We also initiated MAS programs to incorporate *Lr37* and *Lr47* in three HWS germplasms. We initiated crosses to combine these leaf rust resistance genes with *Yr15* and *Yr5*. We initiated work in slow rusting genes *Yr29/Lr46*. These genes do not provide complete protection against the rusts, but slow down disease development and have shown durability (maintained effectiveness for many years). We tested a microsatellite marker developed in our laboratory (*Xwmc44*) that recently was found to be associated with *Yr29/Lr46* in Pavon and have initiated a new MAS program for this gene. The backcrossing program to incorporate *Lr51* was completed for Express, Kern, UC1037 and Yecora Rojo (BC₆). This gene is within a small interstitial segment from *T. speltoides* in the long arm of chromosome 1BL and is resistant to most North American leaf rust races. *Lr47* and *Yr17/Lr37* are being combined with *Lr51*: F₂ seed is available for the crosses Kern *Lr47*x Kern *Lr51* and UC1037*Lr47*x UC1037*Lr51*.

We tested a new marker for *Septoria tritici* blotch resistance gene *Stb3* present in Israel 493 and started using it to introgress this gene into 3 HWS and 1 HRS. Four lines have been advanced two generations and four new lines have been added to this backcross program.

The current status of the MAS projects at UC Davis is listed in Tables 1 and 2 below:

Table 1. HRS-MAS Program, UC Davis.

Character	Yecora Rojo	Anza	RSI5	Express	UC 1041	UC 1036	UC 1037	UC 1358
<i>Lr37, Yr17</i> (leaf & stripe rust)	Fld.Y1	Fld.Y2	BC ₆ F ₂	Fld.Y1	Fld.Y2	Incr. 1	Fld.Y1	BC ₁
<i>Lr47</i> (leaf rust)	Fld.Y3		Fld.Y3	Fld.Y3	Fld.Y2	Fld.Y2	Incr. 1	
<i>Lr51</i> (leaf rust)	BC ₆			Incr. 2		Incr. 2	Incr. 2	
<i>Yr5</i> (stripe rust)	BC ₁		BC ₃		BC ₄	BC ₄	BC ₄	BC ₂
<i>Yr15</i> (stripe rust)			BC ₆	BC ₆ F ₂	BC ₆ F ₂	BC ₆	BC ₆ F ₂	BC ₂
<i>Yr29/ Lr46</i> (slow rusting)	F ₁							
High protein <i>T. dicoccoides</i> (*= also HMW glutenin)	Fld.Y1	Fld.Y1*	Fld.Y1 *	Fld.Y1	Fld.Y2	Fld.Y2	Fld.Y1*	BC ₃
High protein Avalon	BC ₆				BC ₆		BC ₆	
Hardness Express			BC ₆	C ₅ 5A ^m		Incr. 1		
Transgenic HMW		BC ₅	BC ₅			BC ₅	BC ₅	
LMW-Loci	Incr. 1	Incr. 1	Incr. 1				Incr. 1	
BYDV <i>Bdv2</i> (Thelin)	BC ₁					BC ₁	BC ₁	
Septoria <i>Stb3</i> _Israel 493*					(F ₁)		BC ₃	
Septoria CIMMYT.2*	BC ₂					BC ₂		
Septoria CIMMYT.3*	BC ₂					BC ₂		

Table 2. HWS-MAS Program, UC Davis

Character	UC 896	UC 1107	UC 1128	Klasic	Attila	UC 1110	UC 1361	03020 /80	03015/27 Low PPO	UC1419 03010/24
<i>Lr37, Yr17, Sr38</i>	BC ₃	BC ₆				BC ₃		F ₁		(F ₁)
<i>Lr47</i>	BC ₁	BC ₁				BC ₁				
<i>Yr5</i>	BC ₃	BC ₃	BC ₃			BC ₃	F ₁			(F ₁)
<i>Yr15</i>		BC ₅	BC ₆			BC ₃				(F ₁)
High protein <i>T. dicoccoides</i>	BC ₃				Incr. 1	BC ₄	BC ₁			(F ₁)
PPO (noodle color)	BC ₅ F ₂	BC ₆ F ₂		BC ₆		BC ₂				
Thelin <i>Lr19-Bdv2</i>	BC ₁					BC ₁				
Septoria <i>Stb3</i> (Israel 493)	BC ₂	BC ₂	BC ₃			(F ₁)				
Septoria CIMMYT.2*	BC ₂	BC ₂				BC ₂		F ₁		
Septoria CIMMYT.3*	BC ₂	BC ₂				BC ₂				
Waxy D1b		BC ₁				BC ₁	BC ₁		F ₁	
Pavon <i>Lr46/Yr29</i>	(F ₁)	(F ₁)	(F ₁)				(F ₁)		(F ₁)	(F ₁)

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Methyl Bromide ALTERNATIVES For Perennial Crops And Field NURSERIES

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Methyl bromide is a widely used soil fumigant in perennial cropping systems for nematode and pathogen control both in field nurseries and to manage “replant disorder” when replanting perennial crops. The Montreal Protocol, an international treaty, and the U.S. Clean Air Act restricted availability of methyl bromide beginning in January, 2001 to 50% of the amount used in the baseline year of 1991. It was further restricted to 30% of the baseline in 2003 and will be completely banned in 2005. Quarantine use of methyl bromide is exempted from the impending ban. U.S. growers of perennial nursery crops and those replanting orchards and vineyards are in dire need of alternatives to methyl bromide. The availability of acceptable alternatives will impact the supply and quality of these agricultural products to American consumers and the export market.

Perennial Crop Field Nurseries

Soil fumigation with methyl bromide has commonly been used prior to planting field nurseries to insure a high quality product and to meet the California Code of Regulations that state that it is “mandatory that nursery stock for farm planting be commercially clean with respect to economically important nematodes” (CDFA, 1996). Historically, methyl bromide has been effectively used to comply with the nursery regulations. Growers of perennial nursery crops, such as trees, vines, and roses, will need alternatives to methyl bromide in order to continue to produce clean planting material and to meet CDFA’s requirements following the ban on methyl bromide.

Rose Field Nursery Trial – Planted 2001. A rose nursery field trial was initiated in fall 2001 in Wasco, CA. The previous cotton crop, rootknot nematode resistant variety “Nemex”, was removed in August 2001, shank treatments applied in September and drip treatments in Oct. Each treatment (Table 1) was replicated 6 times in a randomized complete block design. Dr. Huey rose rootstock was planted at the end of Nov. Details of nematode control at planting can be found in the 2003 Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. Soil samples were collected to a depth of 24” in March 2003 and processed by sugar flotation/centrifugation. Rootknot nematode populations in the untreated control, untarped Telone C35, and Iota (a biological material) plots are significantly higher than in plots treated with methyl bromide

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(Table 1). Weed control, evaluated spring 2003, was best in the methyl bromide plots and least in the Untreated, Iota, and metam sodium pots. Plant vigor was greatest in the methyl bromide, tarped Telone C35, InLine, and chloropicrin – high rate, and least in the untreated control plots.

Grafted roses are a 2-year crop. As expected, rootknot nematode populations that were reduced to nearly undetectable levels by the use of the rootknot resistant Nemex cotton prior to planting roses, reached detectable population levels prior to the beginning of the second growing season. High variability in the rootknot nematode population level, as shown by the population ranges, was observed in the untreated control, untarped Telone C35, and Iota plots. We will monitor nematode and fungal pathogen populations and evaluate plant quality at harvest in Dec. 2003.

Table 1. Rootknot nematode populations per 100cc soil sampled at planting in a commercial rose trial March 2003, mean of 6 replications. Statistical analyses conducted on log transformed ($\log(n+1)$) data. Data presented are the antilogs of the means, as well as the range of values. Means followed by the same letter are not significantly different at the $P = .05$ level.

Treatment	Mean	Range
Untreated	18.0 a	0-805
Methyl Bromide - 350 lb/acre, tarped - noble plow	0 c	0-0
MIDAS (30% Iodomethane 70% Chloropicrin) - 400 lb/acre, tarped - noble plow	0 c	0-0
Telone C35 - 48 gal/acre, tarped - noble plow	0.8 bc	0-32
Telone C35 - 48 gal/acre, untarped - telone rig	6.4 ab	0-354
Inline – 50 gal/acre, drip	0 c	0-0
Telone EC – 35 gal/acre, drip	0 c	0-0
Chloropicrin – 200 lb/acre, drip	0 c	0-0
Chloropicrin – 400 lb/acre, drip	0 c	0-0
Chloropicrin – 200 + 200 lb/acre, drip	0 c	0-0
MIDAS (30% Iodomethane 70% Chloropicrin) - 400 lb/acre, drip	0 c	0-0
MIDAS (50% Iodomethane 50% Chloropicrin) - 300 lb/acre, drip	0 c	0-0
Metam sodium – 75 gal/acre (42% a.i.), drip	0.5 bc	0-12
Iota (a bacterial suspension from FUSION 360, Turlock, CA)	10.8 a	0-213

Tree, Vine and Berry Field Nursery Trial. A field trial was initiated in fall 2001 in a commercial nursery in Visalia, CA. The previous corn crop was removed in September and treatments applied in October. Each treatment (Table 3) was replicated 4 times in a randomized complete block design. All treatments were applied by shank injection. Details of treatment application and nematode control at planting can be found in the Proceedings of the 2002 Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions. A diverse selection of trees, grapevines, raspberries, and blackberries was planted in March 2002 (Table 2). Vine and berry plants were harvested in Dec. 2002. Roots were chopped and placed in a mist chamber to extract root nematodes. Results are presented for the 3 most susceptible grape varieties (Table 3). Most treatments reduced rootknot populations from the levels observed in the untreated control. Telone C35, tarped and untarped, tarped MIDAS (30:70 and 50:50), and tarped chloropicrin resulted in nematode populations not significantly different from populations in the methyl bromide plots. Few rootknot nematodes were found in berry roots from any treatments. Trees are a 2-year crop and will be harvested in Jan. 2004.

Table 2. Crops evaluated in a commercial tree, grapevine, and berry field nursery trial.

Trees	Grapes	Berries
Common Apple	1103P	Amity Raspberry
Mazzard Cherry	Freedom	Brazos Blackberry
Mahaleb Cherry	Flame	Indian Summer Raspberry
Callery Pear	Thompson Seedless	Heritage Raspberry
Lotus Persimmon	Crimson Seedless	Kiowa Blackberry
Wonderful Pomegranate	Autumn Royal	
Lovell Peach	Cabernet Sauvignon	
Nemaguard Peach	Zinfandel	
Myrobalan Plum	Chardonnay	
Pecan seed		

Table 3. Rootknot nematode populations per 20g roots sampled at harvest Dec. 2002, mean of 4 replications, in a commercial nursery trial planted in 2002. Statistical analyses conducted on log transformed ($\log(n+1)$) data. Data presented are the antilogs of the means. Means for each grape variety followed by the same letter are not significantly different at the $P = .05$ level.

Treatment	Cabernet Sauvignon	Zinfandel	Thompson Seedless
Untreated	420 a	214 a	278 a
Methyl Bromide, 500 lb/a, noble plow	0 c	0 d	0 e
Telone C35, 36 gpa, untarped, telone rig	0 c	0 d	3 cde
Telone C35, 42 gpa, tarped, noble plow	2 bc	0 d	0 e
Midas 30:70, 400 lb/a, untarped, deep shank	11 b	15 bc	102 ab
Midas 30:70, 425 lb/a, tarped, noble plow	0 c	0 d	0 e
Midas, 50:50, 375 lb/a, untarped, deep shank	14 b	25 ab	14 bcd
Midas, 50:50, 375 lb/a, tarped, noble plow	0 c	0 d	1 de
Chloropicrin, 350 lb/a, untarped, telone rig	19 b	4 bcd	22 bc
Chloropicrin, 425 lb/a, tarped, noble plow	1 bc	1 cd	0 e

Grapevine Field Nursery Trial – planted 2003. A 70-year-old, plant-parasitic-nematode-infested “Thompson Seedless” vineyard located at the USDA Parlier, CA research station was selected for a grape vine nursery field trial. Vines were removed in fall, 2002. Each treatment was replicated 6 times in a randomized complete block design. Shanked, tarped methyl bromide was applied in Oct. 2002. All other treatments (Table 4) were applied by drip fumigation in November, 2002. Broadcast drip treatments were applied in 3 inches of water over a period of 16 hours using moderate-flow drip tapes spaced 24 inches apart and buried at a depth of 8 inches, with the exception of one Agrizide treatment applied through drip tape buried at a depth of 2 inches. A metam sodium cap was applied through microsprays as an herbicide treatment on the InLine and MIDAS plots.

Table 4. Citrus nematode populations per 100cc soil sampled at planting March 2003, mean of 6 replications. Statistical analyses conducted on log transformed ($\ln(n+1)$) data. Data presented are the antilogs of the means. Means for each depth followed by the same letter are not significantly different at the $P = .05$ level.

Treatment	0-12"	12-24"	24-36"	36-48"	48-60"
Untreated Control	60.3 a	78.6 a	181.6 a	78.3 a	10.0 a
Methyl Bromide, 400 lb/acre	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
MIDAS, drip (50% IM: 50% Pic), 240 lb/acre	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
MIDAS, drip (50% IM: 50% Pic), 300 lb/acre	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
InLine, 50 gal/acre	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b
Agrizide, drip, 300 lb/acre, 2" deep drip tape	0.2 b	1.6 b	0.3 b	0.0 b	0.0 b
Agrizide, drip, 300 lb/acre, 10" deep drip tape	0.0 b	0.0 b	0.0 b	0.0 b	0.0 b

Soil samples were collected at planting in March 2003 in one-foot increments down to a depth of 5 feet. Samples were extracted using the baermann funnel to recover only live nematodes. The predominant plant parasitic nematode genera found in the samples were *Tylenchulus*, the citrus nematode, and *Meloidogyne*, the rootknot nematode. All treatments provided control equivalent to methyl bromide at planting (Table 4).

Thompson Seedless, Cabernet Sauvignon, and Freedom grapevine sticks were planted in April 2003 and will be harvested in Jan. 2004. Experimental rootstocks developed by D. Ramming were planted in the untreated control plots. These rootstocks have been shown to not support phylloxera development and were developed from parental lines exhibiting resistance to nematodes. This is the first field test of these rootstocks to determine resistance to nematodes and vineyard replant disorder. These plants will be harvested in Jan. 2004.

Conclusions – Perennial Field Nurseries

- MIDAS, tarped Telone C35, InLine, Telone EC, chloropicrin, and metam sodium achieved nematode control similar to methyl bromide at the beginning of the 2nd growing season in a rose field nursery, BUT performance of these materials at the end of the cropping cycle is not yet known, MIDAS is not yet registered, and use of 1,3-D is restricted in California by township caps.
- Tarped, shank-injected applications gave better control than untarped, shank-injected applications in a commercial vine nursery, but tarping represents an additional cost.
- New materials and new rootstocks evaluated here are potential tools in management of nematodes under nursery conditions without methyl bromide, but performance throughout the cropping cycle is not yet known.

Perennial Crop Replant Disorder

Field evaluation of potential methyl bromide alternatives for perennial crops must determine not only efficacy of pathogen control at the time of planting the new vineyard or orchard, but also the efficacy of pest control and impact on crop growth and yield during the early growth and fruiting years. This summary reports the on-going performance of field trials planted in 1998, 2000, and 2001. Complete details on experimental design and previous years' data were reported in the Proceedings of the 1999, 2000, 2001, and 2002 Annual International Research Conference on Methyl Bromide Alternatives and

Emissions Reductions.

Chemical, Genetic, and Cultural Alternatives for Vineyard Replant Disorder – Planted 1998. Drip applied treatments were applied in January, 1998 and shanked treatments in April, 1998 to a 65-year-old Thompson Seedless vineyard, following removal of the vines in fall, 1997. The treatments are described in Table 5. In July 1998, each plot was planted with three grape variety/rootstock combinations; own-rooted Thompson Seedless, Merlot on Harmony rootstock, and Merlot on Teleki 5C rootstock.

Table 5. Treatments applied in a 1998 vineyard replant trial.

- | |
|---|
| 1 - Untreated control |
| 2 - Methyl bromide (400 lbs/acre = 28 gal/acre), shanked, tarped (the treated control) |
| 3 - One-year fallow |
| 4 - One-year fallow plus a sorghum-sudangrass hybrid cover crop |
| 5 - Iodomethane (400 lbs/acre = 21 gal/acre), shanked, tarped |
| 6 - Telone EC (35 gal/acre or 310 lbs/acre of 1,3-D) in <u>60 mm water</u> through a buried drip tape plus Vapam (26 gal/acre of 42% metam sodium) through microsprinklers |
| 7 - Telone EC (35 gal/acre or 310 lbs/acre of 1,3-D) in <u>100 mm water</u> through a buried drip tape plus Vapam (26 gal/acre of 42% metam sodium) through microsprinklers |
| 8 - One-year fallow followed by treatment #6 |
| 9 - One-year fallow followed by treatment #7 |

Soil samples were collected to a depth of 24 inches from each treatment/rootstock combination in October, 2002 and processed by sugar flotation-centrifugation. Nematode populations are given in Table 6. After five growing seasons, the Telone/Vapam combinations and iodomethane have achieved control comparable to methyl bromide of both the rootknot (*Meloidogyne spp.*) and citrus (*Tylenchulus semipetrans*) nematode populations for all nematode/rootstock combinations. Nematode populations are higher on Thompson Seedless roots growing in plots treated with Telone delivered in 100 mm water than in plots treated with Telone delivered in 60 mm water. Plots that were fallowed for a year prior to treatment with Telone, supported lower populations of both rootknot and citrus nematodes as compared to Telone applied without the fallow. The rootknot nematode populations are low and there are no significant differences between the untreated control and methyl bromide on Thompson Seedless. Combination of any chemical treatment with either the Teleki 5C or Harmony rootstock resulted in populations of both rootknot and citrus nematodes that were below detectable levels. The rootknot nematode populations on Harmony rootstock were nearly undetectable for all treatments, as would be expected for a rootknot nematode resistant rootstock. The citrus nematode populations were highest on Harmony.

Table 6. Nematode populations per 100cc soil sampled October 2002, mean of 5 replications, in a vineyard replant trial planted in 1998. Statistical analyses conducted on log transformed ($\ln(n+1)$) data. Data presented are the antilogs of the means. Means for each nematode genus/rootstock combination followed by the same letter are not significantly different at the $P = .05$ level

Treatment	<i>Meloidogyne sp.</i>			<i>Tylenchulus semipenetrans.</i>		
	Thompson Seedless	Teleki 5C	Harmony	Thompson Seedless	Teleki 5C	Harmony
Untreated Control	37 ab	45 a	0 a	604 a	252 ab	1433 a
1-year Fallow	26 ab	61 a	0 a	614 a	164 b	1450 a
1-year Fallow plus cover crop	82 a	59 a	0 a	362 ab	320 a	1042 b
Methyl Bromide (400lbs/acre)	6 abc	0 b	0 a	0 e	0 c	0 c
Iodomethane (400lbs/acre)	37 ab	0 b	0 a	4 de	0 c	0 c
Telone II EC (60mm H ₂ O)	4 bc	0 b	0 a	11 cd	0 c	0 c
Telone II EC (60mm H ₂ O)+Fallow	1 c	0 b	0 a	0 e	0 c	0 c
Telone II EC (100mm H ₂ O)	18 abc	0 b	0 a	58 bc	0 c	0 c
Telone II EC (100mm H ₂ O)+Fallow	3 bc	0 b	0 a	2 de	0 c	0 c

Berries were harvested in September, 2003. Yield (kg berries/vine) in the Thompson Seedless plots treated with Telone delivered in 60 mm water following a one-year fallow was significantly greater than in plots treated with 1-year fallow + cover crop. All other treatments were intermediate. Merlot on Harmony had the greatest yield in plots treated with iodomethane, Telone delivered in 60 mm water following a one-year fallow, or Telone delivered in 100 mm water and least in the fallow+cover crop plots. There was no significant difference in yield of Merlot on Teleki 5C across treatments.

Long-term Fallow for Vineyard Replant Disorder Field Trial – Planted 2000.

Vines were removed from a 65-year-old Thompson Seedless vineyard in Fall, 1996, 1997, 1998, and 1999 (untreated control and methyl bromide plots). Plots were laid out in a randomized complete block design with 5 replications of each treatment, and planted in June of 2000 with own-rooted Thompson Seedless, Thompson Seedless on Harmony rootstock, and Thompson Seedless on Teleki 5C rootstock.

Soil samples were collected in October, 2002 to a depth of 24” from each treatment/rootstock combination and processed with sugar flotation/centrifugation. After 3 growing seasons, citrus nematode populations on Thompson Seedless were significantly lower in plots treated with methyl bromide compared to all other treatments (Fig. 1). Rootknot populations on Thompson Seedless were highest in the untreated plots, lowest in the methyl bromide plots and decreased with each additional year of fallow. When compared to previous years, a stair-step decrease has been observed each year for the rootknot nematode, but was only present after the first growing season for citrus nematode. Initial yield data will be collected this fall.

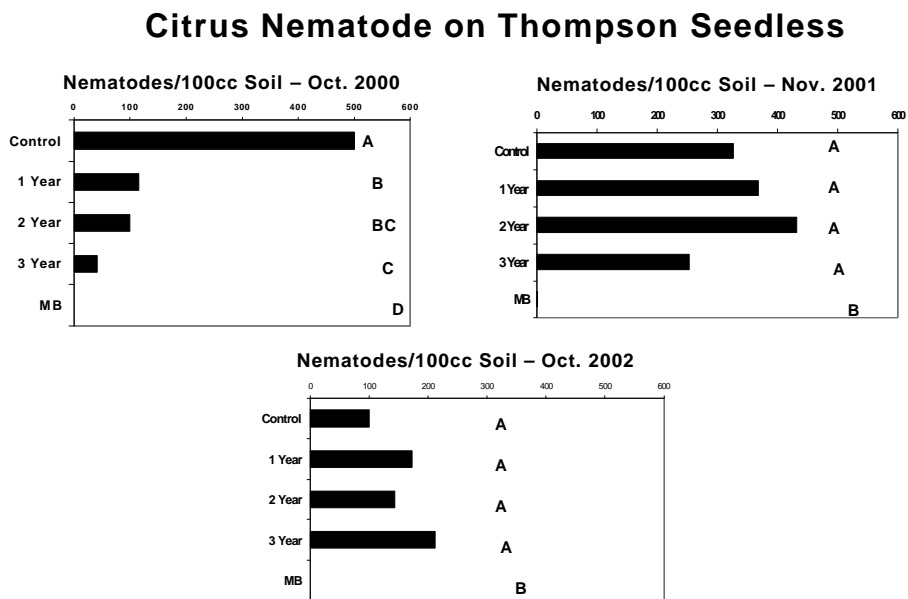
Chemical Alternatives for Vineyard Replant Disorder – Planted 2001. Vines were removed from an 85-year-old, plant-parasitic-nematode-infested Thompson Seedless vineyard located at the USDA Parlier, CA research station in fall, 2000. All treatments (Table 7) were applied in mid April, 2001. In June, 2001 own-rooted Thompson Seedless, Thompson Seedless on Freedom, and Merlot on 1103P were planted.

Table 7. Treatments applied to a 2001 grapevine replant trial.

Untreated Control
Methyl Bromide, 400 lbs/acre, shanked, tarped, the treated control
Shank MIDAS (Iodomethane + Chloropicrin, 240+240 lbs/acre)
Shank Propargyl Bromide - (200 lbs/acre)
Microspray Herbicide - Metam sodium (Vapam, 26 gal/acre)
Drip InLine (50 gal./acre) + Metam sodium (Vapam, 26 gpa) cap
Drip Chloropicrin (400 lbs/acre) + Metam sodium (Vapam, 26 gpa) cap
Drip MIDAS (Iodomethane + Chloropicrin, 240+240 lbs/acre), water cap
Drip Propargyl Bromide, (180 lbs/acre), water cap
Drip Agrizide (sodium azide, 300 lb/acre), water cap
Drip Agrizide (sodium azide, 300 lb/acre), tarped

Soil samples were collected to a depth of 24 inches from each treatment/rootstock combination in October, 2002 and processed by sugar flotation-centrifugation. Nematode populations after two growing seasons are given in Table 8. Nematode control comparable to methyl bromide was achieved on Thompson Seedless with shank-injected MIDAS, and drip-applied InLine and propargyl bromide. On the more resistant Freedom rootstock, all treatments except the Untreated Control, the herbicide cap, and the Agrizide treatments were comparable to methyl bromide. Performance on the 1103P rootstock was similar to that on Freedom, except that the drip-applied chloropicrin, although better than the Untreated, was not as good as methyl bromide.

Figure 1. Citrus and rootknot nematode populations in a vineyard replant trial planted in 2000, mean of 5 replications. Statistical analyses conducted on log transformed ($\log_{10}(n+1)$) data. Data presented are the antilogs of the means. Means for each nematode genus followed by the same letter are not significantly different at the $P = .05$ level.



Rootknot Nematode on Thompson Seedless

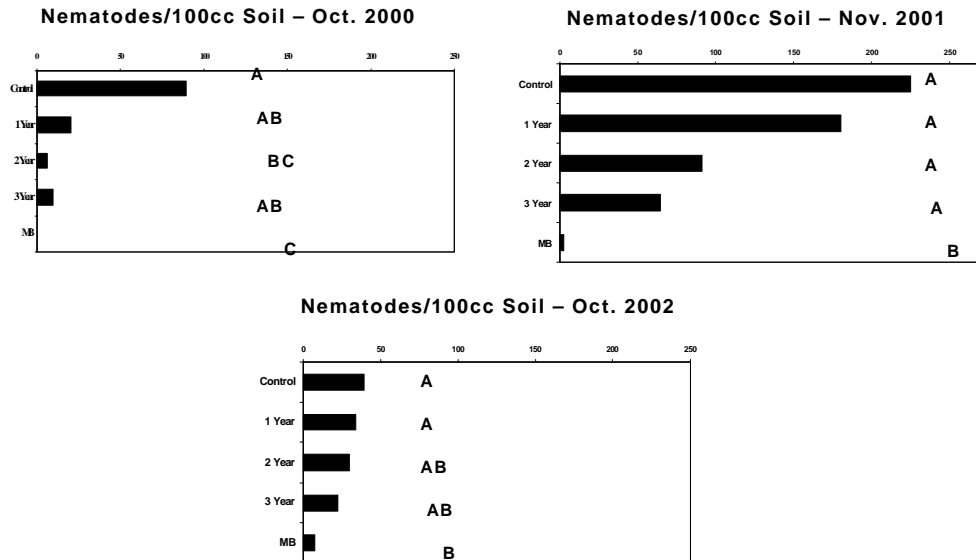


Table 8. Rootknot nematode populations per 100cc soil sampled October 2002, mean of 5 replications, in a vineyard replant trial planted in 2001. Statistical analyses conducted on log transformed ($\ln(n+1)$) data. Data presented are the antilogs of the means. Means for each nematode genus followed by the same letter are not significantly different at the $P = .05$ level.

Treatment	Thomp Seedless	Thomp Sdless/Freedom	Merlot/1103P
Untreated	128.1 a	22.8 a	18.3 a
Methyl Bromide	0 e	0 d	0 d
MIDAS – shank	0 e	0 d	0 d
Propargyl Bromide - shank	32.5 bc	0 d	0 d
Herbicide cap (metam sodium)	102.8 a	8.5 b	12.4 a
Drip InLine	0 e	0 d	0 d
Drip Chloropicrin	18.3 c	0 d	2.2 c
Drip MIDAS	1.9 d	0 d	0 d
Drip Propargyl Bromide	0 e	0 d	0 d
Drip Agrizide, water cap	67.2 ab	3.3 c	11.8 ab
Drip Agrizide, tarped	179.9 a	6.0 bc	3.8 bc

Conclusions - Perennial Crop Replant Disorder

- Iodomethane, Telone/metam sodium combinations, and InLine appear to be good alternatives to methyl bromide for vineyard replant when both rootknot and citrus nematode are present. Iodomethane is not yet registered and use of 1,3-dichloropropene (in Telone and InLine) is restricted in California by township caps.
- The Harmony rootstock continues to support only minimal populations of the rootknot nematode, but supports higher populations of the citrus nematode than either Thompson Seedless or Teleki 5C.
- Efficacy of long-term fallow treatments for vineyard replant depends on nematode genera present but are not as effective as methyl bromide.

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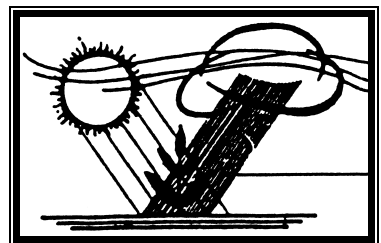
California Dept. of Food and Agriculture. 1996. Approved treatment and handling procedures to ensure against nematode pest infestation of nursery stock. Nursery Inspection Procedures Manual, Item #12. 18 pp.

Session VI
Alternative Nutrient
Management Strategies

Session Chairs:

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Emerging Manure Management Goals and Strategies

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Changes in water quality protection regulation and enforcement have created a new environment for dairy producers. Waivers that applied to animal agriculture have been removed. More aggressive policies were adopted at the Federal level in response to surface water contamination from both point and non-point source discharges. Serious point source events occurred, including ruptured waste storage ponds discharging into streams. Non-point source impacts included nutrient contamination in Chesapeake Bay due to storm water runoff from fields receiving manure from poultry operations. In California, permitting procedures for new dairies were challenged for not following California Environmental Quality Act (CEQA) requirements. State regulatory agencies were challenged for not adequately enforcing the Porter-Cologne Act. Public concern raised to the point that the federal Clean Water Act was re-interpreted by EPA, making policy more restrictive. The California State Legislature ended waivers related to agricultural runoff as of January 1, 2003. Existing law is being re-interpreted in preparation for a new round of enforcement. Because of this, producers will be expected to manage manure and other production wastes with far greater attention to protecting surface water and groundwater.

Groundwater protection is driving the major shifts in manure management. Leaching carries nitrate and other salts to groundwater. Leaching may occur from manure storage sites and from cropland receiving manure. Most groundwater pollutants probably come from cropland rather than manure storage sites because of the much larger acreage involved, the difficulty of managing manure as a nutrient source, and irrigation practices. According to law, in order to protect groundwater, manure and other nutrient sources must be applied to cropland at an "Agronomic Rate". This is called for, but not defined, in regulation. A method to achieve this is proposed in the California Comprehensive Nutrient Management Plan (CNMP) Guidance Document and the University of California Committee of Consultants (COC) report, both still in draft form. The Regional Water Quality Control Board for the Central Valley (RWQCB5) contracted the University of California, Committee of Consultants, to prepare new technical guidelines, based on the best available science, to support new policies for regulating the dairy industry. This article refers to the draft version of the COC report. The findings of that report are subject to change. The final CNMP will be consistent with the final COC report and RWQCB5 policy, when adopted. This article discusses some manure management principles that may be needed to meet these new criteria. It is not a discussion of new regulations.

Planning to make this transition

Implementing change is likely to be incremental. Much of this article discusses the more complex aspects of manure management. But in fact, much if not most progress in protecting water quality will come from ending large, easily changed, over applications of manure. This is very important to keep in mind when reading this article and working with producers. For example, if a field consistently receives extraordinarily high manure rates due to proximity to manure storage facilities, or any other reason, that practice should change immediately. Irrigation lines should be installed if needed to deliver manure to more cropland and reduce loading to overloaded cropland. When poor and easily improved irrigation

practices are used they should be changed; when liquid manure is applied the entire field should receive it, not just some of the checks; pond sludge must be discharged at reasonable rates to many fields and distributed evenly rather than just applied to convenient fields; solid manure must be applied evenly, not concentrated near an access road. Using agitation to keep solids suspended and flowing out at a consistent rate is better than very large discharges to a small acreage every several years when cleaning out the pond. Basic recordkeeping should begin immediately so the producer knows where, when, what form, and approximately how much manure has been applied to a field. Complete recordkeeping may take some time to incorporate into the operation.

It is absolutely essential that engineering and agronomics be integrated in the plan. Agronomic goals should be set for manure management, and facilities designed to allow the goals to be met. Agronomics influences manure storage needs, pipe sizing, solids separation, provision for mixing fresh and manure water before irrigation, and other considerations. It is not reasonable for an engineer without strong knowledge of agronomics to independently design a manure management system. In fact, a CNMP requires signatures of a certified agronomist and an engineer.

To complete all changes envisioned here new skills, knowledge, and investment is needed. A plan for this will require education and an early vision of the final outcome. A producer should make consistent incremental progress over a period of years until the goal of good manure management meeting the potential for the facility is reached. The California CNMP Guide describes various stages this will likely have, and what is needed at each step. *Important: timelines and tasks included in the CNMP must meet regulatory requirements and timelines.*

Whole Farm N Balance

After addressing the “Big Problems” discussed above, the next step is to compare the amount of nitrogen excreted by the animals to the amount of land available for application. When an imbalance is likely, methods short of herd reduction are available. Some of these are:

- 1) Take manure off site.
- 2) Acquire cropland.
- 3) Move replacement animals off site.
- 4) Modify cropping system to increase acreage of high-nitrogen-consuming crops.
- 5) Eliminate low-producing milk cows.
- 6) Handle more manure dry, to increase exportable manure.
- 7) Treat manure to improve marketability or to reduce nutrient content. (Some treatment options such as aeration and composting have air quality impacts that must be considered.)
- 8) Improve precision of land application of manure, in order to limit fertilizer use.
- 9) Modify feed, to adjust the amount and type of nutrients in the manure.

The balance is estimated as follows:

N excreted by the animals – N lost during collection, storage and land application -
N Harvested with the crops grown on fields receiving manure = N Balance

If N Balance is greater than zero planning to regain balance should begin. (Note: this method of analysis may be significantly revised.) New estimates of N excretion and N volatilization losses are being proposed by the Committee of Consultants to the Regional Board and NRCS for use in this calculation. Table 1 compares previously used values to the proposed values. New methods of estimating N excretion are also proposed. The new values in Table 1 will reduce the ratio of Milk Cows to cropland, is likely to cause a much higher rate of solid manure export from dairy operations, and increase competition for cropland near dairies. The sum effect of these changes is to require about 1.9 acres for every acre needed in the past for solid manure utilization, and about 2.8 acres for every acre needed in the past for liquid manure utilization. Again, these are draft values and likely to change, but the trend is towards higher acreage requirements.

Even if a good balance is predicted between manure and land, improper distribution of manure to fields can still cause groundwater impacts. To avoid this, methods to determine crop needs, target application rates and dates, and deliver manure with some accuracy will be needed.

	Current	Proposed
Excreted N, lbs/ Milk Cow / day	.8	1
Volatilization losses during storage		
Liquid Manure, % of Total N	50%	20%
Solid Manure, % of Total N	50%	50%
Volatilization losses during land application		
Liquid Manure, % of Total N	50%	30%
Solid Manure, % of Total N	50%	0%
Total average N loss from volatilization: Storage plus Application		
Liquid Manure, % of Total N	75%	44%
Solid Manure, % of Total N	75%	70%

Table 1 Estimated Nitrogen Fate, from UC Committee of Consultants draft Report

Land Application of Manure

Successful use of manure to fertilize crops, while also protecting groundwater quality, will require more intensive management than commonly practiced. To meet these two goals simultaneously manure should be applied at the “Agronomic Rate”. However, timing

manure applications, accurately applying the desired amount, and selecting the form of nutrient to apply are as important as applying the correct amount. In fact, unless all of these occur yield reduction is likely because the margin for error is reduced. A goal and definition for “Agronomic Rate” is suggested in the CNMP guide. It is: *Total N applied is equal to about 1.5 times Crop N Removal (CNR), ranging between about 1.33 and 1.67 CNR*. This rate considers the lowest reasonable rate of nitrogen loss expected from well managed cropland. Nitrogen losses occur from leaching, volatilization, denitrification, and runoff. The amount to be applied above crop removal compensates for these losses and the necessary inaccuracies inherent in sampling, testing, and applying manure. This should be viewed as a goal to be achieved after several years of investment, learning, data collection, and good management.

The proposal:

$$\text{Total N} = 1.5(\text{Ncr}) - \text{Nirr} - \text{Nlc} - \text{Nother} = \text{“Agronomic Rate”}$$

Total N = Organic N + NH₄-N + NO₃-N applied

Ncr = N removed with the harvested portion of the crop, based on the highest yields in two of the last five crop years

Nirr = NO₃ – N applied with irrigation water

Nlc = Nitrogen released by decomposition of roots and other residues of a legume crop terminated the previous season.

Nother = N from sources such as the atmosphere, soil organic matter, or manure applied in previous years. When equilibrium is reached between mineralization and organic N applications the atmospheric contribution and other miscellaneous sources will predominate. (This is discussed below.)

Manure management should be evaluated using this criteria based on annual, not per crop applications, and on a three year rolling average. The factor of 1.5 varies based on conditions. Soils and other properties will effect what goal is appropriate for a given field. Fields with sandy soils and high leaching potential require higher application rates. (How much should the producer be expected to invest to improve the irrigation system and reduce leaching?) Efficiently irrigated or heavier textured soils may be able to do better. Heavier soils will probably have higher denitrification and lower leaching potential. If leaching occurs when soil nitrate levels are low there will be little groundwater impact. This is why managing nitrogen applications carefully can help overcome problems with an irrigation system. A producer who does not manage manure applications and irrigation well will not be able to reach this goal regardless of field properties and will suffer yield loss and/or degrade groundwater quality. Should dairies farming land very difficult to manage with this constraint consider relocating, or be expected to invest heavily and adjust practices substantially?

Why is careful management of organic N so important?

Key to managing within this goal is applying organic N carefully. Only a portion of the organic nitrogen applied is available to the crop the year of application. N release from manure can be as low as 20% the year of application. If this was the only source of N, the producer would have to apply 5Ncr to just match crop use, more than three times the goal. There would be no excess to account for inevitable N loss. The N released from previously applied manure trickles out, but does not meet needs for timing N availability to the crop. To protect against groundwater contamination inorganic N must be a part of the fertilizer mix. It is used to reduce overall N applications and improve timing of N availability. The source of inorganic N can be liquid manure or fertilizer.

Mineralizing N does not necessarily become available when the crop needs it. Also, N continues to mineralize when no crop demand exists. If high rates of organic N are applied when limiting total N applications to about 1.5 Ncr too much mineralized N is usually released after crop demand has peaked. As a result losses to leaching will increase, crop uptake will decline, and yields will decline. While it is not possible to control mineralization precisely, certain strategies maximize uptake and limit losses. For example, 1) limit the amount of organic N applied to a reasonable percent of the total N, 2) time the application of organic N so that the highest rate of mineralization occurs approximately when crop need is highest, and 3) maintain a growing crop a maximum number of days per year. Spring applications of solid manure are best because peak N mineralization will then usually occur in early summer, near the peak corn uptake period. Early planted winter forage or a sudan crop following silage corn in the fall adds crop growing days and can increase annual N use. There are special considerations in managing early planted winter forage¹. Solid separation for liquid manure is an effective practice. Good separation allows organic N application to be limited, and leaves liquid manure with a higher ratio of ammonium N to organic N. This material is similar to commercial fertilizer and is easier to manage within the constraints of 1.5 Ncr. In order to make a carefully managed manure based system work it will probably be necessary to apply commercial fertilizer to meet peak crop demand. These applications should be carefully timed to meet peak crop N demand.

Fortunately, there is evidence that N mineralization reaches equilibrium with organic N application rates over time. This helps manage the quantity of N to apply, but leaves timing of release up to natural processes. At equilibrium, all of the organic N applied can be considered available for the current crop year. (Of course, field monitoring is needed to assure adequate N is available, and to manage inputs.) Equilibrium is likely to occur after about 5 years of consistent manure application rates in most settings, according to the draft report of the UC Committee of Consultants to RWQCB5. Figures 1 and 2, borrowed from that report, illustrate this.

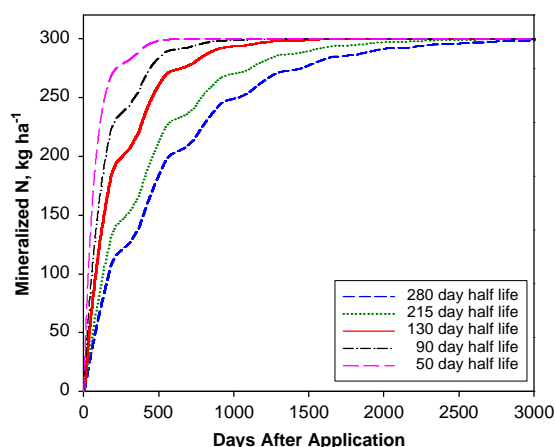


Figure 1 Simulated cumulative mineralization for 300 kg ha⁻¹ organic N applied on May 1 (the origin). Results depicted the N release over five half-lives. (From the draft report of the UC Committee of Consultants)

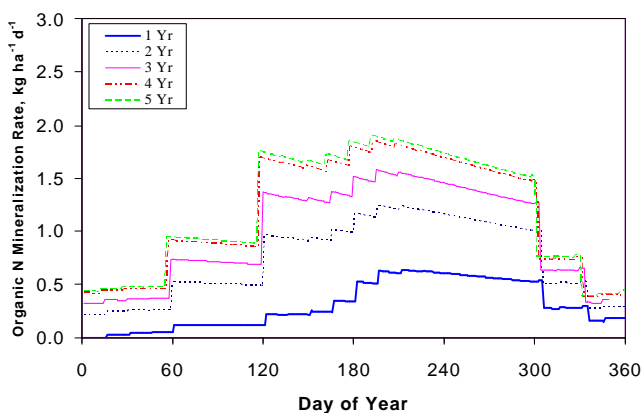


Figure 2 Annual organic N mineralization rate as a function of time for five consecutive years when organic N was applied biweekly to meet 70 percent of the potential N uptake by plants. The N mineralization half-life was 280 days during the summer. The results for years beyond 5 are identical to those of the fifth year. (From the draft report of the UC Committee of Consultants)

After evaluating several methods of applying manure using a computer model, all showed the release rate converging at the application rate after several years. Special management considerations are needed before equilibrium is established to assure crop needs are met or leaching is not excessive. Fields with a history of heavy manure applications should receive a reduced rate in order to establish equilibrium at a lower level. Fields with a history of light manure applications should receive increased rates in order to establish a higher equilibrium release. During transition, additional soil and tissue monitoring will be needed to guide nutrient application decisions. Published mineralization rates should be used during this transition to estimate how much of the organic N applied will be released to the current crop. To meet the goal of 1.5 Ncr, a manure management plan will probably include between 20% and 40% of the N applied as organic N, on a field basis.

Practices most producers will need to adopt to meet these goals

Following the period of transition it is likely that most producers using water to collect and store dilute liquid manure will need to have certain practices in place to meet the goal of applying manure at an “Agronomic Rate”. A list of those follows.

- *Install and properly manage a well engineered irrigation system*
- Record yields, irrigation events, and manure and fertilizer applications by field and date
- Sample manure for nutrient content prior to land application
- Use manure nutrient content data and desired application rate to estimate manure volume or tonnage to apply

- Install and use a method to apply the desired application rate to each field
- Manage organic N to assure adequate N availability and limit leaching
- Schedule applications that anticipate plant N uptake patterns and mineralization
- Prepare a manure application plan that balances the amount, form, and timing of applications to the cropping pattern and manure supply
- Review all data annually, revise the manure management plan, and identify investment needed to meet manure application and yield goals.

1. Campbell-Mathew, Marsha., Using Winter Forages for Dairy Nitrogen Management, Proceedings, California Alfalfa and Forage Symposium, 17-19 December, 2003, Monterey, Ca.

Modeling Temperature Effects on Nitrogen Mineralization

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Abstract: Temperature can dramatically accelerate or dampen nitrogen (N) mineralization and carbon (C) decay rates. This paper outlines an approach for including the effects of temperature on these processes by modifying time according to the Arrhenius equation. It also considers two first-order modeling techniques for N mineralization. The first, MEI, models mineralization directly and excludes immobilization. The second, MII, includes immobilization by modeling N release as a function of C decay. After consideration of an incubation of 31 different materials, it is found that mineralization from unamended composts should be managed differently from amended composts and manures as unamended composts tend to immobilize N. Insufficient samples of MII amendments were available for the chemical analysis needed to estimate MII parameters from chemical analysis.

keywords: Decomposition; Nitrogen, Mineralization Temperature; Land Application, Organic Amendments.

Introduction

Although organic fertilizers and amendments can serve as effective fertilizers, they must be managed differently than inorganic fertilizers. Nutrients in inorganic fertilizers are generally available immediately after application whereas those in organic fertilizers are released more slowly over time. Soil microbes and other fauna convert the organic carbon for use as an energy source. These organisms use a portion of the nitrogen in the amendments to meet their own needs (immobilization) and release any excess in the form of ammonium (mineralization). Because organic nitrogen is largely unavailable to plants, it is the rate at which net microbial mineralization occurs that determines the useful fertilizer value of applied organic materials. The net mineralization rate is determined by a number of factors, but the most important are the chemical structure of the applied amendment, soil temperature, and soil moisture.

The chemical structure of the organic amendment is determined by the structure of its source. Amendments derived from recalcitrant materials, such as bark and wood chips, will decompose slowly, while labile materials, such as grass clippings and fish emulsions, will mineralize relatively quickly. In general, materials rich in lignin, which microbes have difficulty breaking down, will mineralize nitrogen more slowly than those rich in fats, waxes, sugars and starches.

Microbes become much more efficient as temperatures increase, explaining why refrigerated foods are preserved and why composts systems accelerate material stabilization. A rule of thumb is that decay and mineralization rates roughly double for every 18°F (10°C) increase in temperature. (Referred to as Q_{10} , where the "10" refers to the 10°C change in temperature.) Because temperatures vary with location (latitude, elevation) and time (of year and in some circumstances, of day), the local climates under which organic fertilizer studies are conducted can strongly affect observations making it difficult to formulate general recommendations (Alexander 1999). Soil moisture also affects decomposition rates. Conditions optimal for microbial activity tend to reflect conditions maintained in irrigated agriculture so the significance of moisture as a factor is likely less significant than temperature under most California conditions. This paper describes an approach for incorporating the effects of temperature into organic fertilizer management plans.

The approach assumes that carbon decay occurs as a two-compartment first-order processes (Dalias et al. 2001, Gilmour et al. 1998, Melillo et al. 1982, Meentemeyer 1978, Murayama 1984). Crohn and Valenzuela (2003) have demonstrated a simplified approach that assumes all materials are composed of similar labile and recalcitrant materials. At the same temperature, all labile materials decompose at one rate while all recalcitrant materials decompose at another. Each material has a characteristic fraction of material that is labile, while the remainder is assumed to be recalcitrant. The labile fraction can be estimated from measurable chemical parameters. Crohn and Valenzuela (2003) considered only carbon, but the same principal applies when net mineralization is assumed to proceed without net immobilization. When significant, immobilization can be added to the model with a linear relationship between carbon decay and the nitrogen to carbon (N:C) ratio within the material (Aber and Melillo 1980; Aber et al. 1990). Temperature effects are included by using the Arrhenius equation to adjust time creating a temperature-adjusted time stream that effectively expands the time available for decay in warm soils and contracts time under cool conditions. The adjusted time-stream is continuous and easily computed from environmental records. The content of this paper is preliminary. Additional experiments are currently underway to validate the procedure proposed here.

Experimental Procedure

Data used in this paper were taken from Hartz et al. (2000) who incubated 31 manure and compost products at 25°C. Properties of the amendments are presented in Table 1. All values are ash-corrected. Each product was added at a 2% dry weight (d.w.) rate with a 50/50 ratio Yolo silt loam and sand mixture. Nineteen of the materials were incubated for 12 weeks (3 replicates) while another 12 were incubated for 24 weeks (4 replicates). Measurements for the twelve week incubations were made after 4, 8, and 12 weeks while measurements for the 24 week incubations were taken after 8, 16, and 24 weeks. Moisture was maintained at 25 kPa throughout the incubation experiments. C decay was determined by measuring the accumulation of CO₂ within the sealed incubation vessels using an infrared gas analyzer while N mineralization was determined by measuring 2 N KCl extractable NH₄-N and NO₃-N (Hartz et al. 2000). An additional set of complementary experiments under four different temperature conditions is under way at the University of California, Riverside. Proximate carbon analysis was also conducted on eleven of the materials incubated for 24 weeks. Results were expressed in terms of polar, non-polar, acid-soluble, and acid-insoluble extractive fractions, which correspond roughly to sugars and starches, fats and waxes, cellulose, and lignin, respectively (Geng et al. 1993, Crohn and Bishop 1999).

Modeling Approaches

Two approaches were considered. Mineralization excluding immobilization (MEI) is often appropriate for nitrogen-rich materials. For more carbonaceous materials mineralization including immobilization (MII) is more appropriate, particularly is short-term nutrient dynamics are of interest as for potting media or newly planted crops.

MEI: If net immobilization can be neglected, the two-compartment nitrogen mineralization model may be expressed as

$$Nm_t = N_o \left[1 - L_N e^{-k_L t^\circ} - (1 - L_N) e^{-k_R t^\circ} \right] \quad (1)$$

where Nm_t (kg/ha) is the mass of mineralized N at time t , N_o (kg/ha) is the initial organic nitrogen mass in the added amendment, L_N is the fraction of the initial nitrogen mass which is labile, k_L and k_R (day⁻¹) are constants, and t° (days) is temperature-adjusted time.

First-order decay constants can be modified with the Arrhenius equation to incorporate temperature effects (Haug 1993, Leirós et al. 1999, Levenspiel 1999). The temperature-adjusted time stream can be determined as

$$t^{\circ} = \sum_{\Delta t \leq t} Q_{10} \left(1 + \frac{T_r}{10} \right)^{\left(1 - \frac{T_r}{T_t} \right)} \Delta t \quad (2)$$

where T_r (°C) is a reference temperature, often 20°C, T_t is the soil temperature at time t , Δt (days) is the time step, and Q_{10} is the relative change in the decay rates expected after a 10°C (18°F) increase in temperature from the reference temperature. As a rule of thumb, $Q_{10} \approx 2$. Although Eq. 2 appears complex, it can be readily computed with a computer.

III: Net immobilization can be included by rewriting Eq. 1 to describe the carbon decomposition. In this case

$$C_t / C_o = L e^{-k_L t^{\circ}} + (1 - L) e^{-k_R t^{\circ}} \quad (3)$$

where C_t (kg/ha) is the mass of carbon at time t , C_o (kg/ha) is the initial carbon mass in the added amendment, L_C is the fraction of the initial carbon mass which is labile, k_L and k_R (day^{-1}) are constants, and t° (days) is temperature-adjusted time. Mineralized N can then be written as

$$Nm_t = N_o \left[1 - \frac{C_t}{C_o} \left(I - \frac{C_t}{C_o} \right) \frac{1}{I - 1} \right] \quad (4)$$

where I is a fitting parameter.

Parameterization

Microsoft® Excel's Solver component was used to minimize the sum of the square errors (SSQE) between experimental observations and model predictions. The materials were categorized into three groups; Group a, manures and other nitrogen-rich materials, Group b, composts amended with manures, and Group c, unamended composts. Amendments 1 – 19 were incubated for 12 weeks and SSQE was calculated with data collected after 4, 8, and 12 weeks for these materials. Amendments 20 – 31 were incubated for 24 weeks and SSQE were calculated at 8, 16, and 24 weeks for those. All materials within a particular group were assumed to share common k_L and k_R rates but each material was assumed its own L fraction and, for MII models, I parameter. Members of each group were assumed to contain Examples of possible model applications were derived using thermal data supplied by California's CIMIS system. The data describe mean soil temperatures at a 15 cm depth in Riverside, California. Multiple regressions were conducted with SPSS version 11 (Norusis 2002). Regressions considered inorganic nitrogen fraction, organic nitrogen, total carbon, and various ratios of these measurements including the carbon to nitrogen ratio to predict L and I , where appropriate.

Results and Discussion

Parameter values fitted from the incubation data are presented in Table 2. In general amended materials (Table 2, Group a) and amendments (Group b) mineralized N steadily while unamended yardwaste composts (Group c) tended to temporarily immobilize N or mineralized it slowly. The simpler MEI was therefore sufficient except for the unamended yardwaste composts, which were modeled with MII.

Amendments and amended composts

For Groups a and b, nitrogen mineralization was modeled directly (MEI). Initially these two groups were fitted separately, but because the resulting decay rates were very similar, the two groups were combined so that only one set of decay rates will be reported for amendments and amended composts. Labile and recalcitrant nitrogen decay rates were $1.47 \cdot 10^{-2} \text{ day}^{-1}$ and $2.69 \cdot 10^{-4} \text{ day}^{-1}$, respectively. Labile fractions (L) ranged from 0, for a gin trash/manure compost to 0.351 pelletized poultry manure. SSQE values generally were greater for materials 20 through 31, which were incubated for 24 weeks than for amendments 1 through 19, which were incubated for only 12 weeks. Materials incubated for 12 weeks

were sampled earlier than 24-week assays and the assumption that immobilization is small for some amendments and amended materials may have been less sound during the earliest part of the incubation. Two materials in these groups, a gin trash manure compost (amendment 6) and a feedlot manure compost (amendment 11) had exhibited moderate immobilization, and two others, an aged poultry manure (amendment 3) and an aged feedlot manure (amendment 4) immobilized small amounts of nitrogen. These materials fit the model most poorly as measured by the SSQE (Table 2). Best fits were for 24 week amended composts (Group b). SSQE values for 12-week incubations averaged $1.1 \times 10^{-3} \pm 9.9 \times 10^{-4}$ (mean \pm standard deviation) while values for 24-week incubations were $1.9 \times 10^{-4} \pm 2.5 \times 10^{-4}$. Regressions for all nineteen members of Groups a and b suggest using both inorganic (N_i) and organic nitrogen (N_o) fractions to predict L values.

$$L = 4.131N_o + 29.97N_i - 0.0735$$

N_i was a stronger predictor of L ($b=7.13$) than N_o ($b=1.87$), where b represents standardized equation coefficients. For this relationship, $r^2 = 0.86$, $\alpha < 0.001$.

Proximate carbon analysis data was available for only nine of these treatments. Regression of those relationships results in the relationship

$$L = 2.719N_T - .918C_{AI} - 0.0735$$

where N_T is the ash-corrected total nitrogen fraction and C_{AI} is the acid-insoluble proximate carbon fraction. Here $r^2 = 0.74$, $\alpha < 0.02$. C_{AI} was a stronger predictor of L ($b=-0.70$) than N_T ($b=0.23$).

Unamended composts

The model for Group c included immobilization (MII). Labile and recalcitrant carbon decay rates were $1.11 \times 10^{-2} \text{ day}^{-1}$ and $3.49 \times 10^{-5} \text{ day}^{-1}$, respectively. Labile fractions (L) ranged from 0.11 to 0.19 and I values ranged from 1.7 to 2.2. Once more, fits were generally best for the two composts from the 24-week incubation. No statistically significant regression model was able to predict either independent variable in this model from chemical analysis, a result most likely due to the small sample size. However it appears that the process of immobilization is less accurately determined from chemical parameters than is the process of direct net mineralization. Several Group c materials do not immobilize nitrogen leading to I values greater than 2. Beyond 2, no immobilization occurs.

Temperature and Mineralization

Temperature-adjusted time can be used to apply the models described here to field conditions. Mean daily soil temperatures (15 cm depth) from 2002 in Riverside, California, are presented in Fig. 1. Fig. 2 compares cumulative t° to unadjusted time (t) after initialization on the first days of January, April, July, and October. Figs. 3 and 4 provide illustrations of how the t° approach responds to the Riverside data when $Q_{10}=2$ and $T_r=298.15$ K. Fig. 3 shows mineralization of amendment 22, an aged feedlot manure ($k_L=0.01 \text{ day}^{-1}$, $k_R=0.01 \text{ day}^{-1}$, $L=0.3$) and, for Fig. 4, $I=1.9$. Cooler temperatures slow mineralization from the MEI model and delay net mineralization from the MII model. In a region such as Riverside, where as many as three crops can be grown in a single year, nutrient budgets that do not account for temperature effects are clearly inappropriate.

Conclusions

Use of t° to formulate nutrient budgets could allow growers to use parameters developed under one set of climatic conditions within a different environment, assuming that soil moisture conditions are sufficiently similar. Reporting of decay rates in terms of t° would permit growers to include temperature effects in their nutrient management activities, even under temperature-varying field conditions. Additional research is underway to locate Q_{10} parameters for different materials. For example, Crohn

and Valenzuela (2003) found evidence that Q_{10} parameters differ for labile and recalcitrant materials. Plans are underway to make local temperature-adjusted time values accessible via the internet allowing growers to modify application rates based upon local climatic conditions as well as seasonal changes.

The data used in this study reflected relatively short decay periods making it difficult to estimate labile fraction decay rates. Longer studies are needed to generate such values. Nevertheless, given the uncertainty of the immobilization and mineralization processes, the procedures outlined here produce reasonable estimates for design work and warrant further investigation.

Notation

The following symbols are used in this paper.

C_o = initial amendment carbon content (kg or kg/ha);

C_t = carbon content at time t (kg or kg/ha);

k_L = labile fraction decay constant (1/day);

k_R = recalcitrant fraction decay constant (1/day);

k_r = decay rate at reference temperature T_r (1/day);

L = decaying material labile fraction;

M_o = decaying material initial of the (g);

M_t = decaying material mass at time t ;

N_I = initial amendment nitrogen fraction (ash-corrected);

N_O = initial amendment organic nitrogen fraction (ash-corrected);

N_o = initial amendment organic nitrogen content (kg or kg/ha);

N_T = initial total nitrogen fraction;

Q_{10} = relative proportion by which k_r increases after a 10°C temperature increase from reference temperature T_r ;

T = temperature (K);

T_r = reference temperature (K);

t = unadjusted time (days);

t^o = temperature adjusted time stream (days).

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Table 1. Potting Soil Amendment N and C fractions (Hartz et al. 2000)

Num.	Group	Description	Incubation	Total N	Organic N	Total C	C _o :N _o
			time	N	N _o	C _o	
1	a	pelletized poultry manure	12 wks	0.0471	0.0387	0.213	5.5
2	a	aged poultry manure	12 wks	0.0311	0.0291	0.282	9.7
3	a	aged poultry manure	12 wks	0.0273	0.0266	0.268	10.1
4	a	aged feedlot manure	12 wks	0.0202	0.0195	0.250	12.8
5	b	gin trash/manure compost	12 wks	0.0383	0.0362	0.217	6.0
6	b	gin trash/manure compost	12 wks	0.0274	0.0268	0.249	9.3
7	b	poultry manure compost	12 wks	0.0239	0.0229	0.210	9.2
8	b	poultry manure compost	12 wks	0.0202	0.0187	0.162	8.7
9	b	poultry manure compost	12 wks	0.0202	0.0186	0.158	8.5
10	b	poultry manure compost	12 wks	0.0133	0.0126	0.136	10.8
11	b	feedlot manure compost	12 wks	0.0220	0.0218	0.251	11.5
12	b	gin trash/manure compost	12 wks	0.0211	0.0205	0.185	9.0
13	c	gin trash compost	12 wks	0.0120	0.0115	0.111	9.7
14	c	municipal yard waste compost	12 wks	0.0160	0.0159	0.236	14.8
15	c	municipal yard waste compost	12 wks	0.0144	0.0143	0.191	13.4
16	c	municipal yard waste compost	12 wks	0.0160	0.0159	0.208	13.1
17	c	municipal yard waste compost	12 wks	0.0160	0.0158	0.221	14.0
18	c	municipal yard waste compost	12 wks	0.0130	0.0129	0.200	15.5
19	c	municipal yard waste compost	12 wks	0.0100	0.0099	0.120	12.1
20	a	dewatered poultry manure	24 wks	0.0330	0.0301	0.298	9.9
21	a	aged poultry manure	24 wks	0.0252	0.0219	0.292	13.3
22	a	aged feedlot manure	24 wks	0.0241	0.0204	0.302	14.8
23	b	poultry manure compost	24 wks	0.0257	0.0238	0.181	7.6
24	b	feedlot manure compost	24 wks	0.0215	0.0211	0.199	9.4
25	b	feedlot manure compost	24 wks	0.0204	0.0192	0.167	8.7
26	b	feedlot manure compost	24 wks	0.0199	0.0179	0.201	11.2
27	b	feedlot manure compost	24 wks	0.0187	0.0181	0.174	9.6
28	b	dairy manure compost	24 wks	0.0147	0.014	0.155	11.1
29	b	dairy manure compost	24 wks	0.0124	0.0118	0.173	14.7
30	c	municipal yard waste compost	24 wks	0.0140	0.0139	0.217	15.6
31	c	municipal yard waste compost	24 wks	0.0170	0.0168	0.220	13.1

Table 2. **Incubation Study Fitted Parameter Values** (Group a and b k_L and k_R values apply to the MEI model and describe nitrogen mineralization, Group c k_L and k_R values apply to the MEI model and describe carbon decay.)

Num.	Group	Intercept, I	k_L (days ⁻¹)	k_R (days ⁻¹)	L	SSQE	Co:No
1	a	-	1.47e-02	2.69e-04	0.351	8.1e-04	5.5
2	a	-	1.47e-02	2.69e-04	0.139	1.8e-04	9.7
3	a	-	1.47e-02	2.69e-04	0.039	3.3e-03	10.1
4	a	-	1.47e-02	2.69e-04	0.106	2.5e-03	12.8
5	b	-	1.47e-02	2.69e-04	0.165	1.1e-03	6.0
6	b	-	1.47e-02	2.69e-04	0.000	1.7e-03	9.3
7	b	-	1.47e-02	2.69e-04	0.036	7.6e-04	9.2
8	b	-	1.47e-02	2.69e-04	0.081	5.3e-05	8.7
9	b	-	1.47e-02	2.69e-04	0.061	4.1e-04	8.5
10	b	-	1.47e-02	2.69e-04	0.048	9.6e-04	10.8
11	b	-	1.47e-02	2.69e-04	0.000	1.3e-03	11.5
12	b	-	1.47e-02	2.69e-04	0.028	7.8e-05	9.0
13	c	1.75	1.11e-02	3.49e-05	0.185	7.1e-04	9.7
14	c	2.24	1.11e-02	3.49e-05	0.168	1.7e-03	14.8
15	c	2.01	1.11e-02	3.49e-05	0.148	1.6e-03	13.4
16	c	1.80	1.11e-02	3.49e-05	0.166	4.0e-04	13.1
17	c	1.71	1.11e-02	3.49e-05	0.152	3.2e-04	14.0
18	c	1.79	1.11e-02	3.49e-05	0.123	1.0e-03	15.5
19	c	2.10	1.11e-02	3.49e-05	0.126	5.0e-04	12.1
20	a	-	1.47e-02	2.69e-04	0.292	7.5e-04	9.9
21	a	-	1.47e-02	2.69e-04	0.124	4.6e-04	13.3
22	a	-	1.47e-02	2.69e-04	0.135	6.5e-05	14.8
23	b	-	1.47e-02	2.69e-04	0.224	2.1e-05	7.6
24	b	-	1.47e-02	2.69e-04	0.071	4.9e-05	9.4
25	b	-	1.47e-02	2.69e-04	0.080	2.2e-05	8.7
26	b	-	1.47e-02	2.69e-04	0.001	4.5e-05	11.2
27	b	-	1.47e-02	2.69e-04	0.010	8.9e-05	9.6
28	b	-	1.47e-02	2.69e-04	0.011	1.2e-06	11.1
29	b	-	1.47e-02	2.69e-04	0.010	3.5e-04	14.7
30	c	1.94	1.11e-02	3.49e-05	0.156	2.9e-04	15.6
31	c	2.07	1.11e-02	3.49e-05	0.114	7.5e-05	13.1

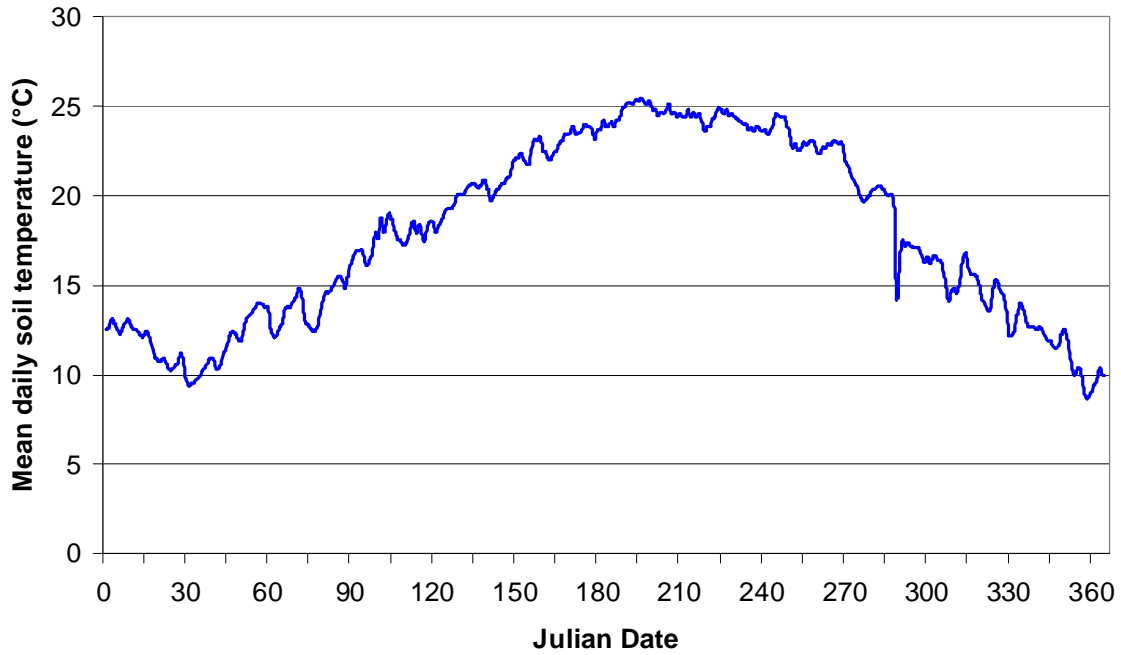


Fig 1. Year 2002 CIMIS Riverside, California daily mean soil temperature data (15 cm depth).

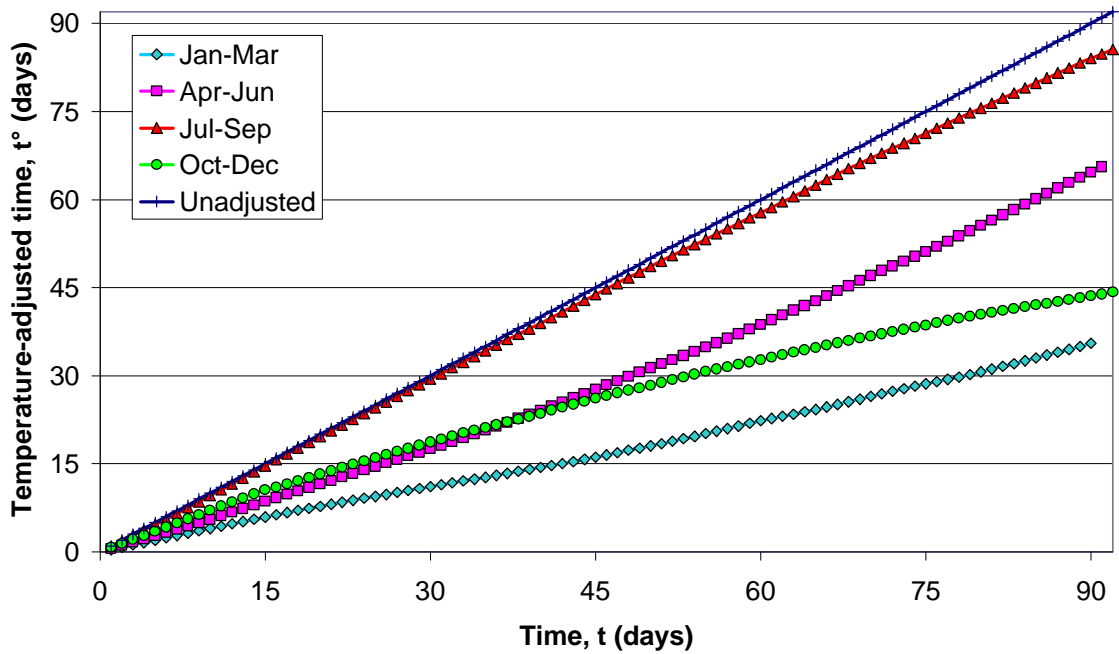


Fig 2. Comparison of temperature adjusted time to unadjusted time using year 2002 CIMIS soil temperature data (15 cm depth) from Riverside, California ($Q_{10}=2$).

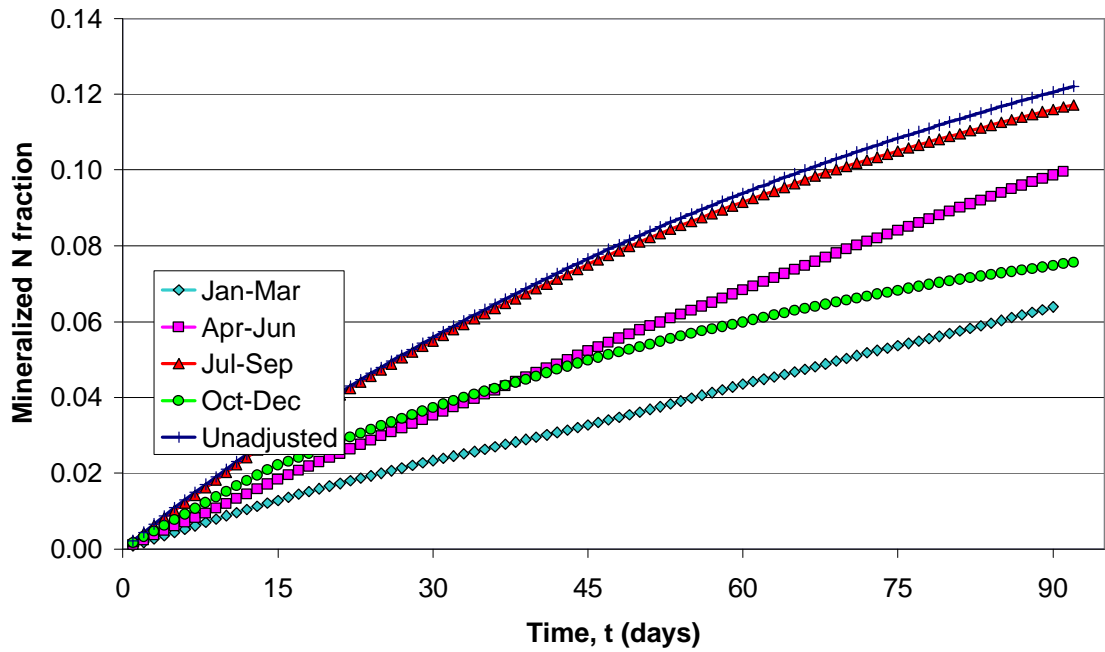


Fig 3. Net N mineralization predictions (without immobilization) using 2002 Riverside, California temperatures for amendment 22, an aged feedlot manure.

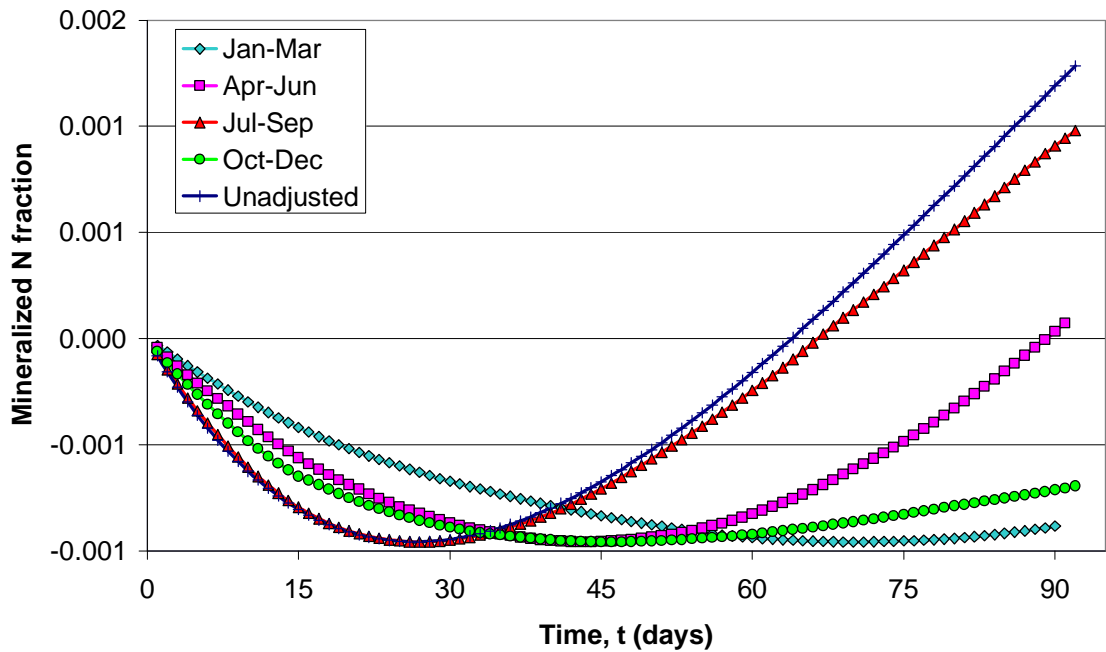


Fig 4. Net N immobilization and mineralized predictions using 2002 Riverside, California temperatures for amendment 30, a municipal yardwaste compost. Negative values reflect the influence of immobilization.

An Assessment of Biomass Resources in California

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Abstract

Biomass resources from agriculture, forestry, and municipal wastes in California are currently estimated at 72 million tons dry weight per year, sufficient to support a gross electricity generation capacity of 8,000 MWe. Although subject to considerable uncertainty, on a technically sustainable basis biomass resources might more realistically supply fuel for 3,700 MWe, an increment of 2,700 MWe above the current generation from direct combustion, landfill gas to energy, and animal manure and sewage digester facilities. Biomass can also serve as feedstock for other industrial processes. Energy crops may become important agricultural commodities as markets for fuel ethanol, biodiesel, hydrogen, and electricity continue to develop. Costs of biomass feedstocks are variable and range from the negative where tipping fees may be charged such as with municipal solid wastes, to \$10-40 per ton for most agricultural and forestry residues, and higher for dedicated biomass crops where the full costs of production accrue to the biomass product. New incentives and regulations, such as the renewable portfolio standard, should enhance opportunities for biomass in helping to meet state objectives for sustainable development.

Introduction

Increasing restrictions¹ on open burning and waste handling make biomass utilization an increasingly attractive option for agriculture. Biomass utilization is also important in the management of municipal and other industrial wastes and in forest stand improvement operations, particularly in light of new initiatives² designed to reduce fuel loadings and risks from wildland fire. Biomass may also emerge in the form of new crops for California as the state moves to reduce fossil fuel consumption and use more sustainable and renewable energy resources. Dedicated biomass crops for energy, fuels, chemicals, and other bioproducts may develop given sufficient market incentives³ or in association with agronomic practices such as phytoremediation of salt affected and other contaminated soils using integrated farm drainage management and other techniques.⁴

A major new incentive for biomass energy development has appeared in the form of the state's renewable portfolio standard (RPS)⁵ that mandates 20% of retail electricity sales to come from renewable resources by the year 2017. Federal renewable fuels standards, if enacted, would provide incentives to further the development of biomass derived ethanol, biodiesel, and other fuels such as

¹ e.g., California Senate Bill 705 (2003) that prohibits open burning of certain types of agricultural wastes within the San Joaquin Valley Air Pollution Control District commencing 2005 and thereafter. SB 705 complements previous legislation curtailing the open burning of rice straw in the Sacramento Valley (AB 1378, 1991). Of the 542,225 acres planted to rice in 2002, 70,500 acres (13%) of the 125,000 acres allowed were burned for straw disposal (California Air Resources Board, Draft progress report on the phase-down of rice straw burning in the Sacramento Valley Air Basin, September 2003). SB 700 (2003) specifies, among other things, districts classified as federal nonattainment areas for ozone adopt regulations requiring owners of large confined animal facilities to reduce air pollutant emissions.

² such as the federal Healthy Forests Restoration Act of 2003, HR 1904.

³ as might occur with the elimination of MTBE and substitution with ethanol as a fuel oxygenate.

⁴ Jenkins, B.M., G. Sun, V. Cervinka, J. Faria, P. Thy, D.H. Kim, T.R. Rumsey and M.W. Yore. 2003. Salt separation and purification concepts in integrated farm drainage management systems. Paper No. 032236, ASAE, St. Joseph, Michigan.

⁵ established under SB 1078 (2002). The subsequent State Energy Action Plan recommended accelerating the development to achieve 20% by 2010. Currently, renewable resources contribute roughly 10% with biomass about 2% (Table 1).

Fischer-Tropsch liquids. Major initiatives developed for hydrogen production will also encourage development of improved processes using biomass. Bioenergy and bioproducts therefore constitute important new markets for agriculture and other industries and can help to mitigate many environmental problems if implemented properly.

Sources of biomass in California

The principal sources of biomass in California are agriculture, forestry, and municipal solid wastes. On an annual availability basis, the latter currently constitute the largest single resource and will remain such over at least the near to intermediate term. Dedicated biomass crops are a fourth category that may develop over the longer term although water supply, competition for land, and cost of production will remain impediments without the state choosing to adopt policies encouraging more sustainable economic development.⁶

A recent assessment of biomass resources has been conducted⁷ for the purposes of evaluating potential contributions to meeting the goals of the RPS (Table 1). The assessment focuses on potential electricity generating capacity that might be developed from biomass, although the production data are suitable for use in estimating feedstock supplies for other purposes. Contributions from individual biomass supply categories are outlined below.

Agricultural biomass

Five main categories comprise the majority of agricultural biomass: orchard and vineyard prunings and removals, field and seed crop residues, vegetable crop residues, food processing wastes, and animal manures.

⁶ In addition to the RPS, the state has adopted other policies in this regard, including AB 1493 (2002) calling for the California Air Resources Board to develop regulations achieving maximum feasible reductions in vehicular greenhouse gas emissions. The recent State Environmental Goals and Policies Report (November 2003) submitted to the legislature in response to AB 857 (2002) adopted sustainable development as a guiding principle for the future.

⁷ the assessment was conducted as a joint effort of the California Energy Commission (CEC), the California Department of Forestry and Fire Protection (CDFFP), and the California Biomass Collaborative (administered by the University of California, Davis). The following individuals contributed substantially to the current assessment: Z. Zhang, V. Tiangco, G. Simons, P. Sethi (CEC); M. Rosenberg, J. Spero, T-T Shih, L. Duan (CDFFP); H.I. von Bernath, G.C. Matteson, R.B. Williams (Collaborative). Agricultural base acreage and crop and animal production data were supplied by the California Department of Food and Agriculture (CDFA). Municipal solid waste base inventory data were supplied by the California Integrated Waste Management Board (CIWMB). Base waste water treatment and biosolids data were supplied by the US Environmental Protection Agency (USEPA) and augmented by CEC. Base in-forest and chaparral biomass data were supplied by CDFFP.

Table 1. California Biomass Resources, Power, and Energy Potentials, 2003 inventory.

Category	Municipal			Total
	Agriculture	Forestry	Wastes	
Production (Million BDT/y)*	21	14	37	72
Gross Electrical Capacity (MWe)	2,083	1,834	4,200	8,118
Technical Electrical Capacity (MWe)	998	982	1,670	3,650
Gross Electrical Energy (TWh)	16	14	31	60
Technical Electrical Energy (TWh)	7	7	12	27
Existing and Planned Capacity (MWe)	147	283	548	978
Existing and Planned Energy (TWh)	1	2	4	7
Technical Capacity Net of Existing and Planned (MWe)	851	699	1,122	2,672
Technical Energy Net of Existing and Planned (TWh)	6	5	8	20
	Fraction of State (%)**			
	Agriculture	Forestry	Municipal Wastes	Total
Production*	29.5	19.0	51.5	100.0
Gross Electrical Capacity	4.1	3.6	8.2	15.9
Technical Electrical Capacity	2.0	1.9	3.3	7.2
Gross Electrical Energy	5.6	5.0	11.4	22.0
Technical Electrical Energy	2.7	2.7	4.5	9.9
Existing and Planned Capacity (MWe)	0.3	0.6	1.1	1.9
Existing and Planned Energy (TWh)	0.4	0.7	1.4	2.5
Technical Capacity Net of Existing and Planned (MWe)	1.7	1.4	2.2	5.2
Technical Energy Net of Existing and Planned (TWh)	2.3	1.9	3.1	7.4

*BDT = bone dry tons. The production quantity for municipal wastes includes only the biomass fraction of materials handled as solid wastes and does not include suspended and dissolved solids entering waste water treatment. Electrical generating capacity and energy quantities include waste water treatment.

**Assumes a total installed generating capacity for the state of 51 GWe (California Energy Commission 2003 Electricity Supply and Demand Outlook, 1 GWe = 1,000 MWe, MWe = Megawatt electric). Installed generation available in the California ISO control area is 54 GWe (California Independent System Operator, 2003 Summer Assessment) and projections of available generation capacity of all types range above 61 GWe for 2004 (California Energy Commission 2003 Electricity Supply and Demand Outlook). Actual California ISO peak demand in 2003 was 43 GWe.

Orchard and vineyard prunings: About 2.5 million tons of woody biomass are produced annually as prunings and tree and vine removals from orchards and vineyards. Close to 1 million tons⁸ is currently used as fuel in power plants, generally blended with other fuels such as urban wood and forest materials. Net electricity generating capacity attributable to this fuel is in the range of 100 MWe distributed over multiple facilities. SB 705 and SB 704 are intended to curtail the open burning of prunings in the San Joaquin Valley and implement incentives for their use as fuel in power generation. Orchard prunings and removals are generally good boiler fuels although somewhat elevated nitrogen contents compared to forestry and urban wood fuels can necessitate greater NO_x control and higher alkali metal contents in ash can lead to greater fouling of fireside heat transfer surfaces. Prices paid by power plant operators for this fuel typically run between \$20 and 30 per bone dry ton (BDT) delivered in chipped form, adding \$0.02 to \$0.03 per kWh to the cost of generated power.

Field and seed crop residues: California agriculture produces close to 5 million BDT/y of field crop residues, principally in the form of straws and stovers. Much attention has been paid to rice straw as a possible fuel for power generation, but none of the existing boilers in California can use it without modification. Alkali metals (primarily potassium) combine with silica in the ash to form glassy

⁸ Morris, G. 2002. Biomass energy production in California 2002: update of the California database. NREL/SR-510-33111, December.

slags and deposits on boiler surfaces at normal operating temperatures (1700-1800°F). Straws can also contain high chlorine concentrations leading to accelerated corrosion, acid gas emissions, and potentially toxic compounds when burned. Potassium and chlorine are readily leached from straw with water,⁹ and experiments have been conducted demonstrating the acceptable use of rain-washed rice straw left over-winter in the field.¹⁰ Leaching adds to fuel cost and so far has not been adopted in California. European boilers have been designed to better handle straw and other high-fouling fuels but the technology has not yet been implemented in California partly due to the higher costs of operation. Delivered costs for straw typically are in the range of \$20 to \$35/BDT exclusive of nutrient replacement costs accruing from straw removal,¹¹ but no large scale collection, transportation, and storage infrastructure has yet developed due to lack of substantial markets. Although open burning of rice straw is now practiced on less than 15% of the acreage, off-field utilization constitutes a small use with most straw being disposed of through soil incorporation with winter flooding. A number of projects have been started to produce ethanol from straw and other lignocellulose, but the technologies are still largely experimental and none are fully commercial. Thermal gasification of straw in integrated gasification combined cycle power plants has been demonstrated in Sweden but not yet attempted in California. Nationwide, a number of initiatives have developed to use corn stover as a fuel to complement the production of ethanol from corn grain. Co-firing of energy crop grasses, such as bermuda grass, switch-grass, and high-fiber sugar cane with coal has been widely investigated and commercial scale projects are now proceeding. Although California does not rely much on coal fired power generation (20% of supply) and so has fewer opportunities for co-firing, results from these efforts may contribute to overall improvements in technology and enhanced future markets for straw in the state.

Vegetable crop residues: Statewide production of vegetable crop residues amounts to more than 1.2 million BDT per year but these are not generally considered for off-field utilization and are commonly incorporated into the soil. High moisture at time of harvest would require field drying for use in combustion systems, a requirement for rice straw as well. They may more appropriately be used in biochemical conversion systems, such as anaerobic digesters that produce a methane-rich biogas suitable as engine fuel. There have been few studies investigating the use of vegetable crop field residues as industrial feedstocks.

Food processing wastes: Food processing operations in the state produce a variety of biomass feedstocks including nut shells, fruit pits, rice hulls, meat processing residues, grape and tomato pomace, cheese whey, beverage wastes, and waste water streams containing sugars and other degradable solids. Dry solids production of shells, pits, hulls, and cotton gin trash exceeds 1 million BDT per year in the state. Total wastes may be at least twice this quantity. A number of these are already used for power generation, including almond shell, walnut shell, and rice hulls. In some cases the material is used at the site of production and fuel costs are not directly assigned. In the case of rice hulls, one generating facility consumes more than two-thirds of the hulls produced in the state, and competes with other uses such as animal litter. Contract prices are generally lower than for wood fuels.

⁹ Jenkins, B.M., R.R. Bakker and J.B. Wei. 1996. On the properties of washed straw, *Biomass and Bioenergy* 10(4):177-200.

¹⁰ Jenkins, B.M., R.B. Williams, R.R. Bakker, S. Blunk, D.E. Yomogida, W. Carlson, J. Duffy, R. Bates, K. Stucki and V. Tiangco. 1999. Combustion of leached rice straw for power generation. In: Overend, R.P. and E. Chornet (eds.), *Biomass: a growth opportunity in green energy and value-added products*. Pergamon, Oxford, pp 1357-1363.

¹¹ Jenkins, B.M., R. Bakker-Dhaliwal, M.D. Summers, L.G. Bernheim, H. Lee, W. Huisman and L. Yan. 2000. Equipment performance, costs, and constraints in the commercial harvesting of rice straw for industrial applications. ASAE Paper No. 006035, ASAE, St. Joseph, MI 49085-9659.

Animal manures: The agricultural animal population in the state is close to 280 million including 230 million broiler chickens. Total cattle population exceeds 5 million, with 1.7 million milking cows, 740,000 beef cows, and 2.8 million other cows. Total manure production from animals is more than 11 million BDT per year, with 8 million BDT from cattle and nearly half of that from milking cows in dairies. Confined animal operations have come under increasing regulatory scrutiny for air and water pollution, odors, noise, and other nuisances especially as the size of individual operations has increased and urban development has expanded into more traditional agricultural areas. Large scale animal operations in the US are now more commonly viewed as industrial facilities rather than agricultural operations and are subject to the same regulatory requirements under the Clean Water Act and other legislation. Power generation options are now widely considered in association with waste handling. Incentive programs, such as the Dairy Power Production Program funded by the California Energy Commission,¹² exist for assisting the industry in mitigating environmental impacts and exploiting manure as a resource. Anaerobic digestion is the principal technology considered for use in stabilizing manure. Anaerobic digesters produce a methane-rich biogas that can be used as fuel for engines, gas turbines (including microturbines), and fuel cells. Biogas or waste heat can also be utilized to heat the digester to improve performance. The gas can be burned in boilers, upgraded to increase methane content, or reformed to hydrogen. The relatively small scale of even large confined animal operations compared with other energy refining and processing operations will likely leave power generation as the preferred alternative for at least the near term or until more modular conversion units with suitable fuel storage and transmission can be developed. Gross generation potential from animal manures in California is about 550 MWe with 271 MWe from milking cows. Not all of the resource will be converted, and more likely the potential generation from animal manure does not exceed 370 MWe, with 136 MWe from milking cows, although the potential will increase as the dairy animal population increases and as technology improves. Beef cattle population has been declining over the last decade and potential impacts from the discovery of bovine spongiform encephalopathy (BSE or mad cow disease) in the US have not yet been predicted. Currently 3 dairy digesters and 1 swine digester are operating in the state for a total of 0.5 MWe, and 14 more digesters are planned that should bring the total to 4 MWe in the near term. The development of improved gasification systems is a national priority for animal litter and manure.¹³

Forestry biomass

The four main categories of forestry biomass are logging slash, mill residues, biomass from forest thinning and stand improvement operations, and chaparral. Although forestry constitutes a major source of biomass, the total resource potential has not yet been fully characterized. Logging slash, mill residues, and forest thinnings are already in commercial use as fuel for power generation. Logging slash and thinnings together supply 1.1 million tons of fuel for 130 MWe of generation from existing facilities. Mill residues constitute another 1.3 million tons and 150 MWe of generation.

Logging slash: Slash is comprised of branches, tops, and other materials removed from trees during logging. As the volume of slash is directly proportional to logging activity, the resource has declined considerably in the state in recent years (Figure 1). The volume of slash produced is about 20% of timber harvest volume, generating approximately 2.5 BDT per thousand cubic feet of timber

¹² <http://www.wurdco.com/>

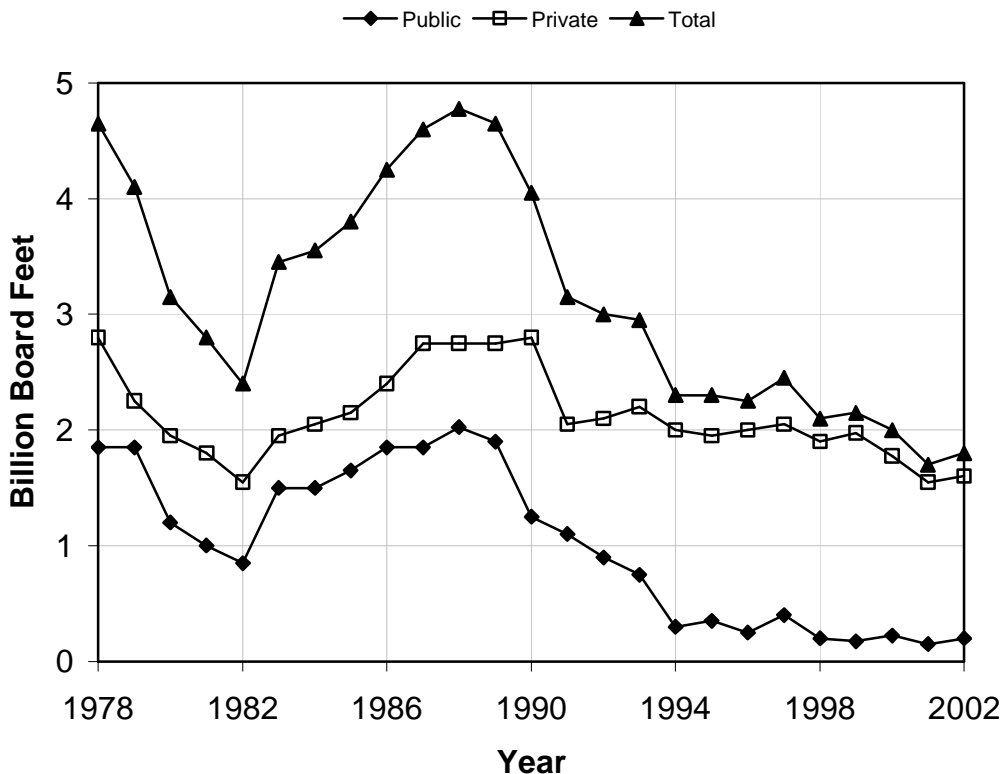
¹³ US Department of Energy, Roadmap for biomass technologies in the United States, December 2002, <http://www.bioproducts-bioenergy.gov/>.

harvest. At current logging rates, the quantity of slash produced is about 0.8 million BDT per year, almost all of it coming from private lands. Harvesting costs range \$10 to 35 per BDT and depend on terrain and transportation access.¹⁴

Forest thinnings: Thinnings result from forest stand improvement operations designed to reduce stand density, enhance overall forest health, reduce the risk of catastrophic wildfire, and protect watersheds. The cost of thinnings is \$20-40 per BDT, and operators have sought to enhance economic feasibility by selectively harvesting more merchantable timber in the process. The issue of mechanically thinning forests remains controversial, however. The estimate here excludes forest reserves, stream and lake-side management zones, slopes steeper than 30%, and sensitive habitat areas.

Mill residues: Wood residues from sawmill operations have long been used for steam and power generation. The resource follows logging although imports and exports can also affect mill activity. Mill waste volume is about half timber harvest volume, amounting to 6.25 BDT per thousand cubic feet. Nearly all mill residue is already utilized as boiler fuel.

Chaparral: This category is comprised of mostly shrubby evergreen plants adapted to the semi-annual desert regions of California, especially southern California. The resource is large, estimated in excess of 6 million BDT per year, but there has been little development of the resource and much of it occurs on steep terrain or in sensitive habitat areas. Where harvesting is feasible, costs are likely to be similar to those for forest thinnings, although as with most biomass stand density can have a significant effect on cost.



¹⁴ Springsteen, B., 2000, Assessment of California waste resources for gasification, Final Report, EER - SDV Contract No. 500-98-037-SDV, California Energy Commission, Sacramento.

Figure 1. Volume of timber harvest (billion board feet) on public and private lands in California, 1978 – 2002.¹⁵

Municipal wastes

Municipal wastes are classified as municipal solid wastes (MSW), municipal waste water or sewage, and biosolids from waste water treatment.

Municipal solid wastes: Total MSW generation in California now exceeds 70 million tons. The total biomass fraction is estimated at 37 million BDT per year, amounting to roughly 1 BDT biomass per person per year. The biomass component of MSW includes construction and demolition wood (also referred to as urban wood fuel), paper, grass and other green waste, food waste, and other organics not including plastics and tires. AB 939 (1989) mandated local jurisdictions to divert at least 50% of waste from landfill by 2000. Not all jurisdictions have satisfied this mandate, and overall the state diversion rate is currently just under 50%. The resource potential of MSW is large with an estimated gross generation potential above 4,000 MWe. Power is now generated at three MSW mass-burn facilities for a total of 70 MWe, and from 49 landfill gas to energy (LFGTE) facilities generating an additional 205 MWe.¹⁶ Planned LFGTE additions should bring the total to 250 MWe in the near term. Another 189 MWe of biomass power is produced from urban wood fuel removed from the MSW stream. Of the diverted fraction of MSW, recycling and composting employ most of the resource but a substantial fraction remains for energy conversion and much actually reenters landfills as alternative daily cover. Landfill gas originates from the anaerobic decay of waste in the landfill. Gas quality is typically reduced compared to gas from other waste digesters due to air intrusion through the soil cover as the landfill is placed under vacuum to extract the gas. Landfills and MSW combustion facilities charge tipping fees to receive waste; urban wood fuel is delivered at essentially transportation cost to existing biomass power plants (\$10-20 per BDT). Importation of lower cost urban wood fuel from the Los Angeles basin into the San Joaquin Valley was a motivating factor behind the exclusion of urban wood fuel from incentives provided under SB 704 in preference to local agricultural biomass. Tipping fees at mass-burn facilities in the Los Angeles area are \$33 to \$37 per ton of MSW, similar to landfills in the region. AB 939 did not allow transformation, including use of MSW in power plants, to count for more than 10% of diversion, and this has been a limitation in increasing diversion and power generation from MSW. Public opposition to combustion as a means of disposing of MSW, even in qualified power plants, is reflected in state policies that have discouraged MSW conversion via this route. Recent legislation has exempted thermal gasification from the transformation category, although the language defining the technology is so far inadequate and the technologies are still for the most part experimental. Improved bioconversion techniques for landfill are also currently under investigation. Bioreactor landfills employing leachate recirculation and membrane covers have the potential to more than double the rate of gas generation. Other types of digesters are also being investigated for MSW, as are processes to ferment MSW to produce ethanol.

Biogas from waste water treatment plants: Some sewage and other waste water treatment facilities employ anaerobic digesters to stabilize a portion of the waste. Biogas produced in the digesters can be used for power generation as well as for heating the digester to improve performance. Current electrical generation from waste water treatment plants is about 39 MWe. The gross potential is above 100 MWe.

¹⁵ California Department of Forestry and Fire Protection, The Changing California, Forest and Range 2003 Assessment, October 2003.

http://www.frap.cdf.ca.gov/assessment2003/Assessment_Summary/assessment_summary.html

¹⁶ Simons, G., Z. Zhang and P. Redding. 2002. Landfill gas-to-energy potential in California. California Energy Commission 500-02-041V1.

Biosolids: Organic solids or sludge resulting from waste water treatment can be used as fuel for power generation. Although quantities are subject to considerable uncertainty, the fraction of biosolids not currently landfilled could potentially support an additional 60 MWe. Handling, drying, and concentrations of heavy metals can limit the use of these materials.

Dedicated energy crops

Growing dedicated biomass crops for energy has not yet emerged as a large scale agricultural enterprise in California, although there is increasing interest due to changes in public perceptions relating to sustainable development, reduction in fossil fuel use, and pollution abatement. Elimination of MTBE from gasoline has caused the market to expand for ethanol as a fuel oxygenate. Attempts to build ethanol capacity in California using straw, wood, and other lignocellulosic biomass have so far been unsuccessful, but fermentation of grain, particularly corn grain, and sugar is well established. US ethanol production capacity from starch and sugar is about 3 billion gallons per year with potential to expand beyond 6 billion gallons per year by 2006, most of it outside the state.¹⁷ California demand for ethanol as a fuel blending stock in 2003 was about 600 million gallons and is expected to be between 740 and 900 million gallons in 2004. Production capacity in California is now only about 9 million gallons per year from two facilities fermenting sugars from cheese whey and beverage industry wastes. One other plant using food industry residuals and a number of corn-based facilities are planned. Many of these facilities plan to use imported corn grain as fermentation stock at least initially but could induce an expansion of in-state corn production. Production of 900 million gallons of ethanol from in-state corn at the statewide average yield of 4.76 tons per acre¹⁸ would require close to 2 million acres or almost 20% of irrigated farm land in the state. Increased amounts of biomass both as fermentation residuals and field crop residues would become available for cogeneration or independent power production. Sugar cane is also being explored as a fermentation feedstock to be grown in the Imperial Valley.

Biodiesel represents another market for California agriculture. Oil crops have long been an important commodity for California although there is little virgin oil going into biodiesel production. Waste oils and fats are currently the preferred feedstocks due to lower cost. Biodiesel yields from safflower and sunflower typically range 60-80 gallons per acre. The state currently uses more than 2.7 billion gallons of on-highway diesel fuel per year and a total 3.9 billion gallons of distillate fuel.¹⁹ Biodiesel is produced via the transesterification of an oil (triacylglyceride) with alcohol in the presence of a catalyst (NaOH or KOH typically). Biodiesel can be used straight (labeled B100) or blended with petroleum diesel, commonly at 20% concentration (labeled B20). Production costs for biodiesel are currently in the range of \$1.50 – 2.70 per gallon. Lower costs are associated with waste oil feedstocks. Biodiesel from sunflower seed at \$220 per ton costs \$2.50 per gallon including byproduct credits.²⁰ Costs for other oil seed crops are similar. Biodiesel constitutes a large market for future oil crops, especially where they may be grown to advantage using saline or waste water.

The production of hydrogen constitutes another potentially large market for biomass. Theoretical

¹⁷ MacDonald, T., G. Yowell, M. McCormack and M. Bouvier, Ethanol supply outlook for California, California Energy Commission 600-03-017F, October 2003.

¹⁸ California Department of Food and Agriculture 2002 Resource Directory, CDFR, Sacramento.

¹⁹ Energy Information Administration, Fuel oil and kerosene sales 2002, http://www.eia.doe.gov/oil_gas/petroleum/info_glance/distillate.html

²⁰ Weber, J.A. and D.L. Van Dyne, Cost implications of feedstock combinations for community sized biodiesel production, University of Missouri, Columbia, 1998.

yields range from 20 wt. % for wood to better than 35 wt. % for lipids.²¹ A wide variety of processes are available for converting biomass to hydrogen including both thermochemical and biochemical techniques. None have yet been demonstrated on a commercial scale but active research is underway.

Conclusions

California has a large and diverse biomass resource base that can contribute substantially to state energy and material needs. The current production inventory is estimated at 72 million tons per year including biomass from agriculture, forestry, and municipal wastes. The gross power potential from this resource is close to 8,000 MWe, or roughly 16% of state generating capacity. The sustainable technical potential of the resource is well below this but likely in the range of 5-10% of total power demand. Greater and improved utilization of biomass also offers benefits in waste management and environmental quality. Recent legislation affecting open burning along with incentives provided under the renewable portfolio standard should improve the economic potential for sustainable biomass development in the future.

²¹ Milne, T.A., C.C. Elam and R.J. Evans, Hydrogen from biomass, state of the art and research challenges, International Energy Agency IEA/H2/TR-02/001, 2002.

Pasture and Livestock Can Be Used to Manage Saline Drainage and Other Waste Waters in the San Joaquin Valley.

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Introduction

Without a means to dispose of drainage water in the western San Joaquin Valley, increasing amounts of farmland will become salt impaired. The use of underlying groundwater and limited numbers of evaporation basins for disposal of the large volume of drainage water produced is not sustainable. A multi-disciplinary team has assembled to test the hypothesis that saline-sodic drainage water can be used in an environmentally sound manner for forage and livestock production. The goal is to use salt tolerant forages to support economic weight gain by cattle or sheep, or for sale to dairies and other cattle feeding operations. If economic livestock production can be based on the reuse of drainage water or other wastewaters in the San Joaquin Valley, this unused water will be transformed from an environmental burden into an economic asset. The amount of water that must be disposed to groundwater or in evaporation ponds will be reduced dramatically. Other economic and environmental benefits associated with irrigated pasture also will be realized.

The study's objectives are to:

- Measure forage biomass accumulation, nutrient and trace element uptake, and the quality of salt tolerant forages produced using saline-sodic drainage water.
- Monitor the mineral status and general health of cattle and measure the growth rate of cattle fed or grazing forages produced with drainage water. Quantify the effects of saline-sodic drainage water on overall water use, drainage water quantity and quality, salt and trace metal balances, soil organic matter, and soil chemical and physical properties over time. Model changes in important soil chemical, physical and biological properties at the local and field scale.
- Estimate the costs and returns associated with forage and livestock production based on the use of saline-sodic drainage water.

Methods

An 80 acre field near Stratford in Kings County, was developed to study the use of drainage and other waste waters for the production of forages and cattle. The field had been abandoned for annual crop production because it was saline and highly variable. The site was leveled and tile drains were installed at a depth of 4 feet, 120 feet apart. A detailed baseline soil assessment for soil physical and chemical properties was done before the project began in summer 1999. Soils were characterized initially for chemical and physical properties using electromagnetic induction techniques followed by directed soil sampling. All survey work was done with GPS mapping and sample site locations were determined using ESAP software (Lesch et al., 2000, 1995). A second, similar survey was carried out in March 2003 to assess changes in the same soil properties. Bermuda grass (*Cyanodon dactylon*) was established in 2000. The site was divided into 8 paddocks, each approximately 8 acres in size, to facilitate rotational grazing. Livestock trials have been carried out for three years (2001-2003). Grazing

began in 2001 with a group of 40 recently weaned stocker cattle. In 2002, 160 cattle were maintained on the pasture, while in 2003 an average of 90 cattle grazed the pastures on average. Cattle were monitored for weight gain and for the effects of trace element, particularly Cu, Mo and Se, on their health. Repeated forage sampling occurred at soil sample locations during the grazing season. Periodic aerial hyper-spectral images of the site were taken. Forages were cut to 2 to 3 inches in height when sampled. After drying, samples were analyzed for quality and mineral content. Continuous monitoring (water volume) and automated sampling (for EC_w) of irrigation and drainage water has been carried out in four of the eight paddocks using automated sampling equipment since irrigation was initiated in 2000.

Results to date

Selected soil chemical and physical properties were measured using electromagnetic induction techniques followed by directed soil sampling. A comparison of averages by depth of selected soil properties from the larger set analyzed is presented in Table 1. The Table compares values observed in 1999 before the project began and in 2003. Se, which is a problem in other parts of the western San Joaquin Valley, is deficient at this site. In the four years of irrigation and crop growth using moderately saline water, salinity related properties declined on average in the first two feet of the soil profile, while the lower two feet were largely unchanged.

The quality of irrigation water used is represented by data from 2002, which was typical for the first three years of the project's operation (Table 2). Total salinity in irrigation water was variable. Irrigation water mixed drainage water as it became available during the growing season with water from the Kings River. In 2003, water from the Lemoore wastewater plant and from a recently opened cheese factory also were used for irrigation as part of the mixture of wastewaters applied. The leaching fraction observed was less than 10%, suggesting that most of the water applied was used by the grass crop. Runoff was negligible, but some loss to groundwater occurred and could not be measured in drain tiles.

Forage biomass and quality were measured at sites selected to reflect soil variation. Pastures were grazed rotationally throughout the 2001-2003 seasons by beef cattle. In 2002, a subset of 35 cattle were monitored for live weight gains, changes in blood and liver Cu, Mo, Se, and overall health. Bermuda grass grew well at moderate salinity levels but failed to produce where salinity (EC_e) exceeded 22 dS m⁻¹. Standing biomass amounts at the start of grazing during the warm months varied from approximately 0.6 tons dry matter per acre to more than 1.6 tons, but values were much lower in early spring (April) and late fall (November). Amounts of forage available varied with differing times of year, fertilization, and grazing practices. Intake by cattle was less than the amount of forage on offer because grazing allowed for selection by the animals. Average forage quality values and the range observed during 2001, 2002, and part of 2003 are presented in Table 3. Forage crude protein contents averaged 13.4 %, and ADF was 29.4. Mo contents varied from 1 to 5 mg kg⁻¹ DM, and Cu:Mo ratios averaged 4.0.

Livestock weight gains were correlated with stocking rate and in the third year averaged 1.5 lbs day. In 2001, only 40 cattle were grazed on the site to first evaluate the effects of saline irrigated forages on animal health. Cattle became Cu and Se deficient, so Cu and Se supplementation were carried out on test groups in the second and third years. Cattle were divided into two groups, with the smaller groups grazed on a pasture near the study site that received only Kings River water, while the larger group was grazed at the study site. Some of the animals received Cu and Se supplements, while others did not. In 2002, approximately 160 stocker cattle were grazed without feed supplements throughout the season on the study site (April through November). In 2003, approximately 90 cattle grazed over the same period. Stocking rates in 2003 allowed for a better balance between pasture productivity and cattle needs than in 2001 and 2002. Results are presented for 2003 in Table 4 as an indication of what types of live weight gain are possible when cattle intake needs and pasture growth are more balanced.

Conclusions

1. After 4 years of irrigation with moderately saline water, pastures are increasingly productive.
2. Salinity related properties in the top two feet of soil have declined, indicating that soil reclamation is occurring through the use of moderately saline water.
3. A large proportion of the irrigation water applied is being used by crops, reducing the amount of saline water for disposal.
4. Beef cattle can be grazed on salt-affected pastures and gain at economic levels without apparent ill effects on livestock health. Trace element imbalances in forages and cattle can be managed and were not a significant concern.

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Table 1. Selected average soil properties in 1999 and 2003.

Variable	0 to 1 ft		1 to 2 ft		2 to 3 ft		3 to 4 ft	
	1999	2003	1999	2003	1999	2003	1999	2003
EC (dS/m)	13.0	11.4	20.2	17.5	22.5	22.5	25.2	24.3
pH	7.6	7.67	7.58	7.87	7.63	7.87	7.57	8.03
Cl (meq/L)	21.8	18.3	35.3	30.2	47.1	30.2	58.7	55.6
SAR	28.2	23.5	51.4	40.3	59.0	40.3	64.9	57.5
B (mg/L)	17.0	14.2	19.0	19.1	17.5	19.1	17.9	21.7

Table 2. Irrigation water quantity and quality (2002).

Value	Irrigation volume (inches per event)	Drainage volume (inches per event)	Irrigation water (EC _{iw}) (dS/m)	Drainage water (EC _{dw}) (dS/m)	Leaching fraction
Average	3.5	0.1	3.6	33.9	0.06
Range	3.2 to 3.9	trace to 0.2	2.0 to 8.0	30 to 40	0.05 to 0.08

Table 3. Selected forage quality average values (2001 to 2002*)

Variable	Mean	Maximum	Minimum	Std deviation
CP (%)	12.1	22.1	5.5	4.5
Ash (%)	13.4	24.1	8.3	3.0
ADF (%)	28.5	40.8	22.1	3.3
B (mg/kg)	217	1004	73	142
Cu (mg/kg)	7.92	13.7	4.0	1.63
Mo (mg/kg)	1.95	5.3	0.4	0.96
Se (µg /kg)	84.9	328	<100	47.3

* Data are not final, due to additional analyses in progress.

Table 4. Grazing results (2003)

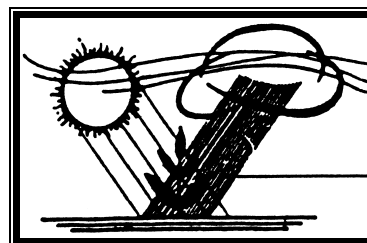
Treatment	N	Ave. Daily Gain (lbs/day)	Std Deviation (lbs/day)
Control pasture (-Cu/Se)	5	1.14	0.29
Control pasture (+Cu/Se)	5	1.27	0.37
Treatment pasture (-Cu/Se)	7	1.58	0.24
Treatment pasture (+Cu/Se)	23	1.56	0.26

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2004 Poster Abstracts

Session Chair:

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Effect of Air Injection Through Subsurface Drip Irrigation on the Growth and Yield of Crops

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Modification of root zone environments by injecting air has continued to intrigue investigators. The concept of aerating the irrigation water increases the potential for the air to travel with water movement within the root zone more generally and affect crop growth. Physical, chemical, and biological soil characteristics that influence crop growth and yield depend on the relative proportions of the liquid and gas phases within the root zone. For example, a soil that is well aerated will favor increased root respiration and aerobic microbial activity. Conversely, in waterlogged soils typical of poor drainage, anaerobic conditions prevail. Since oxygen is essential for root respiration, then immediately after the roots have been surrounded by water they can no longer respire normally.

Through work in other areas, the Mazzei Corporation has developed high efficiency venturi injectors capable of aerating water with fine air bubbles. In 2000, a pilot study was conducted at the Center for Irrigation Technology (CIT) in which air was injected into the root zone of bell peppers via the subsurface drip irrigation (SDI) system. In that study an increase of 33% in bell pepper count, and a 39% increase in bell pepper weight was noted for the aerated plots versus the plots receiving only water. When the roots were examined, there was a significant difference between the root weight to total plant weight ratios for the aerated plants and the non-aerated plants. The findings from the 2000 CSU-Fresno study justified follow-up fieldwork on larger plots approaching commercial scale.

The major goal of the current research is to evaluate the technical and economic feasibility of injection of ambient air into a subsurface drip tape irrigation system, as a best management practice for crop production. Ideally, the technology should be applied to and tested on as many crops as possible. Realistically, we plan on assessing the practice on as many vegetable and fruit crops commonly grown in the San Joaquin Valley, over the next two years. In this phase of the research, our focus is on three crops: bell peppers, fresh-market tomatoes and melons.

This past summer we conducted comparative tests between air injection and water only treated melons (honey dews) on 13 acres plots with a drip tape run length of over 400m. There was a 14% increase in the number of melons and, a 16% increase in the weight of melons harvested due to air injection. These figures translate into a projected increase of \$260 to \$350 per acre for the farmer depending on the wholesale price of melons which can range from \$3 to \$4 per box. With respect to quality, there was no significant difference between the sugar levels measured for the air treated and the water only treated melons.

In another experiment with peppers grown on 40 acres with run of over 400m, we observed that although there was a trend of decreasing yield (both numbers and weights) in moving away from the source of the air and water injection, there was still a positive effect of the air injection towards the tail end of the irrigation tape.

In the third experiment we compared the effects of the air injection on a tomato crop grown on 20 acre plots with drip tape run lengths of approximately 300m. So far we have observed that for the air treated plants there were greater yields from the plants located at the “head” of the drip line versus the plants down at the “tail”. Our initial findings seem to indicate that in the case of the tomato crop, there may have been earlier fruit maturity for the air treated plants.

The tomato and pepper experiment data sets are still being processed.

If the air injected into water delivered through SDI tape continues to show the positive effects on the growth and yield, then the primary benefit of this research to the vegetable and fruit industry would be increased productivity. Negative aspects will identify areas for further research in the on-going effort to develop management practices that are both environmentally sound and economically viable. The research would also allow for a more comprehensive investigation into, and understanding of any air-water slurry and soil-plant relationships.

Understanding winegrape weed management practices of a biologically integrated farming system in San Joaquin County, California

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Abstract

To reduce the risk of groundwater contamination by pre-emergent herbicides, a Biologically Integrated Farming Systems (BIFS) program in San Joaquin County, California, promoted need-based applications through field monitoring, the use of contact herbicides alternatives (considered reduced-risk) over higher-risk conventional pre-emergent herbicides, cover crops, and higher efficiency applicators. We use California's unique Pesticide Use Records (PUR) database to investigate whether BIFS growers reduced their use of pre-emergents; additionally, we attempt to gain a better understanding of herbicide use patterns during and after BIFS program years based on economic, efficacy, and rainfall data. Results showed that simazine decreased significantly in the first year of the program. This temporary decrease in simazine use in the inaugural year may have been due to initial enthusiasm for a locally grower-driven program, low weed pressure, and a shift in weed management strategies. While a high weed pressure year like 1998 increased the use of simazine, more BIFS field acres shifted from using primarily simazine and no glyphosate towards a more diversified approach of using both contact herbicides and pre-emergents. During program years, simazine use on BIFS fields had the highest correlation with rainfall, a proxy for weed pressure, suggesting that BIFS fields did a better job in applying simazine only when weed pressure warranted it. Reductions in simazine were more apparent early in the program while reduced-risk contact herbicides appear to take 3-5 years to establish popularity. This underscores the importance of caution when evaluating a program's success in the short-term; it may take longer than a typical three-year funding cycle to witness the type of changes a program advocates. With low weed pressure and willing participants, grower-driven farmer-to-farmer extension models can be successful.

Addressing Nutrition Imbalances in Greenhouse Mum Production: Progress Report

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OBJECTIVES

- Diagnose soil, water, and plant for nutritional problems.
- Digest and make information adaptable to respective levels of clients.
- Provide suggestions to modify soil-plant-water management practices
- Design a follow up monitoring program to help clients adopt modifications of their choice

INTRODUCTION AND BACKGROUND

Since the early 1980's South Santa Clara County (South County) is home to a large ethnic Chinese community that specializes in chrysanthemum (*Dendrathera grandiflora*) cut flower production. For the majority, they are first generation immigrants from main land China that speak minimum English. Over the last few years, many of these operations have developed production problems. In addition to different pest pressures and market challenges, long term practices of continuous fertilization regimes and complete reliance on often-unsound fertilizer recommendations, resulted in serious decline of flower production, quality, and storability.

Furthermore, language barriers kept this hard working community from taking advantage of regular services offered by different county agencies. In an effort to bridge this knowledge gap, UCCE Small Farm Program (SFP) and the Santa Clara Valley Water District (SCVWD) joined effort to provide a unique voluntary program. This multi-faceted program includes: (a) diagnostics of pest problems, (b) irrigation pump evaluation, (c) irrigation system evaluation, (d) soil, plant, and water analyses and evaluation.

METHODS

Initial contact with new clients (with translator support) typically includes discussion of the history of the family operation, past production problems including losses to disease and insects, typical fertilizer and pesticide materials, irrigation and fertilization practices. We also attempt to preliminarily understand the grower's experiential and technical basis for making management decisions. Soil, well water, and plant tissue sampling and testing are being used to provide an initial picture of soil and crop nutrient status and further to demonstrate to growers the benefits of soil and crop monitoring.

The program approach has three distinct phases, (a) assessment of the overall problems, (b) communication of the results and discussion of specific recommendations, and (c) implementation of selected recommendation

RESULTS

Generally, these growers have varying degrees of technical knowledge concerning fertilizer materials, fate of NPK fertilizers in soil, and the use and interpretation of soil or plant testing. Actual fertilization practices and schedules vary widely among this group, resulting in a wide range of severe under- and over-fertilization. Each grower's traditional fertilization and irrigation practices, have caused either significant soil nutrient imbalances, increasing soil alkalinity or acidity, excessive accumulation of soil chloride (Cl), possible crop toxicity due to chloride, deficient or excessive soil nitrate levels, and accumulation of exchangeable and soluble soil sodium. Poor well water quality (specifically high chloride and sodium) appears to be the dominant cause of production problems for two growers. There is very little information in the literature on Cl effects on this plant. But from our preliminary analyses, we are beginning to delineate a Cl range and its correlative effect on plant visual

symptomatology.

The project is at the different levels of implementation of recommendations at five operations. A new work cycle is being planned for January 2004 as new growers express interest in participating.

Cartographic Modeling with SSURGO and DEM Data Using a Combination of GIS, Visualization Software, and Relational Database Management Systems

Dylan Beaudette, Mingha Zhang. AGIS Lab, UC Davis. 2003

Cartographic models are a powerful tool that can be used to better understand the dynamics that exist between various kinds of spatially related phenomena. Once perfected, they can be used to predict potential outcomes that may result from a perturbation to a natural system. One roadblock to developing useful cartographic models is the availability of accurate, and more importantly, relevant data. The purpose of this project is to demonstrate various ways that freely available digital soil survey data (SSURGO) and elevation data (USGS DEM) can be used to produce useful thematic maps, cartographic models, and 3D visualizations pertaining to soil management. The software tools used to accomplish this were ArcGIS (ESRI), Soil Data Viewer (NRCS), MySQL (relational database management system), and POV-RAY (3D visualization). Results pertaining to the ease of use, time required, and overall quality of the example applications will be discussed. Ideally this project will serve to promote the use of digital soil survey data, as well as provide a starting point for those who are interested. Planned future research deals with how to accomplish the same goals, using only open source (free) software tools.

Ammonia and ROG Emissions Related to a Dairy Operation in the San Joaquin Valley, California

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ABSTRACT

A dairy of 2000 cows, located in the San Joaquin Valley of California was sampled for ammonia and ROG (reactive organic gases) in the fall of 2002. The dairy utilized free-stall management with flush lanes draining into a system of lagoons with a solids separator. Effluent from the lagoons is eventually used as irrigation on cropland surrounding the dairy. Three sampling sites were established at the beginning of the fall crop season, which included a site upwind of the dairy, a site directly downwind of the dairy and another downwind sampling site 300 m downwind in a silage field. Ammonia samples were taken from late August through harvest in early October. ROG samples were taken on three days, October 18, 21 and 23, 2002. The levels of ammonia at the upwind site were considered to be ambient while ammonia levels at the directly downwind sampling site were significantly increased after passage of air across the dairy. Ammonia levels at the second downwind site, decreased by nearly 50% from atmospheric dispersion and possibly ammonia absorption of the silage crop. ROG samples were taken in canisters and analyzed by gas chromatography. While downwind concentrations of TNMHC (total non-methane hydrocarbons) were universally enriched over upwind concentrations. TNMHC concentrations measured at a location between upwind and downwind (Middle of Dairy) were higher than those measured at the Down Wind Fenceline.

Effects Polyacrylamide (PAM) on infiltration rate, run-off, and concentration of sediment in tail water of Central Coast soils.

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Introduction

The Central Coast Regional Water Quality Control Board (RWQCB) identified tail water from furrow and sprinkler systems as a source of nutrients and sediments into the Salinas and Pajaro River watersheds. Treatment of soils with high molecular weight anionic polyacrylamide (PAM) may reduce sediments and phosphorus lost from furrow and sprinkler irrigated vegetable fields by maintaining infiltration and stabilizing soil aggregates. Despite documented benefits of PAM for erosion control in other areas of the country, it is not widely used in the central coast region. This project evaluates the effects of PAM on sediment and nutrient concentration in tail water from vegetable fields across a range of soil types found in the Salinas and Pajaro Valleys. The methodology utilizes column and field studies to quantify the effect of PAM (Amber 1200D²², Amber Chem. Inc, and Soilfloc 100D, Hydrosorb, Inc.) on infiltration rate, run off, and sediment and nutrient (ortho and total P, NO₃, K) loss from sprinkler and furrow irrigation systems. Because PAM has not been shown to be beneficial on all soil types and under all water qualities, the column studies screen a larger range of soil types and water compositions than can be accomplished with field studies. Field studies are also being conducted to evaluate the effect of PAM on infiltration rate in furrows and sediment and nutrient concentration using a recirculating infiltrometer.

Results

Results of the column studies demonstrated that the application of the both PAM products (Amber 1200D, Soilfloc 100D) at a 10 ppm concentration in water with an EC of 1.0 dS/m (SAR = 2) reduced final infiltration rates of all soil types tested in the first year of the project (Placential Clay Loam, Clearlake Clay, Mocho silt loam, Salinas Clay Loam, and Chualar Loam). Soilfloc reduced infiltration more than Amber1200D. The reduction in infiltration rate was attributed to PAM increasing the viscosity of the applied water. Additionally, increasing the SAR of the applied water from 0.9 to 9.0 reduced infiltration rates more in

²² Similar composition to Superfloc A836, Cytec Inc.

soils receiving PAM treated water than in soils receiving untreated water. The effect of PAM on infiltration rate was minimized by pretreating the surface of the soil with water containing a 10 ppm concentration of PAM, and subsequently applying untreated water. The structure of the soil surface was visually determined to be better aggregated in columns either pretreated with PAM or receiving continuous applications of water treated with PAM than in columns receiving no PAM treatment. Measurements in the field (Chualar Loam) using a recirculating infiltrometer also showed that a 10 ppm concentration of Amber 1200D reduced the infiltration rate relative to the untreated control. However, sediment carried in run-off was initially 90 to 95% less in the PAM treated soil compared to the untreated soil.

Conclusions

Results of the first year of column and field studies showed that PAM applications reduced the infiltration rates of central coast soils ranging from loam to clay textures. Without an adjustment in irrigation management, PAM applications in commercial vegetable fields could lead to increases in run-off. However, with adjustments in irrigation management, soils pretreated with PAM would tend to have lower concentrations of sediment in irrigation run-off. Trials conducted during the second year of the project will examine the effect of PAM on sediment and nutrient concentration in run-off of commercial vegetable fields.

Understanding pesticide use reductions in California winegrapes: an analysis of pesticide use in Madera, Napa, and Sonoma Counties using Pesticide Use Reports (PUR) and Geographic Information Systems (GIS)

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Public concerns about pesticides in the environment and their potential effects on human health have fueled increased regulation of pesticide use in agriculture. The Food Quality Protection Act (FQPA) of 1996 is one such regulation that fundamentally changes how the U.S. Environmental Protection Agency (EPA) regulates pesticides. Previously, pesticide tolerances were based on the toxicity of each individual pesticide considered alone. With the enactment of the FQPA, pesticide tolerances are determined not by individual pesticide toxicity, but by calculating cumulative toxicities of pesticide residues in foods in addition to other environmental contaminants. As a result of these regulatory changes, many pesticides are being re-reviewed under the new legislation and may be restricted or removed from use in agriculture. Fortunately, winegrape growers have demonstrated their ability to adapt to a changing regulatory arena. As we move into the eighth year of the FQPA, we will look back and see how pesticide use has fundamentally changed since enactment of the law and what the latest trends are in reduced risk pest management in California winegrapes. This paper will investigate FQPA pesticide use and understand the use reductions in California winegrape communities. Pesticide Use Report (PUR) was used as a resource to identify the use trends in Napa, Sonoma, and Madera counties in California winegrapes. The results show that a majority growers reduced the use of FQPA pesticides and increased the use of safer pesticides. Results from the year 2000 show 94% or more of growers in Madera, Napa, and Sonoma counties did not use any FQPA fumigants. Similarly, 63%, 87%, and 76% of growers in Madera, Napa, and Sonoma counties did not use any FQPA insecticides in 2000. Fungicides were not used by 52%, 48% and 43% of growers, while 33%, 68%, and 48% of growers did not use any herbicides in Madera, Napa, and Sonoma counties, respectively. Grower innovations in pest management will be discussed in this paper.

Measurement of Ammonia and Methane Concentrations at dairies Using Tunable Diode Lasers

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California is the number one dairy state, producing approximately 26 billion pounds of milk and cheese annually. While the growth of this industry results in significant economic returns for the region, there is the issue of effective manure management. Major problems associated with the manure management are high solids and nutrient contents of the effluent stream, and emissions of gases, such as ammonia (NH₃) and methane (CH₄), during the decomposition of manure in storage and when the effluent is applied to fields. As a result of the health, environmental and economic concerns, there is a need to quantify the emission of these gases at dairies. A first step in obtaining these emissions is to obtain the spatial and temporal real time concentrations of these gases.

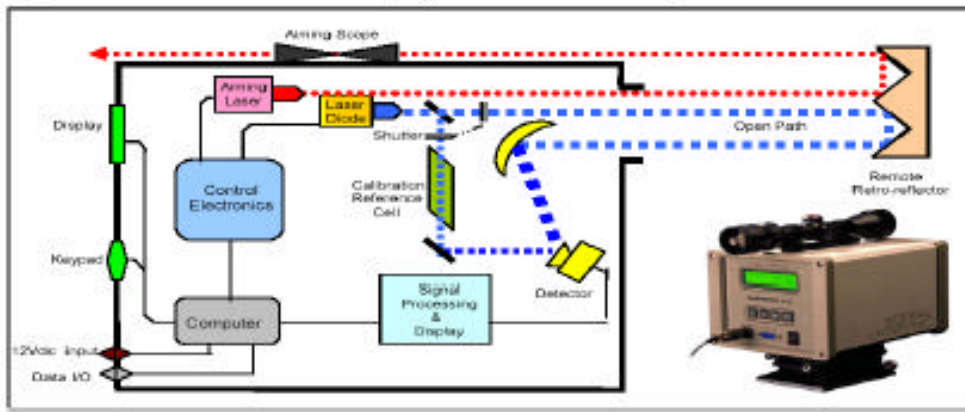
In an effort to quantify the contribution of the dairies to air quality issues in California, commercially available Tunable Diode Laser (TDL) systems, currently being used by other industries, is proving to be a useful tool. Dairymen are particularly interested in quantifying gas emissions on the farm in an effort to better utilize the dairy effluent stream.

The overall goal of the project is to contribute to on-going efforts to make dairy operations sustainable by quantifying CH₄ and NH₃ emissions on dairy farms in order to identify probable areas that contribute to environmental degradation. Recommending management practices to mitigate these adverse effects is also a goal.

Current testing is underway to evaluate the applicability of the TDL system to measure seasonal CH₄ and NH₃ concentrations for dairies located in the San Joaquin Valley (SJV), California. During summer 2003, two dairies were monitored: a “small” and a “large” dairy with 250 and 2000 milking cows, respectively. Tunable Diode Lasers were set at 1.5 meters above the dairy lagoons. Continuous concentration readings were taken for a minimum period of 2 days. Weather data was also collected from stations set up on site. Gas concentrations were converted into real time gas flux measurements by multiplying the concentrations by the simultaneous wind velocity.

Boreal Laser’s GasFinder® measures gas concentration over an open path (fig.1). It consists of an integrated transmitter/receiver unit and a remote, passive retro-reflector array. The transceiver houses the laser diode source, the drive electronics, the detector module, and microcomputer subsystems. The laser light emitted from the transceiver unit propagates through the atmosphere to the retro-reflector and returns to the GasFinder®, where it is focused onto a photodiode detector. A portion of the laser beam is passed through an onboard reference cell to provide a continuous calibration update. These two optical signals are converted into electrical waveforms, which the micro controller processes to determine the actual concentration of gas along the optical path. Response times are in the order 1 second, and the range of measurement can be from 1-1000m.

Figure 1. Schematic showing operation of TDL system



Typical results obtained shown in the graphs below.

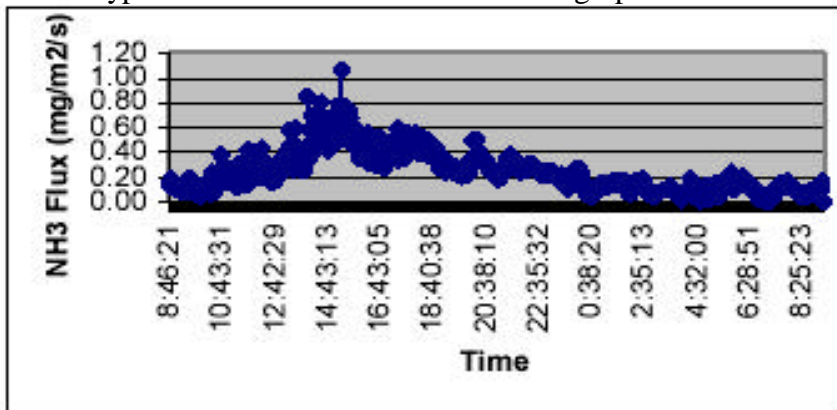


Figure 2. *NH₃ fluxes, corrected for temperature variations, obtained by multiplying concentrations by the wind speed measured with the lasers at the small dairy lagoon from approximately 8am on July 3rd to 9am on July 4th, 2003.*

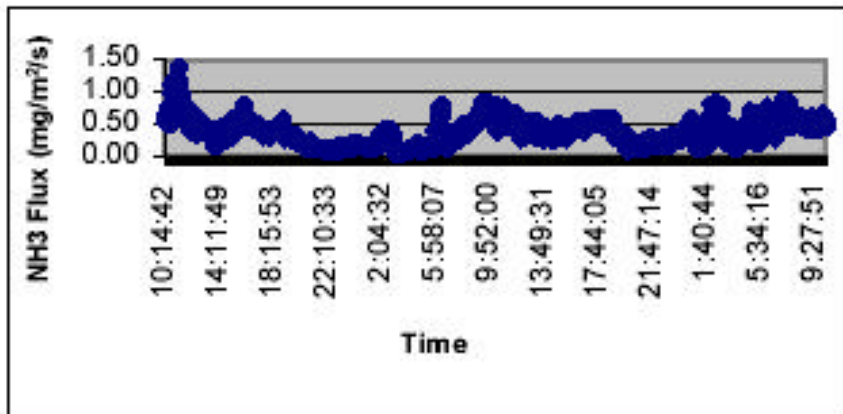


Figure 3 *Fluctuations of methane fluxes for the large dairy lagoon from 1000hrs on July 20 to 2000hrs on July 21 2003*

Findings to date:

Providing that the TDL systems are kept within optimum operating temperature conditions, the TDL technology is suitable for detecting the gas emissions from dairy lagoons during the summer temperatures typical of the San Joaquin Valley, CA.

Data collected with the TDL depict the periods of relatively higher emissions occurring during the day and night times which generally go undetected with the other sampling and

monitoring techniques used in our other related projects. It is essential to conduct monitoring during the fall, winter and spring seasons to assess the performance of the TDL system under these conditions, while at the same time examining any seasonal variability in the gaseous emissions.

In future work:

Each dairy will be subdivided into three major components as follows: Animal housing and feeding area; Lagoon storage and treatment ponds; and, Fields irrigated with the dairy effluent. Using either existing data or collect additional data on soil, air, water, livestock numbers, and field crop to examine any correlation with the measured emissions. At different times during the sampling, the flux profiles will be obtained at different heights, which will then be used to estimate the vertical gas emission rates by employing the integrated horizontal mass flux approach. In the cases of measurement of gas concentrations at a fixed height, we intend to adopt a modeling approach in which the distribution of gaseous concentration is determined through the distributions of individual molecules, after a large number of individual random flights are simulated.

Crop Growth Enhancement with CO₂ injection into the Crop Canopy with Drip Irrigation

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During summer 2002, AG GasSM contracted with the Center of Irrigation Technology California State University at Fresno (CIT), to undertake a 2.1-acre, open-field, test-plot involving 12,000 tomato plants. The major objective of the project was to determine the open-field effects of CarbogationSM brand carbon dioxide (CO₂) enrichment on fresh market tomatoes and to provide third party (university) verification of data results.

Fresh market tomatoes (*Lycopersicon esculentum* cv. Shady Lady) were established as transplants on 60-inch beds with 18-inch plant spacing. Approximately ½ of the tomatoes were provided with CarbogationSM brand CO₂ enrichment, and the other ½ that was not CO₂ enriched was used as a baseline data control-plot. Standard California, agricultural practices and applications (cultivation, fertilizer, herbicide, irrigation, etc.) were applied. Field instrumentation and sampling protocols were established in order to monitor the following parameters: yields; irrigation and water use efficiency; soil conditions; crop characteristics; and, nutritional analysis of the tomatoes.

The elevated CO₂ concentrations in the open field conditions applied via the CarbogationSM brand resulted in a number of positive effects. CO₂ enrichment more than doubled the total marketable harvest weight of the tomatoes. On average, the fresh weight of aboveground portion (stems, leaves and fruits) of the plants harvested from the CO₂ treated plots were 1.5 times those from the control plots, and root biomass was significantly higher in the CO₂ plots for all soil depths. In addition to the favorable crop effects, there was no adverse effect to the soil physical and chemical properties as a result of the CarbogationSM brand CO₂ enrichment. Furthermore, on the basis of marketable yield per amount nitrogen (N) fertilizer and water applied, the CO₂-enriched plants appear to demonstrate higher N and water use efficiency than the control plants.

Site-Specific Tillage Practices for Cotton and Corn Production in California

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For a variety of reasons (such as fossil fuel and farm machinery costs, soil compaction, PM-10 dust, etc) growers in California are looking for ways to reduce soil tillage without adversely impacting the growth and development of crops. The single biggest reason to till the soil is to provide a suitable environment for the seed to germinate. But for the widely spaced crops like cotton and corn, the seeds and seedlings occupy only a small proportion (4-8%) of the land area. Moreover, most of the soil tillage features (e.g., loose soil) are lost after the first irrigation due to soil wetting and drying. Hence, the natural question: how important is it to till the entire soil surface when the effective needed area is only 4-8%?

With the above question in mind, experiments on cotton and corn were conducted at U. C. Westside Research and Extension Center, Five Points and at UC Davis Agronomy Research Farm, respectively, for a period of three years continuously on the same piece of land. For site-specific tillage operations, a special tiller-planter was designed and fabricated at the Department of Biological and Agricultural Engineering at UC Davis. The tiller-planter incorporated mini roto-tillers, which tilled a 3-4" band of soil in front of the planter shoes/chisels. This also combined tillage and planting into a single and the only operation, resulting in a significant saving of time and resources.

The three years of experimentation showed that there was no effect of site-specific tillage on cotton yields as compared to conventional tillage. But a small but significant increase in yield was seen in the second and third years of corn crop due to site-specific tillage, as compared to conventional tillage.

Results of these experiments (including pictures) will be shown and discussed in the poster.

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Responses of Recent Upland Cotton Varieties to Planting Density, Planting Date and Irrigation Management for Short and Long-Season Production

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Abstract

A three-year study was initiated in two locations in the San Joaquin Valley (SJV) of California to develop information on sensitivity of growth, yield and fiber quality responses to planting dates, planting density, and irrigation management practices in a standard Acala Upland variety and two newly-available non-Acala Upland varieties differing in some growth habit and maturity characteristics. Changes in California regulations on varieties allowed in the San Joaquin Valley Quality Cotton District were made starting in 1998. Combined with low commodity prices and increasing input costs, these changes have allowed evaluations of alternatives to Acala Upland and Pima varieties. Generally, Acala and Pima varieties have been managed to take advantage of long growing seasons and high available heat units. With changes in variety regulations, Upland varieties ranging from true early-maturing to medium and late-maturing can be grown if they can fit into a profitable production scheme. In some years, availability and cost of irrigation water and problems with late-season insects and their control costs may provide added incentive to look at alternative varieties or practices that could shorten the duration of growing season needed for cotton in the San Joaquin Valley. The study was conducted at two locations for each year, one in a clay loam soil in Fresno County in the central SJV, the other in a sandy loam soil in Kern County in the southern SJV. Among the variables evaluated, the largest yield responses within any variety were seen with changes in planting date; with the earlier (April) planting dates consistently out-yielding May plantings. Benefits of April planting dates over early May planting dates were quite consistent, and were observed most years in both sites, with all three varieties in the tests. Situations where yield improvements with the earlier (April) planting date were numerically greatest: 1) with longer season varieties such as Maxxa and Nucotton-33B; 2).when fall weather conditions were cooler; and 3). under high yield conditions exemplified by the West Side (clay loam site), with lower relative yield differences under lower yield conditions at Shafter (sandy loam site). Planting density effects on yields were greatest in April plantings, where higher plant populations tended to reduce yields, particularly in the Acala variety. Planting density / population effects on lint yields: 1) were less consistent than observed in prior University of CA studies done on Acala varieties in the San Joaquin Valley; 2) the higher density tended to reduce yields mostly with earlier planting dates at the higher yield location; and 3) higher density plantings gave similar or slightly better yields under lower yield potential conditions (sandy loam soil) or with later (May) plantings. Under lower yield conditions or with later planting dates, higher plant populations generally had little impact or even slightly improved yields. Reductions in lint yield at the higher planting density were generally greater in the Acala variety (Maxxa) than in either non-Acala Upland variety. Delayed irrigations, which produced moderate levels of plant water stress compared with standard irrigation practice often produced slightly higher yields in the non-Acala varieties, but either had no effect or slightly reduced yields in the longer-season Acala variety. Results of these trials will be combined with data from prior planting date and density trials to more thoroughly discuss sensitivity of cotton yield responses to these planting decisions.

Investigating the applications of organophosphates and copper on prune (*Prunus domestica*, L.) orchards in California

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There is evidence that prune growers in Sutter, Tehama, and Tulare Counties in California have a history of using a combination of in-organic copper (Cu) and organophosphates (OP) to treat wintering insects such as peach twig borer, San Jose scale, European red mite, and prune aphids (mealy plum and leaf curl plum aphids). However, copper hydroxide and copper sulfate are not recommended as an effective fungicide or bactericide treatment on prunes. The efficacy of OP may be reduced when Cu is applied with an OP. Furthermore, dormant season applications of OP are a major source of surface water contamination in the Central Valley. The objectives of this study are to (1) investigate the use of OP and Cu during the dormant season on prunes in Sutter, Tehama, and Tulare counties from 1993- 2002, (2) evaluate the ecological risks of applying Cu with OP, (3) recommend alternative pest management practices for prune growers. Pesticide Use Report (PUR) database from the California Department of Pesticide Regulation was used for this investigation. A PUR-GIS application was used to manipulate data from the PUR database about the timing and use intensity of Cu and OP applications on prunes. The analyses results indicated that prune growers who apply Cu use more OP in the dormant season. Since 1993, dormant season applications of OP in all three counties have been declining; however growers that apply Cu during the same application period use more OP than growers that do not use Cu. In 2001, 38%, 81%, and 94% of the prune fields in Tehama, Sutter, and Tulare Counties respectively had reported applications of copper and OP. Since 1993, the percentage of fields applying both Cu and OP has most rapidly declined in Tehama County. Grower education about pest management alternatives is necessary to reduce the environmental impact of these pesticides.

Closing the nitrogen cycle in organic vegetable production systems: Developing budgets to estimate relative nutrient input and uptake

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Nitrogen budgets may help growers manage nutrients in organic vegetable production systems, which rely on the input of N through sources such as compost and cover crops and the incorporation of organic matter from the previous crop. Two important components of developing N budgets for organic vegetable production are: 1. estimates of nitrogen fixation by two commonly-used cover crops in this region; and 2. estimates of loss of nitrate via leaching during the winter and spring. Better estimates of N fixation and NO_3^- leaching will provide organic growers with a more finely-tuned tool to estimate nutrient inputs and outputs and any imbalances between the two.

We compared estimates of N fixation for winter cover crops in this region by two methods, the widely-used difference method and the natural abundance (NA) method. The difference method estimates the contribution as the difference in N content between legume and non-legume crops grown in the same field, while the NA method uses differences in ^{15}N composition of soil and atmospheric N pools to determine the percent of plant N derived from atmospheric fixation (%Ndfa). In 2002-03 we grew two legumes (vetch and bell beans) and two non-legume reference species (oats and mustard) in field and pot experiments to determine %Ndfa by both methods. The choice of non-legume reference plant had an almost two-fold effect on %Ndfa estimates obtained from the difference method, making that method of little use for budgets. In addition, there was no significant difference between ^{15}N composition of sand-grown (fixing all of their N) and field plot (fixing some of their N) legumes. This lack of a difference precludes our use of the NA method to estimate legume fixation in this particular field. However, there was a significant difference between legumes grown in sand and in orchard soil. The orchard soil has no history of legume cover cropping, while the fields are cover cropped annually. This suggests that we can use the NA method to estimate fixation rates for locations without legume cover crop histories.

Fall and spring incorporation of crop and cover crop residue and application of compost occurs when Central Coast soil temperatures are relatively warm. In these conditions, soil microbial communities may mineralize organically-bound N, potentially leading to an accumulation of soil NO_3^- pools. The pools may be susceptible to leaching during episodic winter rains. We are monitoring NO_3^- concentrations in organic vegetable systems by analyzing field soil samples and water samples collected from pan lysimeters. Preliminary data from 2002-03 indicate the potential for NO_3^- leaching. In a field at the CASFS Farm, mean NO_3^- -N concentration in the top 15 cm of the soil was 37 ppm in November 2002 prior to the planting of cover crops and possibly susceptible to leaching. In addition, leachate collected in Dec. 2002 from the pan lysimeters had a mean NO_3^- -N concentration of 23 ppm, showing some NO_3^- loss during the winter's first large rain event. This year we are collecting soil samples every 15 cm to a depth of 90 cm every two weeks to gain finer resolution of NO_3^- concentration through the soil profile over time. We also continue to take samples from the pan lysimeters as they are available.

Seasonal Patterns of Nutrient Uptake and Partitioning as a Function of Crop Load of the 'Hass' Avocado

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For the 'Hass' avocado (*Persea americana* L.) industry of California, optimal rates and times for soil fertilization of nitrogen, phosphorus, potassium have not been adequately determined.

The seasonal pattern of nutrient uptake is a key component of fertilizer management. Matching fertilizer application times and rates with periods of high nutrient demand not only maximizes yield, but also increases nutrient-use efficiency and, thus, reduces the potential for groundwater pollution. The goal of this project was to determine the seasonal pattern of nutrient uptake and partitioning in alternate-bearing 'Hass' avocado trees.

Nutrient uptake and partitioning were determined in two ways: 1) sequential tree harvest, partitioning and nutrient analysis, and 2) ^{15}N labeling. Both tree excavation & ^{15}N data indicate two periods of high nitrogen and potassium uptake occurring in mid/late summer and in the spring before harvest. Little uptake occurred during winter months. Both time of year and fruit status affected ^{15}N recovery in the trees. The percent recovery rates of ^{15}N applied to trees in August and excavated in November were 59 and 35% for the on and off-year trees, respectively.

Most of the ^{15}N recovery in the on-year tree accumulated in the fruit, whereas leaves were the main repositories for ^{15}N in the off-year tree. These results support the hypothesis that N uptake is regulated by tree N demand. On-year trees have a large N requirement and therefore more is taken up to meet that demand. The ^{15}N recovery rates were markedly lower when applied in November compared to August. The cold and wet weather likely contributed to these lower recovery rates in two ways: 1) high rainfall events likely increased nitrogen leaching, and 2) cold weather decreased tree growth which concomitantly reduced tree N demand.

Soil Moisture Sensors and Irrigation Scheduling: 3 Years of Grower Demonstrations in Kern County

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ABSTRACT

Starting Winter 2001 an irrigation scheduling demonstration program was initiated in Kern County by UC Cooperative Extension and the area Resource Conservation District Irrigation Mobile lab to instrument grower's fields with neutron probe access tubes, tensiometers, electrical resistance blocks (Watermarks[®]) and a continuously recording data logger with a visual display that does not require downloading to a computer. Growers were faxed one page weekly irrigation scheduling recommendations also containing a seasonal summary of CIMIS ET estimates, soil moisture and applied water history. Additional fields on the Westside of Kern County were added to this program in 2002 as part of a CalFed Ag Water Use Efficiency project. More grower fields were set up in 2003.

A total of 101 fields covering 8,687 acres belonging to 21 different growers were instrumented over this time period covering 12 different crops, 11 soil textures and 9 different irrigation system types. The frequency of grower reference to field loggers and faxed irrigation schedules ranged from almost nil to very high; with a serious look at the soil moisture data in the weekly faxes and/or field loggers averaging once every 2 to 14 days. Overall grower response was positive, with most stating that the program had made their irrigation more efficient and/or improved crop yield and quality. Often the degree of scheduling responsiveness was limited by ranch logistics and available labor. Many of these fields, primarily low volume systems using expensive water on the Westside, were near optimal or deficit irrigated before entering the program, and, in some cases, soil moisture deficits recorded with this demonstration effort called for **increasing** applied water. The estimated water use efficiency (WUE) using crop ET calculated from local CIMIS weather station potential evapotranspiration (ET_o) and appropriate crop coefficient values (K_c) divided by the applied water was very high, averaging 96% for 2002 (the most complete year of data). This estimate was almost identical to the 97% WUE determined by field measurement of soil water depletion with the neutron probe.

However, every grower has said that the most helpful part of the program has been the "human element" – direct interaction with the consultant through field/lunch meetings and phone calls. Despite the simplicity of the logger used in this study, most growers needed repeated visits to interpret soil moisture trends recorded by field data loggers and to explain the calculations used in faxed irrigation schedules. Once they understood the information provided on the logger display most growers/foremen checked field soil moisture trends on a regular basis. But fewer than half would repair/replace this equipment on their own if it stopped working.

Hydraulic Conductivity of Soils Irrigated with Recycled Saline-Sodic Drainage Water

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Irrigation with saline-sodic water may adversely affect soil physical properties, in turn, reducing infiltration and hydraulic conductivity. Knowing the effect of the soil electrical conductivity (EC), and sodium adsorption ratio (SAR), on soil water retention at various depths will lead to better management practices for soils irrigated with recycled drainage water.

Current research conducted in California, e.g. in the San Joaquin Valley, is addressing the need to reduce irrigation volumes and drainage by encouraging crop utilization of shallow groundwater while still maximizing yields in saline soils. Current infiltration models do not contain parameters, which account for variability in management practices. A study that provides expected infiltration rates and other hydraulic parameters for soils irrigated with saline waters such as agricultural drainage water would provide valuable information to refine these models and contribute to future research on alternative management practices for these systems. Demands for fresh water are increasing steadily in arid regions, thus it is likely that saline irrigation water sources will be used to a greater extent.

The objectives of this study were to determine the hydraulic conductivity and soil water characteristics of soils irrigated with recycled saline-sodic drainage water for their eventual use of these parameters in irrigation management models.

Soils from Red Rock Ranch in Five Points, CA on the west side San Joaquin Valley were collected in 30 cm (1 ft) increments to a depth of 120 cm using a powered drilling machine and hand augers. Soil was taken from a fresh-water irrigated area (Stage 1) and from an area that has been irrigated with recycled drainage water for seven years (Stage 4). Irrigation water salinity in Stage 1 has been < 1 dS/m and in Stage 4 it has averaged about 13 dS/m. Texture, EC, and SAR were determined for all sampling locations and for all soil depths. Five centimeter core samples were also taken and utilized for saturated hydraulic conductivity, water retention, and volumetric water content measurements. The constant head soil core method (Reynolds and Elrick, 2002) was used to determine steady state saturated hydraulic conductivities. A pressure plate chamber was used to collect water retention data (de Jong, 1993).

Soils textures were mainly clay loams. Soil salinity (EC_e) was less than 2.4 dS/m in Stage 1 to greater than 50 dS/m in Stage 4 and SAR was 8.6 and 85.4 for Stages 1 and 4, respectively. The saturated hydraulic conductivity varies greatly with K_s values ranging from 1.02 X 10⁻³ to 9.67 X 10⁻⁶ cm per second. Data collected with the pressure plate apparatus will be used to predict the hydraulic parameters for the empirical equations for soil water retention curves, as described by van Genuchten (1980). For this purpose, we intend to use the non-linear least squares optimization program, RETC, available from the USDA Soil Salinity Laboratory in Riverside, CA.

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Weed control in conservation tillage using subsurface drip irrigation

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Project Summary: Subsurface drip irrigation conserves water and decreases weed populations compared to furrow or sprinkler irrigation. Conservation tillage systems reduce equipment and fuel costs, in addition to conserving soil and reducing dust. Conservation tillage relies heavily, however, on herbicides for weed control. In dry summer regions, lack of moisture near the soil surface prevents annual weed germination. If subsurface drip can be managed to prevent annual weed germination, the need for herbicides would be reduced or eliminated, and would allow the implementation of conservation tillage without an increased reliance on herbicides.

Design: A two-year field experiment will be conducted at the University of California, Davis. The treatments will compare subsurface drip and furrow irrigation under conventional and conservation tillage. Prior to planting, subsurface drip tape will be installed. Tomatoes will be transplanted using a no-till transplanter; fertilization and other practices will be similar to that of growers. After transplanting, furrow and subsurface irrigation treatments will be imposed. A split-split-block design with four replications will be used, with main plot being tillage type, sub-plots irrigation type and sub-sub plots being either standard herbicide treatments or no herbicides. Each irrigation/tillage combination will be a minimum of four beds wide and the length of the field. Hence, the treatments will be (also see Figure 1 of treatment layout):

1. Conventional tillage, subsurface drip irrigation with standard herbicide application.
2. Conventional tillage, subsurface drip irrigation with no herbicide.
3. Conventional tillage, furrow irrigation with standard herbicide application.
4. Conventional tillage, furrow irrigation with no herbicide.
5. Conservation tillage, subsurface drip irrigation with standard herbicide application.
6. Conservation tillage, subsurface drip irrigation with no herbicide.
7. Conservation tillage, furrow irrigation with standard herbicide application.
8. Conservation tillage, furrow irrigation with no herbicide.

Standard herbicide treatments in tomatoes will consist of a post-transplant, banded application of rimsulfuron, made at approximately 14 days after transplanting. Comparisons of tillage type will include two intercrop tillage intensities, conventional (minimum, bed disking) tillage and conservation tillage (no-till). A Wilcox Performer implement will be used in the minimum tillage system. No intercrop tillage will be used in the no-till system. Hand weeding will be used in all plots to remove any emerged weeds at approximately 30 to 40 days after transplanting. Single-wheel (one wheel wide rather than two) harvest trailers will be used so as to maintain harvest traffic to the furrows so as to permit dedicated tractor traffic areas, or “zone production” (Carter, 1996).

Improving weed management, while reducing herbicide use is the primary objective of this study. Thus, weed density, cover, species composition, and distribution across the bed will be measured in each plot at 7, 14, 28, and 42 days after transplanting, and prior to any cultivation or hand weeding. By measuring weed distribution across the bed (assuming weed emergence in the subsurface drip irrigated plots), it may be possible to use very narrow herbicide bands. Hand weeding time will be recorded for each plot in order to assess economic returns.

Furrow irrigation will be applied as needed in amounts that replenish estimated evapotranspiration (ET) losses. Drip irrigations will be applied daily or every other day based on management guidelines recently developed by May and Hanson (Hanson, pers. comm.). End-of-season irrigation cutoff for both systems will be done in accordance with previously developed best irrigation management practices for processing tomatoes (Personal communication, D. May). Applied irrigation water volumes will be monitored using in-line flow meters. Soil water content will be measured in the surface 10 cm at four locations across the bed using a portable time domain reflectometry (TDR) instrument weekly during the first two months following transplanting to assess surface wetting. If surface moisture is excessive, weed germination would be expected to increase.

Plots will be machine harvested for determination of yields and subsamples taken for quality (soluble solid content, color, and disease). Treatment costs and net returns will also be calculated.

In 2004, the study will also be conducted at the West Side REC or with a cooperating grower in that area. Based on the first years results, additional treatments may be added to further refine weed management recommendations.

Initial Results:

In the first season of the experiment the drip system showed significantly less weed growth and populations than the furrow system. Both systems had similar tomato plant biomass, and yield. The furrow yield had higher percentages of red fruit while the drip system was greener. We hypothesize that this was due to the late planting date and a learning curve in using the drip system to properly irrigate the plants. We expect that next year the differences in red fruit as a percentage of total will be minimal.

Biomass production and nutritional value of salt-tolerant forages irrigated with saline-sodic drainage water: field and greenhouse studies

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In recent years, the management of saline drainage water has presented major challenges to agriculture on the Westside San Joaquin Valley (SJV). Subsurface drainage systems are considered essential to control soil salinity and boron, and to lower perched water tables in impacted areas, but their use is limited due to wildlife hazards associated with selenium in the drainage water. The re-use of drainage water for the irrigation of salt tolerant plants is a promising, on-farm, practice to reduce drainage water volumes and thereby facilitate their disposal. Drainage water collection and re-use for irrigation could also be practiced within small districts. Selection and evaluation of halophytes and salt-tolerant forages that can grow under irrigation with the saline-sodic drainage water is currently underway. The selection of forages is based on their tolerance to soil salinity, boron, and poorly-aerated soils with tough surface crusts; along with climatic adaptability and their nutritional value for animal feeds.

Several salt tolerant forages were evaluated under irrigation with synthetic SJV drainage water at two salinity levels (EC = 15 and 25 dS/m) in a sand tank study at the USDA George E. Brown Salinity lab in Riverside (USSL). Some of the same forages are also being evaluated in the field at Red Rock Ranch in Five Points, CA, where they are irrigated with saline drainage water of 8 to 13 dS/m and soil salinity (ECe) is much higher than the EC of the irrigation water due to the fine-textured soil and a lower leaching fraction. The poor physical condition of this cracking clay soil and the hotter, drier field conditions could result in forage performance that is different than that observed under the more hospitable conditions of the sand tank study. Although the field evaluations of forages at RRR are valuable, there is considerable variation in soil salinity from one stand to another and due to the large size of the fields, and long time for establishment of perennial forages in these soils, it would be difficult to establish replicated field plots.

A complementary greenhouse study was therefore initiated to evaluate the more promising, salt-tolerant forages when grown in field soil collected from RRR, but under conditions of similar soil salinities. Five salt-tolerant forages will be tested in the greenhouse study: 'Jose' Tall Wheatgrass (*Agropyron elongatum* var. 'Jose'), Creeping Wild Rye (*Leymus triticoides* var. 'Rio'), salt tolerant alfalfa (*Medicago sativum* var. 'Salado'), Paspalum (*Paspalum vaginatum*), and Bermuda grass (*Cynodon dactylum* var. 'Giant'). Cumulative biomass and forage quality (organic and inorganic) will be measured and compared to results from the sand tank study at USSL and sampling of the large stands at RRR. Not all forage species were present, however, in each of these three locations.

For the greenhouse study, the plants were germinated using a greenhouse soil mix (peat, perlite, and vermiculite) and then transplanted into pots of 12 in. diameter x 14 in. depth. The pots were filled with a soil mixture consisting of 60% clay soil from RRR and 40% sand. The treatments will consist of three irrigation water qualities: tap water (~0.5 dS/m), low saline (8 – 10 dS/m) and high saline (18 – 20 dS/m) water. Concentrated drainage water (45 dS/m) collected from the solar concentrator at RRR water was diluted to make the low and high saline waters. Data are not yet available for this greenhouse study.

In the field at RRR, productivity was measured by a rotational cutting system in which the entire forage plot was initially cut to 6 in. and then cuts were taken in 1 m² sub-plots when the stand reached 12 in., 18 in., and its

final height prior to heading, or flowering for the alfalfa. This allowed measurement of standing biomass rather than re-growth from the last cut. The data that follow are for the first sampling period (fall to early winter). Creeping Wild Rye growing in soil with $E_{Ce} = 12.9 \text{ dS/m}$ produced the highest cumulative biomass (13,000 kg DM/ha/yr) over a one-year period (9/30/02 to 9/29/03) under irrigation with drainage water averaging 12.5 dS/m. Jose Tall Wheatgrass growing in a more saline field ($E_{Ce} = 20 \text{ dS/m}$), produced only about 8,800 kg DM/ha over the same time period. Although the biomass production of the Tall Wheatgrass was low in this highly saline field, its forage quality was higher than the CWR. For the better of two stands of tall wheatgrass, metabolizable energy (ME) was 9.34 MJ/kg, crude protein (CP) was 18.5%, neutral detergent fiber (NDF) was 52.2%, and ash was 9.6%. For ME and CP, a higher number indicates better forage quality; whereas with NDF and ash, lower percentages are desirable. Creeping wildrye had lower, but acceptable, quality as compared to tall wheatgrass with an average ME = 8.72 MJ/kg, CP = 19.4%, NDF = 56.3% and ash = 8.6% for the two stands. In comparison, 'Salado' alfalfa which was irrigated with fresh water in 2003, but was growing in mildly saline soil ($E_{Ce} = 4.5 \text{ dS/m}$), produced about 16,000 kg DM/ha and had the highest forage quality with an average ME of 9.67 MJ/kg, CP = 26.5%, NDF = 31.0%, and ash = 10.3%. The active growing period of alfalfa was from the beginning of April to the end of September, and most of the biomass production came from that period of time. In comparison, the tall wheatgrass and creeping wildrye which are cool season grasses have longer growing seasons (February to November), but their growth does slow significantly in the summer.

For inorganic forage quality (ion composition), nitrate levels for all the forage samples was below 200 ppm $\text{NO}_3\text{-N}$ which is a safe range for feeding all animals. Selenium levels reached 6-8 ppm (mg/kg DW) for the Jose Tall Wheatgrass that was growing in the most saline field. Sulfur content in the forage tissue average 0.4 to 0.6% which is above the maximum tolerable concentration (MTC) of 0.4%. These sulfur levels were not considered to be dangerous, but monitoring would be advisable.

Thus far for Tall Wheatgrass, the field data compare favorably with the results of the sand tank study in which Tall Wheatgrass consistently had amongst the highest organic forage quality. Amongst the forages compared, Tall Wheatgrass did not have the highest biomass accumulation in the field as it did in the sand tank study, but this was likely to be a result of the soil salinity being close to 20 dS/m in the field.

Results of the greenhouse study should provide better relative rankings of productivity and quality for these candidate forages under conditions similar to the field.

Investigating use of diazinon and chlorpyrifos and alternative insecticide management in San Joaquin Valley

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Diazinon and chlorpyrifos are commonly used dormant season insecticides for control of wintering insects in orchards. Residues of these two toxic pesticides found in the river systems of the watershed pose a severe threat to aquatic species. Due to their toxicity diazinon and chlorpyrifos were listed in the State Water Control Board's TMDL (Total Maximum Daily Load) assessment. This study investigates the use of diazinon and chlorpyrifos in San Joaquin Valley and identifies available insect management alternatives using the Pesticide Use Report (PUR) database. Preliminary results show decreasing use over the last five dormant seasons with diazinon use decreasing much faster than chlorpyrifos. The study investigates varying pesticide practices for insect management in the watershed on different commodities. Identification of effective alternative practices that reduce environmental impacts provides a foundation for changes in the conventional methods of pest management and assists the TMDL assessment for diazinon and chlorpyrifos.

Weed survival in the mulch

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Abstract

Survival of four major weeds, Little Mallow (*Malva parviflora L.*), California Burclover (*Medicago polymorpha L.*), Bermudagrass (*Cynodon dactylon (L.) Pers.*) and Yellow Nutsedge (*Cyperus esculentus L.*), were tested in static piles of freshly ground yard waste mulch and in aged yard waste mulch. Weed propagules were buried at 4 different depths and excavated at 9 different times. The greater depths caused higher temperatures. Higher temperature increased weed mortality. At least 53 °C for 4 days were required to destroy Bermudagrass rhizomes and Yellow Nutsedge nutlets. The annual weed seed, Little Mallow seed were destroyed in yard waste mulch heated 40 to 71 °C after 28 days, however, 5 % of California Burclover seed survived at these temperatures for 56 days.

Assessing dormant organophosphate and pyrethroid sprays in almond fields in California

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California almond growers have commonly used organophosphate pesticides (OPs) in the dormant season to control several key pests. However, dormant OP and pyrethroid uses have raised concerns in California due to their detection in surface water. Concentrations of diazinon in the Sacramento and San Joaquin River watersheds have been detected at levels high enough to be toxic to some aquatic organisms, thus threatening the health of downstream ecosystems. Recent studies of pyrethroid toxicity have also raised concerns due to their potential for off-site movement. This study assesses dormant OP and pyrethroid use and provides suggestions on alternatives to reduce the environmental impact of these uses. The Pesticide Use Report (PUR) database is the basic source of information for the analysis. This study also incorporates information from the almond industry and regulatory agencies such as US EPA and California Department of Pesticide Regulation. Preliminary results showed a dramatic decline in use of OPs for the dormant spray period from 1992-2002 and increases in use of pyrethroids from 1992-1999. Since 1999 pyrethroid use declined as well. The study will discuss the spatial distributions of the co-occurrence of OP and pyrethroid use and high residue detections in the watershed. The results can be used in outreach materials to help almond growers reduce the use of dormant OPs and pyrethroids on their farms.

Does tomato have a higher tolerance to purple nutsedge under elevated CO₂?

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Integrated weed management involves the use of multiple tactics that favor crop growth over weeds. The growth of C₃ crops is often enhanced by CO₂ enrichment. This phenomenon could be of interest for C₃ crops that are often poor competitors with C₄ weeds. An increase in the competitive ability of C₃ crops by CO₂ enrichment may result in a decrease in the need for postemergence weed control. A field study was conducted in Fresno, CA in 2002 to test the effect of the density of a C₄ weed, purple nutsedge (*Cyperus rotundus*) on the growth and yield of a C₃ crop, tomato (*Lycopersicon esculentum*). The plants were grown in pots in the field under ambient CO₂ conditions (370 ppm) and at elevated CO₂ levels ranging from 1.5 to 2 times ambient concentrations, with densities of 0, 1, 2, 3 and 4 nutsedge plants/pot. Tomato plants were able to withstand higher densities of nutsedge under elevated than under ambient CO₂ conditions. Tomato fruit yield was higher under elevated than under ambient CO₂ under all weed densities. CO₂ elevation had no effect on nutsedge biomass and tuber production.

Determining N and C budgets, and agronomic potential of alternative cover crop mixtures and management in a California conservation tillage, tomato-corn system

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International Agricultural Development Graduate Group

High crop production levels in California have been sustained by the use of synthetic fertilizers, pesticides, irrigation water, and intensive tillage operations. These tillage operations keep production costs high, generate significant amounts of dust, increase wind and water erosion, and reduce soil organic matter contents. The resulting loss in soil C offsets gains in crop C sequestration and contributes to rising atmospheric CO₂ levels. Recent efforts in conservation tillage (CT) research have been aimed at reducing tillage costs, protecting air, water, and soil quality, and increasing soil fertility and the rate and duration of soil C storage. In this study, we are examining and comparing the compatibility of novel inter-cover crop mixtures with a low-input, irrigated, CT tomato-corn rotation. Preliminary studies have demonstrated the agronomic potential of a late-summer inter-cover crop mixture of sorghum-sudan (SS), cowpea (CP), and lablab (LL), and led to the hypothesis that adding this component to CT systems will enhance soil quality and fertility, increase C sequestration, aid in weed suppression, increase water quality and water use efficiency, and reduce runoff of water and nutrients. The SS is an aggressive N scavenger and is expected to tie up and cycle forward free N leftover from tomato production, forcing the CP and LL to meet more of their N needs through N-fixation. Continuous cropping/cover cropping produces more annual biomass to be cycled back into the system, providing a greater potential for higher soil C storage.

Our cover crop study consists of three replications of five treatments: 1) Lana vetch seeded in mid-late November, 2) SS, CP, LL seeded in late August, minimal sprinkler irrigation, 3) SS, CP, LL, lana vetch seeded in late August, minimal sprinkler irrigation, 4) SS, CP, LL seeded in late August, minimal sprinkler irrigation, and overseeding of lana vetch in mid-late November, 5) Fallow (no cover crop between the tomato and corn crops). In spring 2004, corn will be seeded directly into the cover crop residues.

We will be evaluating the agronomic performance of the different treatments and their effects on whole system C and N cycling. Data will include cover-crop stand establishment, soil and plant C and N pools, weed density and seed production, and corn growth and yield. To measure treatment effects on N dynamics, we are labeling the cover crops with ¹⁵N to more precisely monitor both N fixation and the amount of cover crop-derived N used by corn the following season. Labeling will also help us determine which cover crop treatments are best synchronized to meet corn N demands. We will use soil physical fractionation techniques to detect changes in N pools and its isotopic signature, and C pools over the 1.5 years of this study. We will also measure fluxes of CO₂ and N₂O. The results on C and N cycling and fluxes will be integrated to assess the potential of CT and cover crops in the mitigation of greenhouse gas emissions.

The Influence of Planting Dates on Forage Quality of Oats

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ABSTRACT

Oat (*A. sativa* L.), a small grain cereal, is grown in California primarily as hay and grain for livestock and horses. The quality of oat hay directly affects its value to the consumer and ultimately the profit realized by the grower. Two factors used as a measure of hay quality are intake and digestibility. Intake and digestibility are directly linked with the type and amount of fiber present in the hay. The type and amount of fiber in oat hay is influenced by: the temperature and length of photoperiod the plant experiences during the growing period; genetic composition; and management practices.

Previous research on the quality of oat hay has, in general, focused upon single factors such as environment, plant growth requirements or agricultural management practices. This study was designed to evaluate the effects of multiple factors (varieties, planting dates, growth stage at harvest) upon the quality of oat hay. Another reason for this study is the lack of recent research in this area.

This research addressed oat hay quality by measuring the variability of fiber content in oat plants exposed to different temperatures and photoperiods. Four oat varieties (Bates 89, Ogle, Pert, and Swan) were selected to be grown for a two-year study. The plants were harvested in the boot stage, dried, and then analyzed for Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) values. The values for year one and year two were compared using SAS (ANOVA and Duncan's Multiple Range Test). Statistically, there were significant differences found between varieties, planting dates, and between years 1 and 2. However, when NDF and ADF values were translated into Relative Feed Values, these differences were found to be slight and would probably have little or no effect upon the economic value of the oat hay.

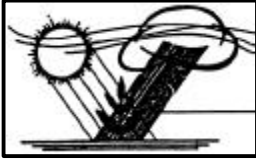
Evaluating percolate water quality following land application of winery processing wastewater

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Land application of food processing wastewater is a common disposal technique because it allows for the beneficial reuse of nutrients, organic matter, and water. However, excessive application of wastewater can lead to subsurface and ground water degradation, because these wastewaters typically contain elevated levels of organic carbon, total suspended solids, nutrients, and minerals. Most food processing wastewater application studies emphasize on the environmental impacts to groundwater. Little information is available on the quality of subsurface water as it migrates through the soil. The objective of this study was to evaluate the effects of winery processing wastewater application on the quality of percolated subsurface waters at a research site located in Fresno, CA. Percolate waters were sampled with suction lysimeters installed at 2- and 4- foot depths. Hydraulic and organic loading rates were monitored for each wastewater application. The site was characterized by sandy soils (60-85%) with elevated nitrogen levels. The quality of the wastewaters varied greatly over time with biochemical oxygen demand (BOD) ranging from about 800 to 17,000 mg L⁻¹. High variations were also observed for nitrogen, organic carbon and solids levels. The pH of the applied wastewaters was relatively constant and quite acidic (3.2-3.9). Hydraulic and organic loading rates varied greatly among applications and were dependent on wastewater quality, application duration, and size of discharge area. Elevated levels of NO₃-N, Mn, Fe, total dissolved solids (TDS), total organic carbon, and alkalinity were found in the percolate waters. The average percent TDS removed were usually above 40% for all sections; greater removal was observed at 4 feet. Percent total kjedhal nitrogen removals were also very high, ranging from 67% to 99%.

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**CALIFORNIA CHAPTER – AMERICAN SOCIETY OF AGRONOMY
2004 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 Council members.

- a. _____
- b. _____

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

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
