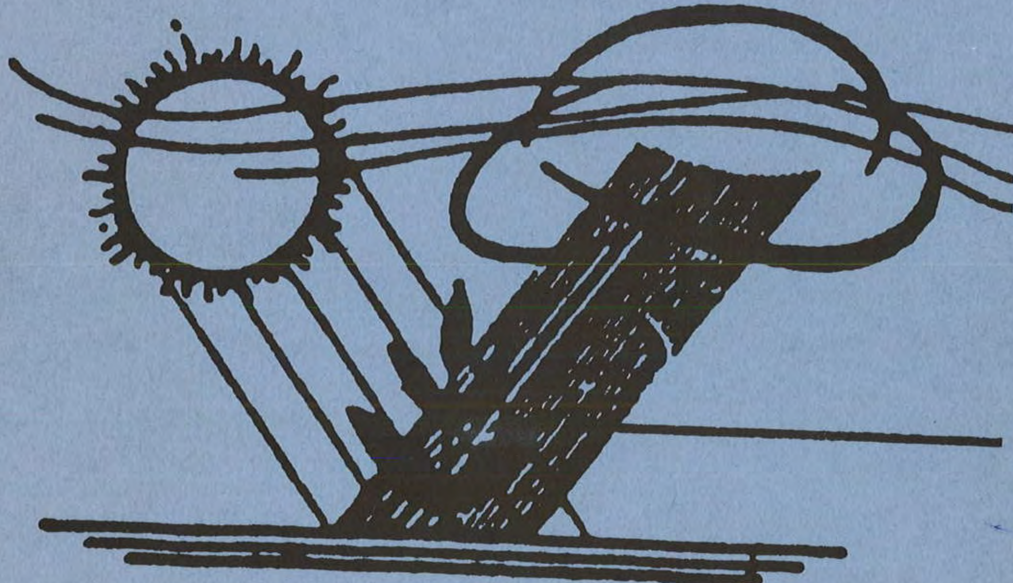
PROCEEDINGS
2001
CALIFORNIA PLANT AND SOIL CONFERENCE

GLOBALIZATION & CALIFORNIA AGRICULTURE
HOW WILL WE COMPETE?



CALIFORNIA CHAPTER OF AMERICAN SOCIETY OF AGRONOMY
AND
CALIFORNIA PLANT HEALTH ASSOCIATION

FEBRUARY 7 – 8, 2001

Radisson Hotel
2233 Ventura Street
Fresno, CA 93721

WEDNESDAY, FEBRUARY 7, 2001

GENERAL SESSION

Session Chair: **Bob Dixon**, Dixon Agronomics

10:00 Introduction – Session Chair

10:10 **The Next WTO Round: What Does it Mean for California Agriculture?** – Colin Carter, Agricultural and Resource Economics, UC Davis

10:40 **China: Threat or Opportunity? A Grower's Perspective** – Jerry Barton, Escalon, California

11:10 **California Farmers – The Endangered Species** – A.G. Kawamura, Orange County Produce, LLC, Irvine, California

11:40 Discussion

12:00 **UNIVERSITY – INDUSTRY LUNCHEON: INTERNET TECHNOLOGY AND ITS IMPACT ON AGRICULTURE** – Bill Evans, Rubicon Consulting

CONCURRENT SESSIONS

I. IRRIGATION & DRAINAGE MANAGEMENT

Session Chairs: **Dave Zoldoske**, CIT, CSU Fresno and **Sharon Benes**, Dept of Plant Science, CSU Fresno

1:30 Introduction – Session Chairs

1:40 **Wateright: A Web-Based Irrigation Tool** – David Zoldoske and Pete Canesso, Center for Irrigation Technology, CSU Fresno

2:00 **Chemigation Uniformity in Drip Irrigated Trees and Vines** – Larry Schwankel, Land Air & Water Resources, UC Davis

2:20 **Economic Comparison of Drip, Sprinkle, and Gated Pipe Irrigation Systems for Annual Crops** – Larry Chrisco, Harris Farms, Coalinga California

2:40 Discussion

3:00 BREAK

3:20 **Options for Managing Salinity in Western San Joaquin Valley** – John Letey, Center for Water Resources, UC Riverside

3:40 **Irrigation of Halophytes & Landscape Plants with Saline Wastewaters** – Edward Glenn, Environmental Research Lab, University of Arizona, Tucson

4:00 **Sustainable Use of Saline-Sodic Irrigation Waters** – James D. Oster, Dept. of Soil and Environmental Sciences, UC Riverside

4:20 Discussion

4:30 ADJOURN

II. DAIRY WASTE MANAGEMENT

Session Chairs: **Marsha Campbell-Matthews**, UCCE Stanislaus County and **Carol Frate**, UCCE Tulare County

1:30 Introduction: Session Chairs

1:40 **Overview of Dairy Lagoon Water Nutrient Management** – Carol Frate, UCCE Tulare

2:00 **Dairy Lagoon Water Composition, Sampling and Field Analysis** – Marsha Campbell-Matthews, UCCE Stanislaus County

2:20 **Engineering Lagoon Water Application Systems** – Eric Swenson, Creative Mechanical Solutions, Modesto, California

2:40 Discussion

3:00 BREAK

3:20 **Dairy Nutrient Management Effects on Groundwater Quality** – Thomas Harter, Land Air & Water Resources, UC Davis

3:40 **NRCS Assistance in Preparing and Implementing Manure Management Plans** – Dan Johnson, NRCS

4:00 **Biology and Engineering of Animal Wastewater Lagoons** – Ruihong Zhang, Biological and Agricultural Engineering, UC Davis and Marsha Campbell-Matthews, UCCE Stanislaus County

4:20 Discussion

4:30 ADJOURN

THURSDAY, FEBRUARY 8, 2001

CONCURRENT SESSIONS

III. ADVANCES IN NUTRIENT MANAGEMENT

Session Chairs: **Jerome Pier**, J.R. Simplot Co. and **Casey Walsh Cady**, CDFA/FREP

8:30 Introduction – Session Chairs

8:40 **Fertilizer Use Efficiency and Influence of Rootstocks on Uptake and Accumulation of N Wine Grapes Grown in the Coastal Valleys** – Larry Williams, Viticulture & Enology, UCD

9:00 **Assessment of Nutrient Uptake Storage and Root Growth in Alternate Bearing Pistachio Trees** – Rich Rosecrance, School of Agriculture, CSU Chico

9:20 **The Response of Vegetables to Controlled Rebase of Nitrogen Fertilizers in the Desert Southwest** – Charles Sanchez, University of Arizona, Yuma Valley Agricultural Center

9:40 Discussion
10:00 BREAK

10:20 **The Organic Transition Phenomenon: Myth or Reality?** – R. Ford Denison, Agronomy & Range Science, UC Davis

10:40 **Ammonia Emissions and Fertilizer Application Practices in California's Central Valley** – Charles Krauter, Dept. of Plant Science, CSU Fresno

11:00 **Ammonia Emission Modeling for California** Chris Potter, NASA, Ames Space Flight Center

11:20 Discussion

IV. PEST MANAGEMENT

Session Chairs: **Dan Munk**, UCCE Fresno County and **Lee Bucknell**, UCCE Modesto County

8:30 Introduction – Session Chairs

8:40 **Successes in Yellow-Starthistle Control** – Joe DiTomaso, Vegetable Crops, UC Davis

9:00 **Managing Lygus in the Landscape** – Dr. Pete Goodell, Area IPM Specialist, UC Kearney Agricultural Center

9:20 **Resistance Monitoring and Applications for Arthropod Management** – Beth Grafton-Cardwell, Area IPM Specialist, UC Kearney Agricultural Center

9:40 Discussion
10:00 BREAK

10:20 **Biotechnology Issues and the Glassy Winged Sharpshooter** – Martina McGloughlin, Life Sciences Informatics Program, UC Davis

10:40 **Developing a Robotic System for Wads in Cotton** – David Slaughter, Biological & Mechanical Engineering, UC Davis

11:20 Discussion

12:00 **CONFERENCE LUNCHEON**

V. PRECISION AGRICULTURE & ENVIRONMENTAL MONITORING

Session Chairs: **Ron Brase**, Cal Ag Quest, and **Stephen Kaffka**, Agronomy & Range Science, UC Davis

1:30 Introduction – Session Chairs

1:40 **Addressing Susatinable Agriculture at a Landscape Scale** – Adina Merenlender, Environmental Science and Pest Management, UC Berkeley

2:00 **From Yield Maps to Management Zones** – Stuart Pettygrove, Land Air & Water Resources, UC Davis

2:20 **Soil Salinity Mapping in the Imperial Valley** – Steve Burch, IID

2:40 **Commercially Available Services and Products for Precision Farming** – Karol Aure, Precision Farming Enterprise, Davis

3:00 Discussion

3:20 ADJOURN

VI. CARBON SEQUESTRATION AND CARBON CREDIT ISSUES IN CALIFORNIA

Session Chairs: **William Horwath**, Land Air & Water Resources, UC Davis, and **Dan Hostetler**, CSU Pomona

1:30 Introduction – Session Chairs

1:40 **Use of Herbicides in No-Till Systems to Promote Soil C Sequestration** – Bruno Alesii, Monsanto

2:00 **Changes in Soil Biology as a Result of Soil C Sequestration Management** – Kate Scow, Land Air & Water Resources, UC Davis

2:20 **Management Strategies to Promote Soil C Sequestration** – Jeff Mitchell, Vegetable Crops, UC Davis

2:40 **Economics Associated with Soil C Sequestration Management** – David Zilberman, Agriculture and Resource Economics, UC Berkeley

3:00 Discussion

3:20 ADJOURN

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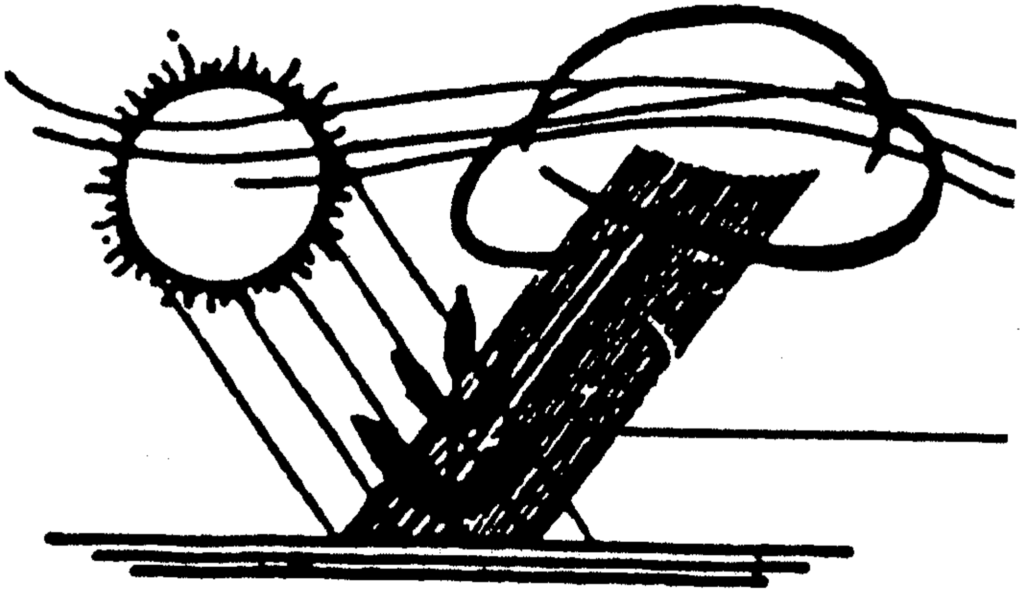

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Claude Phene
A. E. (Al) Ludwick

2001 Cal Qualset
James D. Rhoades
Carl Spiva

2001 Honorees of the California Chapter of the American Society of Agronomy

Cal Qualset

James D. Rhoades

Carl Spiva

Calvin(Cal) O. Qualset

Cal was born and raised on a grain farm in Nebraska. He attended the University of Nebraska where he maintained his interest in agriculture receiving a B.S. Degree in Agriculture. He came to the University of California, Davis where he obtained a M.S. Degree in Agronomy and a PhD in Genetics. After a short academic career at the University of Tennesee he returned to California as a Professor of Agronomy in the Department of Agronomy and Range Science.

Cal has had a major influence on the successful development of the winter cereal industry in California. Cal is trained in quantitative genetics and has used his training in selecting traits that would enhance the adaptation of winter cereals introduced to California. He devised more efficient breeding systems and studied the genetic control of important genetic traits such as plant height, photoperiodism and vernalization requirement, leaf size, leaf angle, grain protein quality and nitrate assimilation. He also uncovered male sterility in wheat, a trait necessary to manipulate hybrid varieties. From his research arose genetic stocks with and without vernalization, horizontal and erect leaves, low and high tillering and normal and branched rachis.

Cal used his knowledge of genetics to incorporate selected traits into breeding methods and continued to conduct breeding and selection programs with wheat, durum wheat, oats and triticale. He cooperated with others in the introduction of germplasm, including the CIMMYT program in Mexico. The successful adaptation of these materials resulted in release of a number of successful varieties grown by California growers. At one time 85% of the varieties produced in the state came from Cal's breeding effort. Wheat varieties released included Yolo, Yecora Rojo, Phoenix, Tadinia(*Septoria* resistant) and the first triticale in the US, Siskiyou. He also released a short stature oat called Pert.

Cal has successfully combined genetic research with a germplasm development program. He has released a number of varieties and trained an exceptional group of graduate students now well recognized as leaders in the field of plant genetics. During this very active program he has published over 185 papers in highly regarded journals and books and established a nationally and internationally reputation as a leader in cereal genetics. Recently, after retiring from the University and appointed Professor Emeritus, Cal has turned his attention to the critical issue of conservation of genetic resources. He recognized the essential effort of conserving sources of genetic variability and through major effort on his part established the California Genetic Resources Conservation program which he serves as Director. The role of this organization is to identify genetic resources that may be lost and provide financial assistance in preserving this material for later use. With the dramatic advances in the application of molecular genetics to germplasm manipulation, this conservation effort is even more critical.

Cal has contributed to his profession in numerous ways. He served two tenures as Chair of the Department of Agronomy & Range Science. He served as Associate Dean of Plant Science in the College and was Chair of the Genetics Graduate Group. He also served as Acting Director of California Crop Improvement Association and has served on the Board of Director of that organization.

Cal has an exceptional record of professional accomplishments. He has served as editor of Crop Science, and is on the editorial board of Plant Breeding, California Agriculture, Fields Crop Research in recognition of his expertise in genetics and breeding. He was elected Fellow of American Society of Agronomy(ASA), of Crop Science Society of America(CSSA) and of American Association for Advancement of Science(AAAS) , highly prestigious awards. He was elected President of ASA and of CSSA recognizing his exceptional service to those professional Societies. Cal has served numerous national and international groups as a consultant or as a committee member. These include FAO, IITA, INTA, CIMMYT, ICARDA and other international organizations focused on improving agriculture production.He has also served national programs such as USDA, CSRS, NRC, USAID and other agencies addressing agricultural projects in the US.

Cal"s exceptional career has contributed greatly to California agriculture. He has been active in improving genetic resources with a focus on enhancing the productivity of California cereal growers. He has accomplished this while extending knowledge and promoting the role agriculture in California plays at the national and international level. Calvin O. Qualset is highly deserving of this award from the California Chapter of ASA.

James D. Rhoades

James D. Rhoades is nominated as a 2001 Honoree of the California Chapter of the American Society of Agronomy because of his extensive and sustained scientific leadership in developing original and creative concepts, together with practical approaches and technology, to assess and control salinity in irrigated lands and associated water resources.

For three decades, Dr. Rhoades has conducted research on the salinity problems plaguing the irrigated lands of California and the Southwestern United States, as well those deleteriously impacting crop production, soil and water conservation, and environmental quality in the remainder of the irrigated land of the world. Although irrigated agriculture only constitutes about 15 percent of agricultural land in the U.S. and world, it accounts for at least 30-35 percent of all the food and fiber produced and is the primary source of vegetable and fruit production. The importance of irrigated agriculture is expected to increase dramatically in the next 20-40 years, as the world population expands markedly. The sustainability of irrigated agriculture is threatened by the associated processes of soil salinization, water logging and water pollution. Dr. Rhoades has made numerous contributions to help deal with these problems in California, nationally and internationally. These includes the development, in California, of the procedures used to judge the suitability of salt-affected waters for irrigation, as well as the development of concepts and management strategies for drainage water reuse and recycling that are now being used worldwide to increase available water supplies and to reduce the pollution of water resources resulting from irrigation.

Dr. Rhoades was involved in the development of the automated/mobilized soil salinity assessment technology that for the first time in history makes it practical to inventory and monitor salinity in irrigated fields and lands and to identify the diffuse sources of salt-loading to ground waters. This technology identifies the causes of soil salinization patterns observed in such areas, and evaluation of the effectiveness and adequacy of the irrigation and drainage systems and their operation. Dr. Rhoades' expertise is sought by major national and international agencies because of his scientific competency, wide experience, and abilities to diagnose problems and find practical solutions for them. He is generally recognized as the leading national, and international, expert on salinity.

Jim Rhoades has been exceedingly successful in transferring and having his technology accepted by action agencies and agricultural-user groups. A technical bulletin, written by Dr. Rhoades for FAO-UN describes these water reuse concepts, computer model, and water quality guidelines. This innovative technology package is now being incorporated into a national plan being implemented in Egypt for drainage water reuse. These concepts also form the basis for a multi-agency plan in the U.S. that is being used to mitigate water quality problems associated with drainage disposal in San Joaquin Valley of California. Dr. Rhoades' novel, cyclic reuse concepts have generated widespread research around the world in the past ten years and is unanimously, supported by numerous publications/results of peers, even though his concepts originally contradicted, conventional, prevalent philosophies for reuse and water quality protection.

Adequate inventories of the extent and magnitude of soil salinity were lacking in the U. S. and abroad because no suitable methodology existed to measure salinity in fields and lands. Methods for monitoring changes, evaluating irrigation and drainage practices, or locating the sources of diffuse pollution by deep percolation from irrigated lands were nonexistent or were tedious, laborious, or impractical. Over a span of twenty years Jim Rhoades developed approaches and equipment to carry out large-scale assessment surveys. First, he developed geophysical sensors to measure the electrical conductivity of soil directly in the field and the theory and methods to infer soil salinity from these measurements, voiding the effort and expense of collecting and analyzing soil samples. He advised and consulted with commercial companies in the manufacture and distribution of this equipment. Later he incorporated sensors into mobilized systems, along with automated controls, data loggers and satellite navigational equipment. Thus measurement techniques were automated and spatial referencing was applied. Dr. Rhoades led in the development of theory and computer software to process the extensive field data and he developed procedures to fill gaps in each of the technologies described above. In 1998 he formalized a CRADA for the commercialization of the system and it is now being produced.

Jim Rhoades has established cooperative programs with the Natural Resources Conservation Service, the U.S. Bureau of Reclamation and several Resource Conservation Districts to help implement salinity assessment programs in numerous irrigation districts in both California and Colorado. He served USDA George E. Brown Jr. Salinity Laboratory in a sustained and highly noteworthy way for thirty years as researcher, Senior Research Scientist, and National Laboratory Director, and as a national and international advisor. He also served in numerous leadership roles in various scientific societies and organizations and was elected Fellow of the American Society of Agronomy and the Soil Science Society of America.

Dr. Rhoades' research and leadership accomplishments are outstanding. His impact on soil and water conservation, and water quality protection in California, are truly noteworthy.

CARL SPIVA

From 1949 to 1976, Carl worked for Occidental Chemical Company. First he was responsible for sales and agronomic services for central California area. After 1965, he became chief agronomist, and provided agronomic services and education for Occidental's sales department and their dealer field men throughout the Western U.S. From 1976 until the present, he has worked as a private consulting agronomist. He has provided agronomic services and soil fertility/reclamation training for several small to large clients, including UNOCAL, PureGro, Western Farm Service, John Taylor Fertilizer, Wilbur-Ellis, and many other smaller companies. Carl has lectured on soil fertility, reclamation, and best management practices at many grower meetings throughout the West. He was an originator and conducted the first of many Certified Crop Adviser preparation courses for hundreds of field men throughout California, Arizona, Oregon, Washington, and Idaho when this program was first introduced. He has lectured to more fertilizer industry field men than any other industry person, according to colleagues. Carl has also been an invited speaker and frequent guest lecturer on soil fertility and reclamation at schools and colleges, and a frequent contributor of articles on soil fertility and reclamation in farm magazines and other related publications. He has had many foreign consulting assignments included: training field sales personnel of INCITEC, largest Fertilizer company in Australia, on site; a range improvement project in Morocco, as a part of a team of agronomists from Utah State University and the University of California, Davis in 1982, where the team evaluated native range land and selected seed farm site for small seeded legume production. Short terms in two successive years; sugar beet production using pelleted seed and PGR additives in United Kingdom for Germains Seeds; banana plant nutrition and water quality evaluation project for Standard Fruit Company (a Dole company) in Honduras, several soil and plant nutrition projects for Dole in Mexico and Baja California, and as a featured speaker on soil fertility/reclamation for Apples at the 4th International Apple Symposium, Chiuhahua, Mexico. He is a member and former chair of the soil improvement committee of the California Fertilizer Association. He is a member and past president of California Chapter of the American Society of Agronomy.

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2000
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Three-Year Term:

Lee Bucknell, Agriculture Department, Modesto Junior College
Dan Munk, UC Cooperative Extension, Fresno
Sharon Benes, Plant Science, CSU Fresno

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POSTERS WITH ABSTRACTS

WATERIGHT

Water Management on the Internet

Dave Zoldoske, Ed. – Director
Pete Canessa, PE – Ag Engineer
Center for Irrigation Technology
California State University at Fresno 93470
Phone: (559) 278-2066 Email: david_zoldoske@csufresno.edu

The purpose of this paper is to introduce WATERIGHT. WATERIGHT is a web site on the Internet. It is a joint development of the Center for Irrigation Technology and the Agricultural Information Technology Network. Both are located on the campus of California State University at Fresno. Major funding for WATERIGHT has come from the U.S. Bureau of Reclamation.

WATERIGHT's "address" is WWW.WATERIGHT.ORG. The use of WATERIGHT is free of charge.

A web site is a series of related "electronic pages". These pages might contain textual, numeric, or graphic information. They may enable communications. They may enable interactive computation or games. They may contain "links" to other web sites. WATERIGHT contains all of these page types.

The general purpose of WATERIGHT is to make technical knowledge accessible to the world both inside and outside of formal education. In that sense it is an "extension" education effort. Its specific purpose is to serve as an educational and irrigation scheduling resource for water managers in agriculture and commercial turf, as well as homeowners.

The Internet is a very powerful tool for education. Publishing on the Internet provides many advantages, including:

- Cost effectiveness - publishing information on the Internet provides probably the cheapest, per-contact cost of any education medium. Anyone in the world can access WATERIGHT, at any time.

- Fast response – changes requested by users, fixes to programming, or the addition of new content are available to the target audience immediately upon publishing.

- User convenience - the more convenient a medium is, the more likely it is that it will be used. Using a web site is:
  - Immediate - no waiting in line.
  - Anonymous - the user is free to come and go on the site without having to provide identification.
  - Flexible – the user can view content at 3:00 PM or 3:00 AM.
  - Self-paced – the user can view content as many times as needed.
  - Interactive – it allows development of personalized information.

- Allows consolidation of both basic and advanced material. Your target audience only needs to go to one place.

- User awareness of the media is increasing.

- Listing in the World-Wide Web's "yellow pages". This is like a giant library catalog.

WATERIGHT contains three types of content:

1) Data/Information - this would include access to the different weather networks, answers to frequently asked questions, the links page, a glossary, the text of most of the CIT technical publications, and crop coefficient curves.

2) Education (advisories and tutorials) - these are in-depth explanations about various aspects of water and energy management, including:
    i) Developing a water management plan.
    ii) Non point source pollution .
    iii) Energy use for pumping (this advisory contains a calculator for estimating site-specific energy use and cost).
    iv) Planning Furrow/Border Check/Sprinkler/Micro irrigations (these advisories contain a calculator for estimating site-specific operational parameters).
    v) Water budget and graphical/sensor-based irrigation scheduling techniques.

3) Water management aid – WATERIGHT provides for interactive development of seasonal irrigation schedules.

The Advisory for Energy Use for Pumping is an example of WATERIGHT as an educational resource. Sub-topics within this Advisory include:

- How to calculate energy use/cost - the discussions covers both electric-powered and internal combustion engine-powered pumps. Specific equations are presented with examples of how to use them.

- What is a "pump test" - this explains how one can test a pump for efficiency. Within this section are also requirements for a valid pump test and how to interpret the results.

- Options for saving energy - this section discusses pump and power-source efficiency, total dynamic head in the system, amount of water pumped, and lowering the unit cost of the energy itself.

Also contained within this Advisory is a calculator that allows a user to estimate site-specific energy use and costs. This provides the opportunity to ask "what if"-type questions (i.e. "what if the pressure is lowered from 70 psi to 55 psi?"). The calculator can be used with English or metric units, and with electric, diesel, gasoline, or natural gas as the energy source.

Figure 1 is a screen display of the calculator. The user fills in the appropriate blanks and then presses one of the calculate buttons in the middle of the page. The answers appear in the bottom section. A full set of instructions is provided above the calculator on the same page.

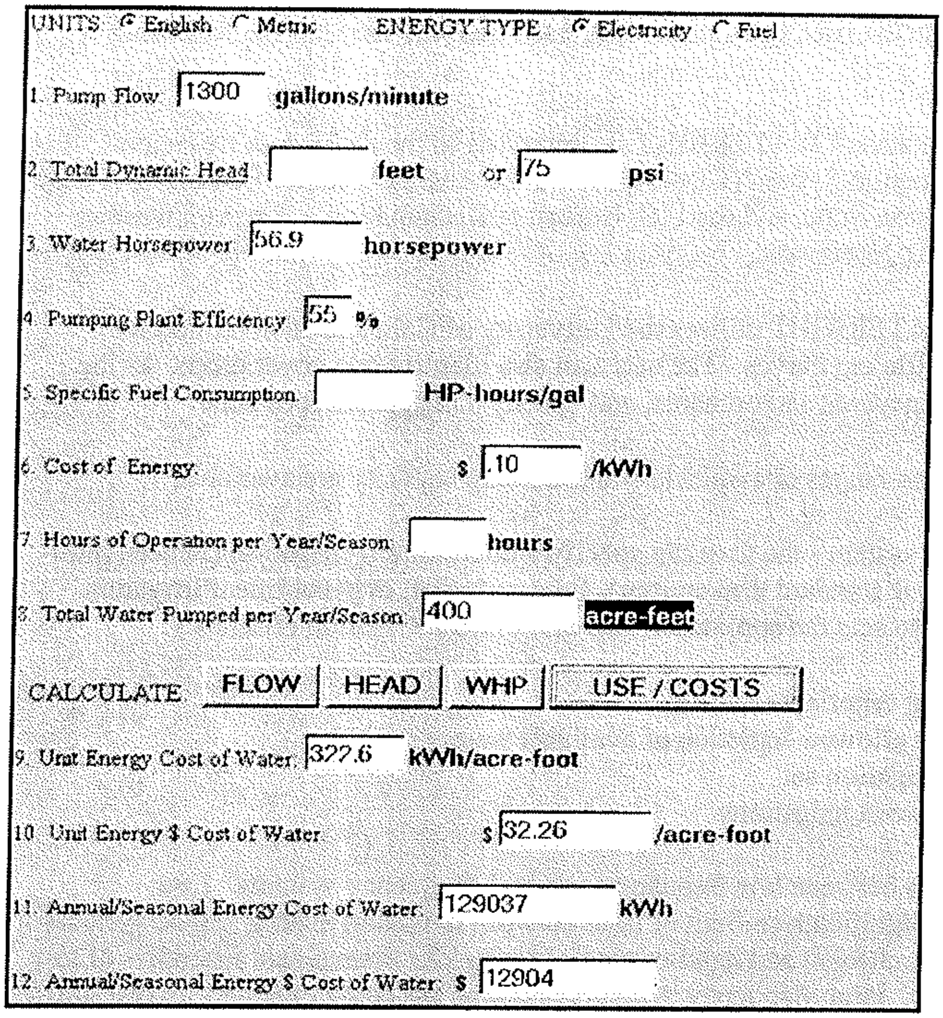

Figure 1 - Screen display of the energy-use calculator in the Energy Use for Pumping Advisory

One of the main purposes of WATERIGHT is to serve as a management aide to irrigators. Specifically it provides for the interactive development of seasonal irrigation schedules. Three audiences are addressed:

1) Agriculture

2) Commercial turf

3) Homeowners

For each, a different approach to scheduling is taken in order to make the process as intuitive as possible. (Note that a tutorial for use of the WATERIGHT irrigation scheduling programming, as well as tutorials concerning both water budget and graphical irrigation scheduling methods, are contained on the site.)

For agriculturalists this includes the ability to identify and store data for up to 15 different fields. Note that the data resides on the user's computer. For each field the user has the following flexibility in setup:

- Choice of weather station - WATERIGHT is connected to the California Irrigation Management Information System (CIMIS), the Public Access Weather Stations (PAWS) network in Washington State, and the U.S. Bureau of Reclamation's AgriMet weather stations in the Pacific Northwest.

- Choice of crop - WATERIGHT utilizes the University of California convention for describing crop coefficient curves. The user can also identify two cover crops, set the maturity level for vineyards and orchards, and specify a maximum root zone.

- Choice of soil - seven ranges of available water holding capacity are available.

- Choice of irrigation system - the user can specify a flood, micro-irrigation (fanjets, mini-sprinkler, drip tape, or standard drip emitter), field sprinkler, or pivot/linear irrigation system. The user also sets the application rate and overall irrigation efficiency.

- Choice of scheduling criteria, including:
    - Management allowed depletion of available water
    - Hours per irrigation set
    - Set days between irrigations

WATERIGHT differentiates between low frequency and high frequency systems. Low frequency systems imply a significant amount of time between irrigation events. Flood systems (furrow, level basins, border checks) and hand-move field sprinkler systems are examples of low frequency irrigation systems. High frequency irrigation systems are being operated several times a week or even every day. Micro-irrigation (emitters, drip tape, fan jets), center pivots, or linear-move sprinklers are examples of high frequency irrigation systems.

When developing a schedule for low frequency irrigation systems the individual irrigation events are identified. Figure 2 is a portion of an example schedule. One can see that for the average year, a recommendation is to irrigate on 5/21, then again on 6/12. Both the net and gross water applications, based on the user-set irrigation efficiency, will be calculated.

Seasonal Irrigation Schedule										
For Week Ending	Average Year		This Year		Averages for Week				Change This Yr vs Avg Yr	Total ETc to Date
	ETo	Rain	ETo	Rain	Kc	ETc	Root Zone	Avail.		
	In/Day	In/Wk	In/Day	In/Wk		In/Dy	Ft	In	%	In
4/7/00	0.15	0.17	0.18	0.00	0.18	0.03	1.00	1.60	24	0.18
4/14/00	0.16	0.11	0.17	0.01	0.18	0.03	1.00	1.60	7	0.37
4/21/00	0.17	0.22	0.13	0.83	0.18	0.03	1.00	1.60	-25	0.58
4/28/00	0.18	0.11	0.19	0.00	0.18	0.03	1.25	2.00	3	0.79
5/5/00	0.20	0.18	0.21	0.00	0.20	0.03	1.57	2.51	7	1.03
5/12/00	0.21	0.05	0.20	0.00	0.24	0.04	1.90	3.03	-4	1.34
5/19/00	0.22	0.08	0.17	0.12	0.29	0.05	2.22	3.55	-22	1.73
AVE. YEAR: Irrigate 5/21/00: Net= 1.86 In. Gross= 2.48 In.										
5/26/00	0.23	0.04	0.26	0.00	0.37	0.08	2.55	4.06	14	2.28
6/2/00	0.24	0.03	0.26	0.00	0.46	0.10	2.87	4.58	10	3.00
6/9/00	0.24	0.06	0.22	0.22	0.55	0.12	3.19	5.10	-10	3.85
AVE. YEAR: Irrigate 6/12/00: Net= 2.76 In. Gross= 3.68 In.										
6/16/00	0.25	0.03	0.26	0.02	0.65	0.15	3.52	5.62	3	4.91

Figure 2 - Portion of an example irrigation schedule for a low frequency irrigation system produced by WATERIGHT

Irrigation schedules for high frequency irrigation systems are reported in terms of recommended hours of operation for seven-day (weekly) periods. A portion of an example schedule for a high frequency irrigation system is seen in Figure 3. In Figure 3 one can see that for the week ending 4/4/00 the recommendation is for about 24 hours operation for that week.

Seasonal Irrigation Schedule											
For Week Ending	Average Year		This Year		Averages for Week				Change This Yr vs Avg Yr	Total ETc to Date
	ETo	Rain	ETo	Rain	Kc	ETc	Root Zone	RunTime		
	In/Day	In/Wk	In/Day	In/Wk		In/Dy	Ft	HH:mm	%	In
3/7/00	0.10	0.37	0.06	0.61	0.57	0.06	4.00	14:01	-41	0.40
3/14/00	0.11	0.33	0.11	0.15	0.60	0.06	4.00	15:52	-3	0.85
3/21/00	0.13	0.41	0.16	0.00	0.63	0.07	4.00	17:36	25	1.35
3/28/00	0.14	0.38	0.14	0.00	0.66	0.09	4.00	21:58	-2	1.97
4/4/00	0.16	0.09	0.19	0.00	0.69	0.10	4.00	24:02	19	2.66
4/11/00	0.18	0.07	0.20	0.00	0.72	0.12	4.00	29:31	13	3.49
4/18/00	0.19	0.21	0.12	1.20	0.74	0.13	4.00	33:03	-38	4.43
4/25/00	0.21	0.13	0.20	0.00	0.77	0.15	4.00	36:59	-4	5.48
5/2/00	0.22	0.04	0.24	0.00	0.80	0.17	4.00	41:02	7	6.65

Figure 3 - Portion of an example irrigation schedule for a high frequency irrigation system produced by WATERIGHT

For either type of irrigation system the schedules will also include cumulative reference and crop evapotranspirations, average crop coefficients for the week, average root zone depth for the week and current versus historical trends in weather.

It is important to realize that the schedules produced by WATERIGHT are seasonal schedules based on long-term historical weather averages. They are not real-time irrigation schedules. They should be used for guidance only and it is the user's responsibility to check the actual condition of the plant and soil at all times. As with most aspects of water management, knowledge and experience are the keys for interpretation and utilization of the results.

WATERIGHT is a living document. It is constantly being improved and expanded. Topics are being developed for new Advisories and Tutorials. These would include:

- Salinity and drainage
- Options for drainage disposal and treatment
- Advances in soil and plant moisture sensing

- Energy economics in irrigation system design

An "advanced irrigation scheduling" page is now in beta testing. It will be used by a U.S. Bureau of Reclamation-funded project for educating growers as to the use of irrigation scheduling. The advanced page adds options for:

- User-defined crop coefficient curves.

- User adjustments to normal ETo and normal crop coefficients.

- User-defined start of scheduling date and soil moisture content. (Thus, WATERIGHT does become a real-time irrigation scheduling tool.)

- Stored irrigation and soil moisture data, with graphical reports.

In summary, WATERIGHT is an important educational and management resource on the Internet. It is a flexible, responsive, and cost effective method of extension education. Content includes raw data, developed information, in-depth advisories, links to other pages of interest, and the ability to interactively develop seasonal irrigation schedules. Three audiences are targeted, agriculture, commercial turf, and homeowner. WATERIGHT is a living document and as such the content is constantly being refined and expanded.

The Internet is becoming more and more important as an educational tool and WATERIGHT is at the leading edge of these efforts.

WATERIGHT is a joint development of the Center for Irrigation Technology and the Agricultural Information Technology Network, both located on the campus of California State University at Fresno. Major funding for WATERIGHT has come from the U.S. Bureau of Reclamation. The Center for Irrigation Technology is one of four research centers that operate under the auspices of the California Agricultural Technology Institute. CIT is committed to advancing water management practices and irrigation technology. CIT programs are in the areas of irrigation equipment testing, field research and analytical studies, educational outreach, and specialized computer programming.

Chemigation Uniformity in Drip Irrigated Trees and Vines

Larry Schwankl
University of California, Davis
530-752-4634
e-mail: ljschwankl@ucdavis.edu

Terry Prichard
University of California, Davis
550-468-9496
e-mail: tlprichard@ucdavis.edu

INTRODUCTION

A major advantage of a drip irrigation system is its capacity to apply water soluble chemicals during an irrigation (chemigation). These injected chemicals frequently are fertilizers but drip system maintenance chemicals, such as chlorine and acid products, are also commonly injected. Other injectable products including gypsum, herbicides, and pesticides.

With proper design, installation, and management, a drip irrigation system can apply water very evenly (uniformly) throughout the orchard or vineyard. With some simple management steps - choosing an appropriate injector, correctly determining the amount of chemical to be injected, and injecting for the correct amount of time - chemical applications through the drip irrigation system can be equally as uniform. Injections which are improperly done result in a non-uniform application of injected material. The most common mistake made in chemigation, particularly in fertilizer injection, is to inject for too short a time period. Doing so results in those trees or vines which are closest hydraulically to the injection point receiving more fertilizer than those farther away - a non-uniform chemigation. The least desirable scenario is to inject fertilizer at a high rate for a short time period; then shut down the irrigation system when injection is stopped. This will lead to very poor chemigation uniformity.

DRIP SYSTEM INJECTION

Injection Amount

When injecting through a drip irrigation system, two objectives should be kept in mind. First, the irrigation amount applied should be correctly determined so that the applied water (and injected material) remains in the plant's root zone. Applying more irrigation water than the plant's root zone can hold will result in the deep percolation of water below the plant's root zone. If the injected material travels easily with the water (e.g. nitrates), over-irrigation can also result in deep percolation of the injected material. Good irrigation scheduling techniques can minimize this environmental hazard and optimize water and injected material application efficiencies. If the irrigation set is long enough to allow a choice of when to inject, a good time is in the middle of the irrigation set. This will make it more likely that the injected material will stay in the root zone even if some over-irrigation occurs.

Injection Period

The injection period during the irrigation should be chosen so that there is a uniform application of injected material throughout the drip system. It is important to remember that once injection starts, the injected material **does not** immediately reach all the drip emitters. Likewise, once injection stops, injected material does not immediately disappear from the drip lateral line. There is a travel time required for water and injected material to move through the drip system. This travel time varies depending on the design and layout of the drip irrigation system. For all practical purposes, injected materials travel at nearly the same rate as the irrigation water. This is referred to as "slug flow". In the following discussion of drip irrigation system travel times, it should be assumed that injected materials travel through the drip system as the irrigation water does.

Water, and any injected chemicals, travel through the drip system's mainline and submain piping at fairly high velocity. These pipelines are generally sized so that the flow velocity is less than 5 feet per second (fps) to minimize frictional pressure losses, but flow velocities of 1 to 3 fps would be common in the mainline and submains. Some pipeline systems are quite long though so movement of water and injected materials through them may take quite awhile. Pipeline travel times of 20 to 30 minutes is not uncommon, and in field-monitored drip irrigation systems the authors have monitored pipeline travel times as long as 65 minutes (see Table 1). It is possible to calculate the travel times in the mainline / submain system, but this requires that all the flowrate and pipe size information used by the irrigation system designer be available to the irrigation manager or consultant. In fact, the authors have found that this information is seldom available. It is often easier and more accurate to simply measure the travel times in the field.

Flow velocity of irrigation water in the drip lateral lines is slower than through the mainline and submains, and it is particularly slow at the tail end of the lateral lines. Understanding the flow conditions in drip lateral lines helps explain this. At the inlet of a drip lateral, the flow rate is that of all the combined downstream emitter discharges. For example, if there are 60, 1-gallon per hour (gph) emitters installed in the lateral line, the flow rate at the head of the drip lateral would be 60 gph or 1 gallon per minute. For a typical, 16 mm inside diameter, drip tubing, the resulting flow velocity would be 1 foot per second. The flow velocity in the drip line is dependent on the flow rate and the tubing size. For the same size drip tube, the higher the flow rate, the higher the flow velocity. For the drip lateral example we're using, downstream of the first emitter, the flow rate in the drip tube would be 59 gph. Downstream of the second drip emitter, the flow rate would be 58 gph; and so on. Since the flow rate decreases along the drip lateral, so does the flow velocity. The slowest moving water is between the next-to-last and the last emitter. For our example, the flow rate in this section is only 1 gph. For a typical drip tubing (16 mm inside diameter), the flow velocity would be only about 1 foot per minute in this last drip line section.

The total travel time of water along a drip lateral line is therefore dependent on 4 factors. How long the drip lateral is, how many emitters are installed in the lateral line, the discharge rate of the emitters, and the size (inside diameter) of the drip tubing. Knowing these factors, the drip lateral line travel times can be calculated, but it is often easier to field measure travel times.

Field Measurement of Travel Times

One of the easiest ways to measure drip line travel times is to "trace" the movement of injected chlorine through the system. Injecting chlorine into the irrigation system is a recommended drip system maintenance procedure. The presence of chlorine in the emitter discharge from emitters can be easily monitored using a pool/spa chlorine test kit with chlorine concentrations as low as 1-5 ppm being easily monitored. The chlorine's passage through the drip system can be readily traced using this technique, and the water/injected material travel time determined. The recommended procedure is as follows:

Step 1: Start up the drip irrigation system and allow it to come up to full pressure. If the drip system has not been recently flushed (pipelines and lateral lines), this should be done. Allow the drip system to return to full pressure after flushing.

Step 2: Begin injecting chlorine so that the chlorine concentration in the irrigation water is approximately 10 to 20 ppm. Note the time when injection begins. The equation for calculating the amount of liquid chlorine to inject is:

$$\text{Injection Amount (gal/hr)} = \text{Drip System flow rate (gal/min)} \times \text{Desired Cl concentration (ppm)} \times 0.006 \div \text{Cl source concentration (\%)}$$

Step 3: Go to the drip emitter at the head of the drip lateral farthest (hydraulically) from the injection point. Using the chlorine test kit, monitor the discharge from that emitter and note the time when the chlorine registers on the test kit. This tells you the travel time through the mainline/submain system.

Step 4: Go to the last drip emitter at the tail end of the drip lateral just monitored (drip lateral farthest hydraulically from the injection point). Monitor discharge from this last emitter until chlorine registers on the test kit and note the time when this occurs. This will indicate the travel time of water/injected material through the entire drip system.

A field evaluation study of various tree crop and grapevine drip irrigation systems in the Sacramento and San Joaquin Valleys of California was done in 1998. The authors collected travel time and chemigation uniformity information on a number of commercial drip irrigation systems. Table 1 shows the travel times for some of these evaluations. It is evident from this information, that there is not a typical water/injected material travel time to the far point in a drip irrigation system. It must be measured for the drip system you're dealing with, but this only needs to be done once.

Table 1. Water / chemical travel times through the pipelines and drip lateral lines for the vineyard and orchard field sites evaluated.

Site	Mainline and Submain Travel Time (min.)	Mainline / Submain Length (ft)	Lateral Line Travel Time (min.)	Lateral Line Length (ft)	Total Travel Time (min)
1	22	1000	10	175	32
2	30	1500	10	340	40
3	65	5000	10	340	75
4	15	1400	23	630	38
5	8	700	23	625	31
6	17	820	28	600	45

Post-Injection Irrigation Times

It is important that irrigation continue following an injection. This accomplishes two things. First, it allows the injected material to be cleared from the drip system. Secondly, it assists in making sure that the chemigation is uniform, i.e. all emitters discharge nearly the same amount of injected material.

Clearing the drip system of the injected material is often important due to emitter clogging concerns. For example, leaving fertilizer in the drip system may encourage biological growth (e.g. biological slimes) which can lead to emitter clogging. Leaving materials containing calcium (e.g. gypsum, calcium nitrate) in the drip system may lead to chemical precipitation of calcium carbonate (lime) which again may cause emitter clogging. The exception to this recommendation may be the injection of drip system maintenance products such as chlorine or acid. It may be desirable to leave these products in the drip system at system shutdown to minimize clogging problems. While the advancing front of injected chemical is quite abrupt, the recession or disappearance of the chemical is not nearly so abrupt. Flow velocities at a pipe or tubing wall are very small (theoretically zero) so some of the injected material "hangs up" on the pipe/tubing walls and takes quite awhile to clear from the drip system. This may be important if it is desirable to clear all traces of the injected material from the drip system (e.g. to prevent clogging).

Allowing irrigations to continue following an injection is important to ensure a uniform chemigation application. Just as it takes time for the injected material to travel through the drip system once injection starts; it takes an equal or greater amount of time for the injected material to clear out of the system (see Table 1). It first clears from the head of the system, with the last point to clear being the emitter farthest hydraulically from the injection point. This is just the opposite of what occurs when injections began, and it balances out the amount of injected materials discharged from emitters throughout the drip system. This gives a uniform chemigation application.

Field Evaluation of Chemigation Uniformity

Field evaluations were done at the University of California, Davis on a single drip lateral line to evaluate the impact on chemical application uniformity of varying the injection times and the post-injection irrigation times. The results of some of these evaluations are shown in Table 2. The lateral line evaluated was a 500-foot drip lateral (16 mm polyethylene tubing) with a 1 gallon per hour, pressure-compensating, drip emitters installed every 5 feet. It was determined through field evaluation that the travel time for water / chemicals passing through the lateral line was 25 minutes.

Table 2. Chemigation uniformity in a drip lateral (500-ft. long with 1-gallon per hour drip emitters installed at 5- foot intervals) for various injection time periods and various post-injection clean water irrigations. The water / chemical travel time to reach the end of the drip lateral was 25 minutes.

Injection Time (min)	**Post-Injection Irrigation Time (min)**	**Relative Chemigation Uniformity***
50	50	100
50	25	98
50	0	25
25	50	90
25	25	95
25	0	11
13	25	81
13	0	7

* Relative Uniformity is the uniformity of each test as compared to the injection uniformity of the 50 minute injection time / 50 min post-irrigation time injection test.

Note that excellent chemical application uniformity was achieved when: (1) the injection period was equal to or greater than the water / chemical travel time to the end of the drip lateral (25 minutes in this case), **and** (2) the post-injection irrigation time was equal to or greater than the lateral line's water / chemical travel time.

The relative uniformity for each injection test was determined by injecting potassium chloride during the injection phase. All discharge water from selected emitters at 50-foot intervals was collected, measured for volume and analyzed for potassium concentration. The resulting potassium loadings from each measured dripper were evaluated and a coefficient of variation (CV) was calculated for each test. Finally, the CV's for each injection test were compared to determine a relative uniformity for each test. The 50 minute injection period / 50 minute post-injection irrigation period test was used as the standard to compare all other injection tests to and was accordingly given a relative uniformity value of 100.

The results in Table 2 also show that there are two injection strategies to avoid. First, avoid injection periods which are less than the drip system's water / chemical travel times to the end (hydraulically) of the system. Illustrative of this is the scenario in which the injection time was 13 minutes and the post-injection irrigation time was 25 minutes. Due to the short injection period, injected chemical had not reached the end of the lateral line prior to injection being stopped. While the post-injection irrigation helped distribute injected material to all points along the lateral, the relative uniformity of the test was 81. While this chemigation uniformity may seem acceptable, a strong case can be made for the argument that chemical injections should be as uniform as the emitter discharge uniformity or else the drip irrigation system is not being utilized as well as it should be.

Secondly, an injection should always be followed by a period of "clean" water irrigation. This post-injection irrigation period should be at least as long as the water / chemical travel time to the end of the drip irrigation system. The injection scenario in which the injection period (13 minutes) was shorter than recommended (25 minutes or longer) but was followed by an adequate clean water application (25 minutes) was effective in helping achieve a good, although not optimum, chemigation uniformity. Contrast this with injection scenarios in which the injection times are as recommended (25 or 50 minutes), but the drip irrigation system was shut down at the end of the injection (0 minutes post-injection irrigation). This leads to relative uniformities of 11 and 25 respectively - poor and unacceptable chemigation uniformities. Without post-injection irrigation, emitters at the tail ends of the drip lateral discharge less injected chemical than do the emitters at the head of the lateral.

The worst chemigation uniformities would result from a too short (less than the end-of-system travel time) injection period followed by drip system shutdown. This scenario is illustrated in an injection test in which the injection time was 13 minutes followed by no post-injection irrigation. The relative chemigation uniformity for this test was only 7 with the emitters at the tail end of the lateral discharging no injected chemical. This is obviously an injection strategy to avoid.

Microsprinklers

The previous discussion has dealt with drip irrigation systems and not with another type of microirrigation system - microsprinklers. Microsprinkler systems would have similar mainline / submain travel times as drip systems since the friction loss / flow velocity design criteria are similar. Microsprinkler systems would have shorter lateral line travel times though. The majority of the lateral line travel time for drip systems is at the tail end of the lateral where flow rates (and thus flow velocities) are small. In microsprinkler systems, the flow rate in the last section of lateral line is the discharge rate of the last microsprinkler (e.g. a typical discharge may be 10 gallons/hr). The lateral line flow velocity associated with this 10 gallon/hr microsprinkler flow rate would be 10 times that of a drip emitter with a discharge rate of 1 gallon/hr. Thus, while travel time effects on chemigation uniformity should still be considered in microsprinkler systems, the travel times will be less in microsprinkler systems as compared to drip systems.

SUMMARY

Chemigation uniformities equivalent to the water discharge uniformities of permanent crop drip irrigation systems can be achieved by: (1) using injection time periods equal to or greater than the time it takes for water / injected chemicals to reach the hydraulic, most-distant point in the drip system, **and** (2) once injection stops, continuing to run irrigation water for a time period equal to or longer than the travel time to the most distant point hydraulically in the drip system.

If the travel time to the end (hydraulically) of the drip system is not known, it can be simply determined using injected chlorine as a tracer and a pool/spa test kit for detection. Field-measured travel times ranged from 30 to 75 minutes for orchard and vineyard drip irrigation systems in the Central Valley of California.

Acknowledgment

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Options for Managing Salinity in Western San Joaquin Valley

John Letey
Distinguished Professor of Soil Physics
Soil and Water Science Unit
University of California, Riverside 92521
Phone 909 787-5105 Email: john.letey@ucr.edu

Agricultural production in the western San Joaquin Valley of California is jeopardized by the presence of high water tables containing high concentrations of salts and toxic chemicals. Sustained agricultural production requires the separation of salts from the root zone and providing drainage to keep the water table from encroaching the root zone. The two major sources of salts in the western San Joaquin Valley are salts imported with the irrigation water, and salts stored in the vadose zone from geologic times. The first decision in managing the problem is to select places for the salts to be deposited away from productive agricultural land, or sacrificing a portion of productive land to preserve productivity on the other portion.

Groundwater hydrology is an important factor. In this report I will only consider the water flowing to subsurface drainage lines. The water flow to subsurface drainage lines is illustrated in figure 1. Note that the flowline originating from the midpoint between the drainage lines moves deeply into the vadose zone before rising up to the drainage lines. Decreasing the spacing between drainage lines reduces the depth to which the stream lines flow. A major consequence of this behavior is that, at a given time, the drainage water and dissolved chemicals are not the same water and chemicals that left the root zone during that time. This phenomenon explains why selenium concentrations continue to be high in the drainage water even though there has been no selenium added with the irrigation water and the selenium in the root zone has been leached out in previous years.

Because of the huge subsurface volume under consideration, there is a large capacity to "mine" the salts or store additional salts in the vadose zone. Much of the salt content in the present drainage water consists of that being flushed out from geologic origin. Therefore the amount of salts requiring disposal from drainage water is greater than the amount being added with the irrigation water.

Subsurface drainage waters brought to the land surface must be disposed. Options include use for irrigation, placement in evaporation ponds, or treatment to remove impurities. Using the water for irrigation is constrained by the concentrations of salts and boron in the drainage water. Placing the drainage water in evaporation ponds is constrained by the selenium which is harmful to birds that use the pond. Treatment by reverse osmosis is constrained by the cost of treatment and the need to dispose the concentrated brine. The salts still have to be disposed somewhere. Cost of treatment can, at least partially, be offset by the value of the product water. The economic viability can be enhanced by a marketing arrangement with the urban community for which water has a higher value. Strategies to partially mitigate the effect of selenium in evaporation ponds include pond design, bird hazing, alternate or compensation habitat, or disruption of the selenium transfer in the food chain. Detailed evaluation of these strategies is beyond the scope of this paper.

USE FOR IRRIGATION

Pure water is transpired by plants. A very small percentage of the salts added with water is taken up by the plant. Thus most of the salts are left within the root zone. As water is transpired the salt concentrates in the root zone. Plants differ in a degree to salt tolerance. All have an upper limit and all require some degree of leaching to reduce salts in the root zone.

The amount of leaching depends upon the salt concentration of the irrigation water and the salt tolerance of the crop. Increasing the irrigation salt concentration increases the amount of leaching and decreasing the salts tolerance also increases the amount of leaching. For the more sensitive crops it is impossible to get maximum yield by irrigating with high saline waters regardless of the leaching fraction.

The general relationships between the relative yield of corn (a salt-sensitive crop) and cotton (a salt-tolerant crop) to the amount of applied water on the horizontal axis in figure 2. Each curve represents a given salinity level of the irrigation water as measured by the electrical conductivity (EC) of the water in units of dS/m. Note that for a given water application, the yield tends to decrease with increase in irrigation water salinity. The decrease in yield is much greater for corn than for cotton. Also for a given salinity the yield tends to increase with increased water application because of the salt leaching that occurs with higher water applications. Graphs similar to figure 2 are presented for several crops in Letey and Dinar (1986).

Drainage waters in the western San Joaquin Valley have high salinity. Typical EC values are between 8 and 12 dS/m. Some areas have lower and some areas have higher values than these. When these waters are used for irrigation, the water leaving the root zone will be very concentrated in salinity. However, because of the large travel time from the root zone to the drainage line, these high salt concentrations may not be removed in the drainage lines immediately. In this case salts are being added to the storage in the vadose zone. Under conditions of high water table and installed drainage system, there will always be drainage water when there is leaching from the root zone. Thus ultimately there will be water and salts to be disposed of somewhere in the system. Using drainage water for irrigation reduces the volume to be disposed. But it does not eliminate the need to ultimately dispose the water and salts away from the root zone to maintain agricultural productivity.

From the information presented in figure 2, it is obvious that drainage waters would not be used to irrigate corn. They could marginally be used for cotton depending on the EC of the drainage water. If the EC exceeded 8 dS/m, cotton yields would be impaired. Irrigation with saline waters could degrade soil physical properties as well as directly decrease crop yield. Management to mitigate the effects on soil degradation may be required. An analysis of the effects of irrigation water quality on soil physical properties is not within the scope of this paper.

This presentation has only considered the effects of the salinity. Boron is a common element found in drainage waters. High concentrations of boron in irrigation water can be damaging to crops. As with the salinity, crops vary in their tolerance to boron. However tolerance to salinity does not necessarily translate to tolerance to boron or vice versa. Because of the boron in the drainage waters, boron rather than salinity may be the limiting factor in using drainage water for irrigation. Except for calling attention to this factor no other mention will be made concerning boron in this manuscript.

REDUCING DRAINAGE VOLUME

Irrigation management to reduce drainage volumes is important. Reducing the amount of water applied also reduces the amount of salts added to the system. Reducing the drainage volume reduces the amount of salts and toxic chemicals removed from the vadose zone. Two factors are important for good irrigation management: applying water uniformly and having control on the amount of water applied. If water is not applied uniformly, some parts of the field get too much water and some parts of the field get too little water. Those zones receiving high water contribute to high drainage volumes. Those areas receiving low water may have deficient water for maximum crop growth. It is impossible under nonuniform irrigation to have both high yield and low drainage volume. With uniform irrigation it is possible to have both goals, high yield and low deep percolation. The ability to control the amount of water applied at any irrigation is also important. The goal is to apply the amount of water lost by evapotranspiration between irrigations. Pressurized irrigation systems such as drip or sprinkler allow control over the amount of water applied. Surface irrigation systems such as furrow or flooding does not allow precise control on the amount of water that infiltrates, because the amount of water that infiltrates is dependent upon soil properties as well as other factors.

Another approach to reducing drainage volume is to control the drainage line outlet. Because most drain lines are spaced deep, it is possible to have the water table some distance higher than the drainage line without significantly affecting the roots. By curtailing discharge into the drainage line, the water is retained in the soil profile which can be extracted by the root system between irrigations. The drainage outlet can be controlled to discharge only when the water table becomes excessively high or it becomes necessary for some drainage to remove the salts from the root zone. Limited research has been done on this method of controlling drainage volumes. The present design of drainage systems is not conducive to this practice because they all lead into a sump located at the lower end of the field. The drainage outlet control must be placed on each drainage lateral. This approach warrants further investigation.

CHOOSING OPTIONS

Shifting irrigation and drainage management may incur costs. For example installing pressurized irrigation systems can be costly. These costs must be recuperated from a combination of higher yields and reduced costs associated with disposing drainage water. Using drainage water for irrigation may entail growing a crop of lower economic value than could be grown using good irrigation water. However the benefits of reducing the costs for disposing the drainage water by other means must be considered. An economic analysis considering the combination of all options is required to determine the economically optimal combination of options. Ultimately arrangements must be made to dispose salts.

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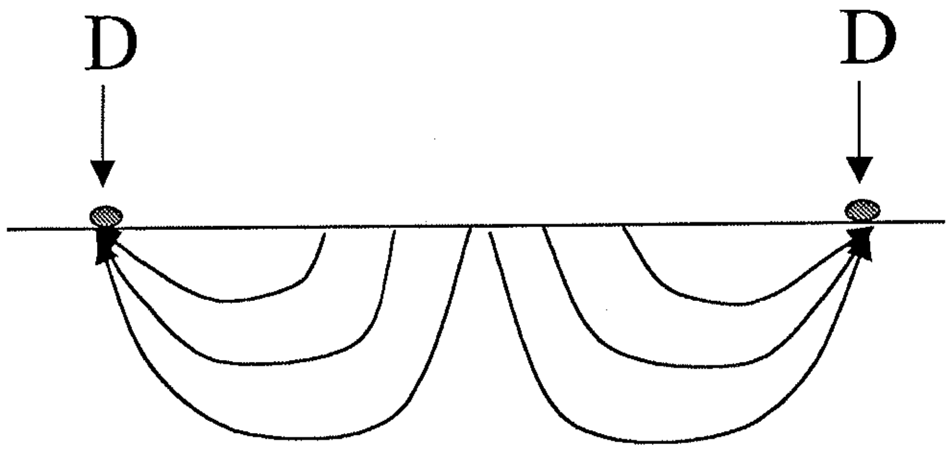

Figure 1. The water flow lines through soil to the drainage system lines identified as "D".

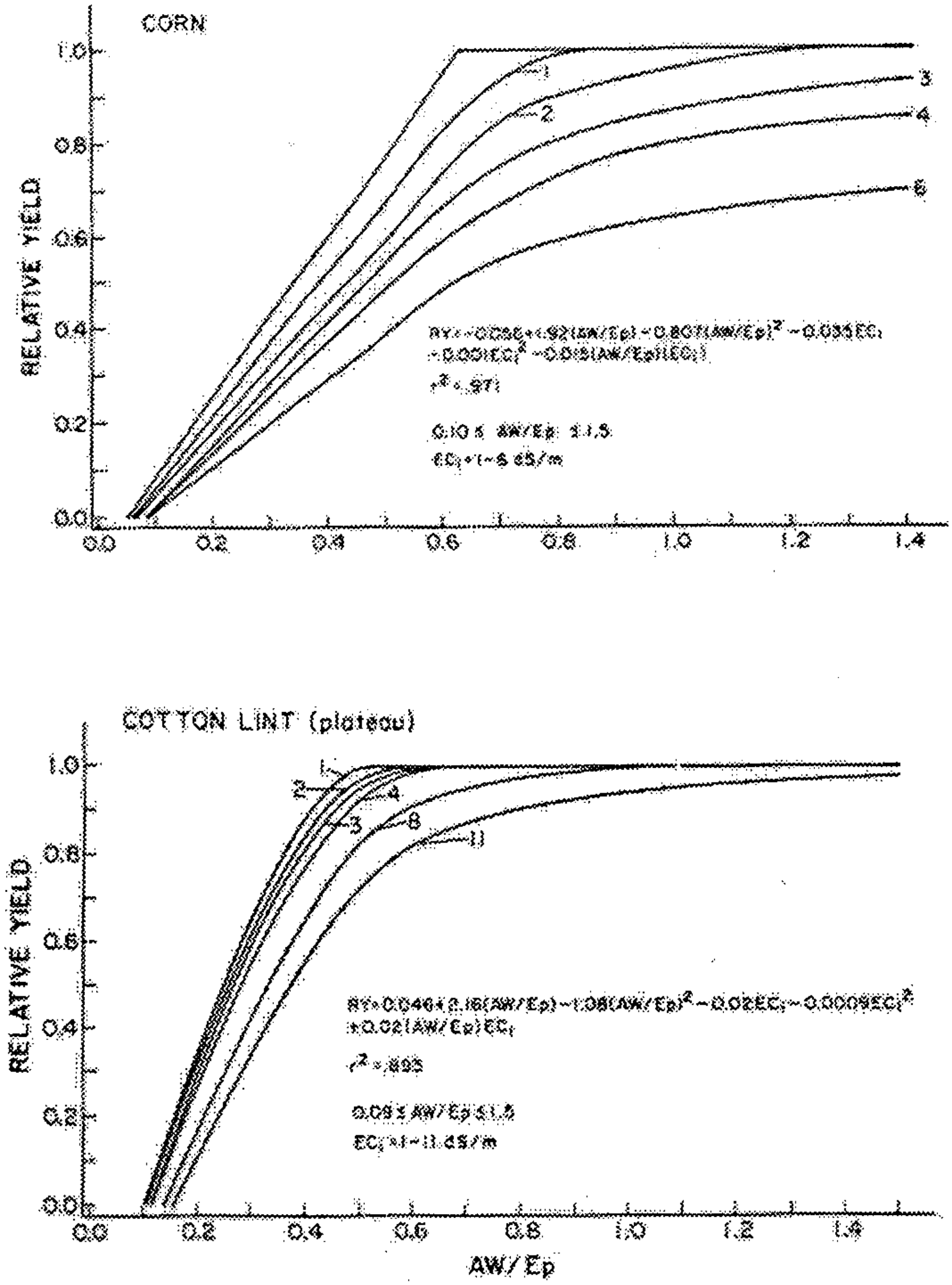

Figure 2. Relationships between yield and applied water for waters of different salinities. Numbers on curves refer to EC of irrigation water; AW and Ep represent applied water and pan evaporation.

Irrigation of Halophytes and Landscape Plants with Saline Wastewater

Edward Glenn (Professor) and Vanda Gerhart (Research Scientist)
Environmental Research Laboratory, Department of Soil, Water and Environmental Science. University of Arizona, 2601 East Airport Drive, Tucson, AZ 85706
Eglenn@ag.arizona.edu, vgerhart@ag.arizona.edu

Introduction

Similar to other arid regions of the world, the southwestern United States does not have enough water to meet agricultural and increasing municipal and industrial demands. At the same time, disposal of poor-quality water has become difficult due to the potential for environmental damage at the point of discharge. An obvious strategy to help cope with both problems would be to reuse poor-quality water for beneficial, consumptive uses such as agriculture and landscaping. We will review research and demonstration projects conducted by our laboratory and others, that have tested the feasibility of using saline wastewater on plants.

The largest producer of saline water in the western United States is irrigated agriculture, which generates several million acre-ft per year of discharge (Westcot, 1988; Rhoades et al., 1989). This water comes from both runoff (tailwater) and subsurface drainage. As an example, the Imperial Irrigation District in California generates about 1.5 million acre-ft per year of discharge, containing approximately 3,000 ppm TDS (Rhoades et al., 1989). This water represents 35% of the amount applied to fields as irrigation water. About half is tailwater and the rest is subsurface leachate, collected from under fields in drain systems. This water is conveyed in canals to California's largest inland lake, the Salton Sea. The Salton Sea is a closed evaporation basin with agricultural drain water as virtually its only source of inflow, and it faces an environmental crisis as salts inexorably accumulate in the lake (Glenn et al., 1999). Even larger volumes of drainage water are produced in the San Joaquin Valley (San Joaquin Valley Drainage Program, 1991). This water presents a particularly difficult disposal problem due to presence of selenium, which can be toxic to wildlife (Presser, 1994). Numerous smaller irrigation districts throughout the west face site-specific challenges in disposing of agricultural drainage water (Westcot, 1988).

Among non-agricultural sources, cooling towers use more water and generate more waste brine than any other industrial process in the western states. Cooling towers are used by closed-cycle, steam turbine, electric generating facilities to condense high-quality (expensive) boiler water for reuse. Power plant cooling towers can utilize municipal water or poor-quality sources. For example, the largest power plant in the United States, the Palo Verde Nuclear Generating Facility in Arizona, uses the entire waste stream from Phoenix's sewer treatment facilities in its cooling towers (Tanner et al., 1999). The water is cycled 20 times before discharge, at which point it is approximately 15,000 ppm TDS and is high in nitrates and other nutrients. It is collected in two large evaporation lagoons, which presently exceed seawater salinity. These enriched ponds support an algae-brine shrimp food chain and have become an attractive nuisance for migratory waterfowl, that undergo occasional mass mortality on the ponds from unknown causes. Other power plants use potable water in their cooling towers. However, they typically cycle the water 7-10 times as a conservation measure, and the resultant blowdown water is in the range of 2,000-5,000 ppm TDS (Engel et al., 1985; Glenn et al., 1998b). This water is typically discharged into municipal sewer systems (for a fee), where it represents a potential salinity hazard to downstream water users.

Shopping malls, hospitals, airports, universities and large office complexes use cooling towers in their HVAC systems. These dispersed sources actually generate more total volume of discharge than the electric power industry in some western states (Arizona Department of Water Resources, Phoenix, unpublished information). They generally cycle their water fewer times than power plants, resulting in more dilute brines (typically 1,000-4,000 ppm TDS). This water is usually discharged directly into municipal sewer systems with no attempt at reuse, even though these same institutions are among the largest users of potable water for maintenance of large-scale landscapes.

Saline wastewater has been successfully used to irrigate conventional crops (Ayers et al., 1993; Engel et al., 1985; Rhoades et al., 1989; Westcot, 1988) and halophytes (Benes et al., 2000; Brown and Glenn, 1999; Brown et al., 1999; Glenn et al., 1998b,c; Grattan et al., 1999) at a research scale. Even seawater-salinity waters can be used to irrigate the most tolerant halophytes (Glenn et al., 1991, 1998a, 1999). If technical feasibility and safety can be demonstrated through longer-term, pilot-scale projects, there is an opportunity to reuse agricultural and industrial waste brines for consumptive use on plants (salt tolerant crops or landscaping), thereby increasing overall water use efficiency and minimizing the amount of saline water that must ultimately be discharged away from the site of production (Riley et al., 1997).

Reuse of Agricultural Drainage Water: Atriplex in the San Joaquin Valley

The poisoning of wildlife that occurred when selenium-containing, agricultural drain water was discharged into Kesterson Reservoir (Ong et al., 1995; Presser, 1994) lead to a reevaluation (still underway) of methods of disposing of drain water (San Joaquin Valley Drainage Program, 1991). The Environmental Research Laboratory conducted some early research into the use of *Atriplex* (saltbush) and other halophytes for the on-farm reuse of drain water. *Atriplex* is a highly salt tolerant genus of Chenopods, with approximately 200 species distributed around the world. They are often valuable range plants. Experiments in Westlake and Tulare Drainage Districts screened *Atriplex* species for yield (Watson, 1990), adaptability to mechanical harvest (Watson and O'Leary, 1993), nutritional quality for livestock, and accumulation of potentially toxic substances (Watson et al., 1994).

At Westlake Farms (Stratford, CA), *Atriplex* were planted as row crops and irrigated with drainage water with EC = 18 dS/m (Watson and O'Leary, 1993), clipped four times over three years using a mechanical harvester then baled. Yields differed among species, with regrowth potential ranging from 2.2-5.2 t/ha/yr at an irrigation rate of approximately 1 m/yr. Species capable of forming adventitious roots and shoots, such as *A. undulata* and *A. deserticola*, yielded over twice as much as single-stem species such as *A. canescens* and *A. nummularia*. Protein content also varied among species, ranging from 7.3-10.3% of above ground biomass, with a tendency to decrease with number of harvests (Watson et al., 1994). Ash content tended to be high (15-24.8%). The plants were irrigated with water containing approximately 0.15 ppm selenium, and above-ground tissue levels were in the range, 1-8 ppm (lower than levels in natural populations of *Atriplex lentiformis* growing in the valley). While selenium and sulfur contents in some species were above the whole-diet, recommended levels, all species could safely make up to 30% of a ruminant diet. This is the normal rate of inclusion of forage into feedlot rations. Subsequent experiments showed that *Atriplex*, *Suaeda* and *Salicornia* biomass could completely replace Cynodon hay as the forage in a lamb-fattening ration at 30% inclusion, despite high mineral content (Swingle et al., 1996). Lambs fed halophyte biomass had equal weight gain and carcass quality as control animals, but they had lower feed conversion efficiency and higher water intake due to the presence of salts in the halophyte tissues. Meal extracted from *Salicornia bigelovii* seeds after extraction of oil was able to replace cottonseed meal as the main protein source in lamb rations.

This research demonstrates that in principle, drain water can be safely used to produce alternative forage crops while reducing the volume of brine that must ultimately be collected and evaporated. In parallel experiments, the concept of a reuse cascade was developed as an overall strategy for managing saline waste in the San Joaquin Valley (San Joaquin Valley Drainage Program, 1991). Subsurface drain water, containing 5,000 ppm or greater TDS, would be used to irrigate progressively more salt-tolerant crops. The cascade would start with moderately tolerant crops such as grass hays and progress to *Atriplex*, saltgrass (*Distichlis*), *Salicornia bigelovii* (a potential oilseed) and other euhalophytes. The concept of agroforestry, using Eucalyptus trees as a step in the cascade, was also explored (Karajeh et al., 1994). At the penultimate step, euhalophytes can extract water from the soil solution up to 80,000 ppm TDS (Glenn et al., 1998a, 1999). Thus, the original volume of brine can be reduced to less than 10% of its original volume. At this point, it becomes economical to reduce the salts to a solid for disposal in a landfill, using small evaporation ponds or sand-bed evaporators, which minimize exposure of the brine to wildlife (Hayes and Kipps, 1992; Glenn et al., 1998c).

The cascade concept has advanced to the demonstration phase in the San Joaquin Valley through projects implemented by private farmers working with resource agency personnel and researchers from the California Department of Water Resources, USDA Natural Resources Conservation Service and California State University. Gratten et al. (1999) and Benes et al. (2000) have reported on on-farm research to test the effectiveness of the cascade method (or On-Farm Sequential Drain Water Reuse System) for reducing drain water volume using halophytes. Halophytes tested include *S. bigelovii*, *D. spicata* (saltgrass) and *Atriplex nummularia* (oldman saltbush). Less tolerant species, to be used earlier in the cascade, included *Cynodon dactylon* (bermuda grass), *Agropyron elongatum* (wheatgrass) and *Elymus triticoides* (creeping wildrye). The halophytes can withstand more saline irrigation but have lower forage value than the grass hays. Significantly, even when irrigated with highly saline drain water (EC = 22 dS/m), the halophytes maintained evapotranspiration rates of 7-10 mm/day, similar to high-water-use, conventional crops (Benes et al., 2000). This is important because the purpose of the halophyte crop is to use as much water as possible in a relatively small portion of the field.

Particular attention was paid to *S. bigelovii* (Grattan et al., 1999) due to its potential economic value as an oilseed crop (Glenn et al., 1991). Although it is native to coastal salt marshes (Glenn et al., 1998a), it also produced well in the San Joaquin Valley over a wide range of salinities (10-45 dS/m)(Grattan et al., 1999). ET rates exceeded those of the reference grass at a farm site in the western part of the valley. *S. bigelovii* has been tested as both a vegetable crop (harvested early) and as a seed crop (harvested at maturity) since 1996 and may be the most attractive candidate species for the most saline stage in the re-use cascade.

Reuse of High Salinity Cooling Tower Blowdown for Urban Landscaping

Water of similar quality to agricultural drain water (3,000 – 5,000 TDS) is produced by power plant cooling towers when their initial water source contains appreciable levels of salts. For example, the Ocotillo Electric Generating Facility, in Tempe, Arizona, starts with well water containing approximately 500 ppm TDS (Glenn et al., 1998b,c). The Arizona Department of Water Resources requires cycling 7 times or more as a conservation measure, since this plant qualifies as a major water consumer under state regulations. Thus, the reject water typically contains 4,000 or greater TDS. Although it is currently discharged to the sewer system, this may not be feasible in the future. Arsenic (a natural constituent in the groundwater) cycles to levels that approach the EPA drinking water standard of 10 ppb, and this standard will be lowered to 2 ppb in the future. Hence, if the power plant achieves the regulated number of cycles, the blowdown will exceed discharge limits for arsenic and cannot be placed in the sewer system. Numerous urban power plants face similar constraints to their disposal of blowdown water, due to increasingly stringent regulatory standards for water discharged into sewer systems. We explored the feasibility of using this water to irrigate highly tolerant landscape plants on site.

We tested *A. nummularia*, a shrub, and two grasses, *Paspalum vaginatum* (seashore paspalum) and *C. dactylon*. Based on previous greenhouse trials, these species represented a salt-tolerance gradient; *A. nummularia* and *P. vaginatum* were able to grow on undiluted seawater (30,000 – 40,000 ppm TDS), whereas *C. dactylon* was able to grow only up to 10,000 ppm TDS. In three years of outdoor trials at the Ocotillo facility, we grew each species in replicated, 1.5 m^2 buried lysimeters on three water sources: well water (500 ppm TDS); blowdown water (mean = 4,100 ppm TDS) and a mixture of well water and blowdown water (2,300 ppm TDS)(Glenn et al., 1998b). Lysimeters were either 1 m (grasses) or 1.5 m (shrubs) deep and were fitted with bottom drains so leachate could be quantified and analyzed. Each lysimeter was equipped with a neutron hydroprobe access port, and soil moisture was monitored weekly to determine the soil water deficit. Each lysimeter was irrigated with just enough water to return the soil to field capacity. No leaching fraction was applied and generally the lysimeters did not produce drainage except after a rain. Each lysimeters were surrounded by separately-irrigated guard plants of the same species to simulate closed-canopy plots. Although all plants grew well under all irrigation treatments, *A. nummularia* had the highest biomass production and water use of the test species. There were no significant differences among irrigation treatments, and yields (2-3 kg dry matter per m^2 per year) and water use (1-1.5 m per year) were higher than values for high-yielding, conventional crops such as alfalfa and sudangrass grown in Maricopa County.

This experiment was followed by three years of open-plot field trials at the same location, to see if the results could be replicated on a larger scale and to determine the effects of irrigation with saline water on deeper soil layers (Glenn et al., 1998c). Plants were irrigated conservatively, with no leaching fraction and only enough water supplied to replace water in the top meter of soil profile (to minimize subsurface drainage). However, water use and yields were still high (within the range found for lysimeters). Despite the shallow irrigation, *Atriplex* roots eventually penetrated to 5 m depth. No discharge of water or salt to deeper soil layers (> 2 m) was detected after three years, when moisture and salt levels in soil cores taken from inside plots were compared to control cores taken outside the irrigated area. There was an overall accumulation of salts in the top 2 m of soil profile, but model results indicated that a leaching fraction of just 5 % (supplied by rainfall) could keep this zone with the salinity range tolerated by *Atriplex*. It was concluded that halophyte irrigation could proceed for 20 years (the projected life of the power plant) without discharge to underlying, potable aquifers or unacceptable accumulation of salts in the vadose zone. These experiments demonstrated that long term irrigation of halophytes with saline water is possible as an alternative to discharging blowdown water to the sewer system.

Both experiments showed strong seasonality of water demand. Weekly irrigation was necessary in summer to prevent soil from drying, whereas from December to February, water demand was minimal and it could be supplied by occasional winter rains or a single irrigation per month. Fortunately, there was a rough correspondence between peak blowdown production and peak water demand of plants at this location. This facility was a "peaking plant", designed to provide supplemental electricity when lower-cost sources were not sufficient to provide local needs. In the southwest United States, peak demand is associated with the air-conditioning season, running from May to September. At other locations, methods for storing or disposing of blowdown generated in winter when consumptive demand by plant is low, would have to be developed.

Irrigation of Landscape Plants with Moderately Saline Blowdown Water

Brine from HVAC systems is generally less saline than brine from power plant cooling towers, since they are not subjected to the same regulatory requirements for recycling. We tested the feasibility of recycling HVAC cooling tower blowdown to irrigate the type of plants that are typically used in southwest landscaping projects. We grew nine tree, shrub and groundcover species for three years in test plots at the Tucson Electric Power Company's Irvington Road Generating Facility (Table 1)(Gerhart and Glenn, 2000). They were irrigated with well-water (335 ppm TDS), blowdown water (2,340 ppm TDS) or a mixture of the two (1,338 ppm TDS). The two saline treatments are within the TDS range generated by institutional cooling towers (e.g., Engel et al., 1985). Plants were grown in individual holes augured into the local sandy-loam soil, backfilled with a mixture of soil and peat-based planting mix. Holes for trees and shrubs were 1.5 m deep while those for groundcovers were 1 m deep (all holes were 1 m in width). As with the experiments described above with halophytes, soil moisture was monitored with a neutron hydroprobe and sufficient water was added to replace that lost to evapotranspiration, with no leaching fraction built in.

Table 1. Landscape plants tested at Tucson Electric Power Plant.

Type	Species	Common Name
Trees:	*Prosopis chilensis*	Chilean Mesquite
	Cercidium var. Desert Museum	Desert Museum Palo Verde
	Acacia stenophylla	Shoestring Acacia
Shrubs:	*Sophora secundifolia*	Texas Mountain Laurel
	Leucophyllum spp.	Texas Ranger hybrids
	Caliandra californica	Fairy Duster
Groundcovers	*Malephora spp.*	Ice plant
	Rosemarinus officinalis	Rosemary
	Dalea greggii	Dalea

Although the test species were not chosen based on salt tolerance, there were no significant effects of salinity treatment on yield or annual water use of any of the test species. This is a significant finding, indicating that water up to 2,3400 ppm TDS (over twice Colorado River salinity) can be used for irrigation of common municipal landscape plants. As expected, there was a significant effect of irrigation treatment salinity on soil salinity, with soil cores showing a linear increase in soil salt content with increased salinity of the irrigation supply. However, soil salinity did not increase over two years, indicating that a mass balance within the planting holes might have been achieved (salts in = salts out). Although no leaching fraction was supplied, rainfall must have moved salts below the root zones.

During the first two years, irrigation was supplied to meet plant water demands. By monitoring soil moisture levels over two years, we were able to develop monthly crop coefficients for each species. We correlated plant water demand per unit canopy area with potential evapotranspiration, calculated from local meteorological data using Blaney-Criddle or Penman ET formulas. This step is required by the Arizona Department of Environmental Quality, in setting best management practices for the reuse of industrial waste water on plants. However, we found that this lead to relatively high rates of water application to plants (15-20 l/day for trees and 3-6 l/day for shrubs and groundcovers) and rapid growth of plants, which led to split trunks and high maintenance requirements. High water use and high yields is desirable for crop plants, but the goal for landscapes is to maintain the appearance of the plants while minimizing growth and water use, to reduce maintenance requirements. In year three, we irrigated with 50% of monthly water demand (based on data from year two). Plants maintained appearance under this restricted schedule, but effects on soil salt profiles has not yet been evaluated.

Conclusions

Despite the positive research results by ourselves and others, large-scale reuse of saline water for agriculture or landscaping is not yet common. Halophyte forages tend to be of lower quality than conventional forages; they have lower protein and higher mineral content and may become woody over several years of cutting. As wild plants, they are invariably more difficult to grow and harvest than conventional crops, even if specialized equipment is not required. Irrigating with highly saline water requires careful management and a high level of agricultural skill. Feed lots will be reluctant to incorporate alternative forages with an economic incentive – thus, halophytes will almost inevitably represent low-value crops requiring high maintenance. Farmers will not undertake halophyte farming unless it turns out to be the most cost-effective means of disposing of agricultural drain water in a given irrigation district. This may turn out to be the case in the San Joaquin Valley, where selenium (leached from soils) presents a special disposal problem. In the future, as non-sustainable disposal methods such as deposition in closed basins such as Salton Sea become untenable, reuse of drain water for halophyte crops may become common. Eventually, there may be enough economic incentive for biotechnology (seed) companies to improve the agronomic characters of halophytes, or find ways to introduce high tolerance into conventional crops. As an oilseed and vegetable crop, *S. bigelovii* may be more valuable than forage halophytes as an initial high-salinity, commercial crop.

Reuse of saline water on urban landscaping presents its own set of risks and unknowns. Landscape architects often specify the quality of water to be applied to their designs. For example, golf courses may be designed for irrigation with water "not to exceed" 800 ppm TDS. Even though the turf grasses typically used on western golf courses can be irrigated with water of much higher salt content, guidelines for how to use this water do not yet exist, and the golf course operator will be assuming risk in ignoring the design criteria. Using water containing 2-3 times more salt than potable water requires careful soil and water management, and there is a risk that the salts can either migrate to the water table or accumulate in the soil profile, presenting a salinity hazard to future users of the land and water. A landscaper will need to have specific knowledge of the geological and hydrological conditions of his site to determine if blowdown can safely be used for on-site irrigation. Obviously, institutional water users will not turn to blowdown brine without a compelling reason. This could happen if regulatory agencies eventually restrict the amount of potable water that can be used on landscape projects. In the face of diminishing fresh water supplies in high-population-growth water districts, it is conceivable that regulators will require the use of wastewaters on landscape plantings ahead of potable waters as a conservation measure. Western municipalities are increasingly using treated sewage effluent for irrigating large, landscaped areas, despite potential or at least perceived public health problems involved in using such water. They are driven in this direction by tightening supplies of fresh water and restrictions on the discharge of waste water into the natural environment. As water supplies and waste disposal options tighten further, methods for the safe use of saline water sources might make this supply available for common use as well. Further research and demonstration projects are required to demonstrate safety and develop best management practices for saline water reuse in the western United States.

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Sustainable use of saline-sodic irrigation waters.

J.D. Oster

Emeritus Specialist and Adjunct Professor
Department of Environmental Sciences
University of California
Riverside, CA

INTRODUCTION

Saline-sodic drainage water is a resource for forage production in the San Joaquin Valley. Some warm and cool season grass species are among the most salt- and boron-tolerant crops. Along the Westside San Joaquin Valley, forages for dairy, beef and sheep production are currently in short supply, a situation that is expected to continue. Using saline-sodic drainage water for forage production could provide a supplemental resource for animal production while reducing the volume of drainage water requiring disposal.

Along the Westside San Joaquin Valley, the salinities of the drainage waters range from 6 to 20 dS/m, SAR's range from 6 to 35, and the boron content in 80 % of the drainage waters is less than 14 mg/L, with 50 % having less than 4 mg/L. The keys to sustainability while irrigating with these waters are: 1) grow the appropriately salt and boron tolerant crops, and 2) use cropping and soil amendment strategies that can prevent the development of adverse soil physical properties. Rainfall, or irrigation with non-saline waters, poses the greatest hazard on lands previously irrigated with saline-sodic waters. The possible consequences include crusting, poor tilth, ponding, and poor aeration.

The key to sustainable soil management is to recognize the connection between the salinity of the soil solution and irrigation water and sodicity with respect to the stability of soil structure and soil permeability to both air and water. There are two principles that need to be applied: 1) Irrespective of the degree of exchangeable sodium percentage, it is possible to maintain soil permeability by choosing the appropriate salinity level in the irrigation water, 2) Mechanical disturbance of the soil, such as that generated by the impact of water drops, or water flow across the soil surface, increases the decline in soil structure.

Irrigation with saline-sodic waters also raises the issue of reclamation. Can soils irrigated with saline-sodic drainage water be reclaimed once salinity and sodicity levels are too high for salt and sodium sensitive crops? I believe the answer is yes for reasons given in the final paragraphs of the Discussion Section. However, I also believe it would be better to bypass the need for reclamation. This could be done by dedicating lands over the long-term, as is done for evaporation ponds, to crop production systems that can be sustained when irrigated with only saline-sodic water.

DISCUSSION

Theoretical background

For negatively charged clay surfaces, the exchangeable cations balancing the negative charge on the surface experience electrical forces attracting them towards the surface and thermal motion causing them to diffuse away from the surface. As a consequence, the cation concentration decreases with distance from the clay surface. The distance from the clay surface where the cation concentration is the same as the cation concentration in the outside solution is known as the Debye length (Verwey and Overbeek, 1947). This length depends on the charge of the exchangeable cation and the salt concentration, or salinity in the outside solution (Table 1).

Table 1. The Debye Length in nm (1 nm = 10^{-9} m). For comparison, the diameter of the water molecule is about 0.3 nm.

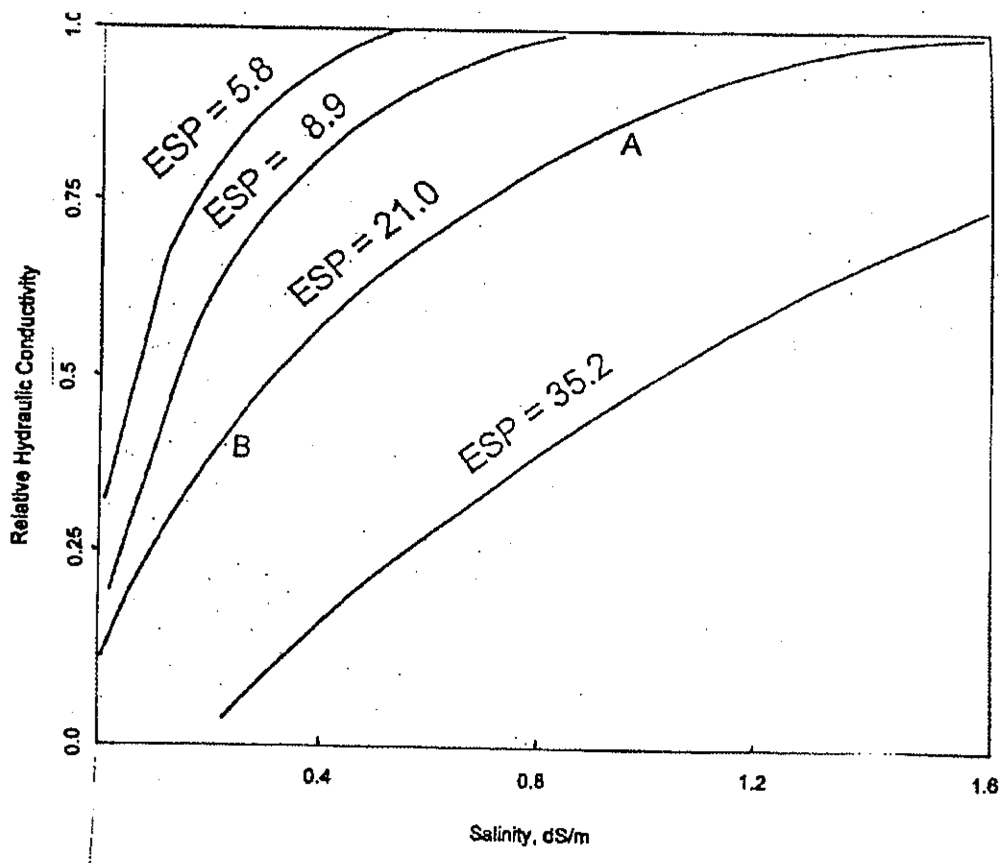
Molar Concentration (approximate salinity in dS/m) of the outside solution				
Salt	ESP	0.1 (10 dS/m)	0.01 (1.0 dS/m)	0.001 (0.1 dS/m)
NaCl	100	0.96	3.0	9.7
$CaCl_2$	0	0.56	1.8	5.6

When two negatively charged clay crystals are sufficiently close for the two layers of cations to overlap, the resulting concentration of ions at the mid-plane between the particles is greater than that in the outside solution. This difference in ion concentration gives rise to an osmotic pressure difference which tends to draw water between the clay plates, causing them to move further apart, or to swell. The degree of swelling increases with increasing exchangeable sodium and decreasing salinity in a manner similar to that for the Debye Length (Table 1).

Soil permeability to water

One of the first applications of Verwey and Overbeek's theory to saline and sodic soils was done by Quirk at the University of London in about 1950. He measured changes in the rates water percolated through a soil as a result of changing its exchangeable sodium percent (ESP) and the electrolyte concentration of the percolating solution (Quirk and Schofield, 1955). The soil was obtained from Sawyers 1 Field at the Rothamsted Experimental Station. Reeve (1960), an replotted Quirk's data (Figure 1) in a manner where it is clear that as the ESP increases, higher levels of soil salinity are required to maintain hydraulic conductivity. Also, it is clear that increased levels of soil salinity will increase hydraulic conductivity for a given ESP.

Figure 1. Effects of salinity and exchangeable sodium percent (ESP) on relative hydraulic conductivity of Sawyer Soil (Reeve, 1958).

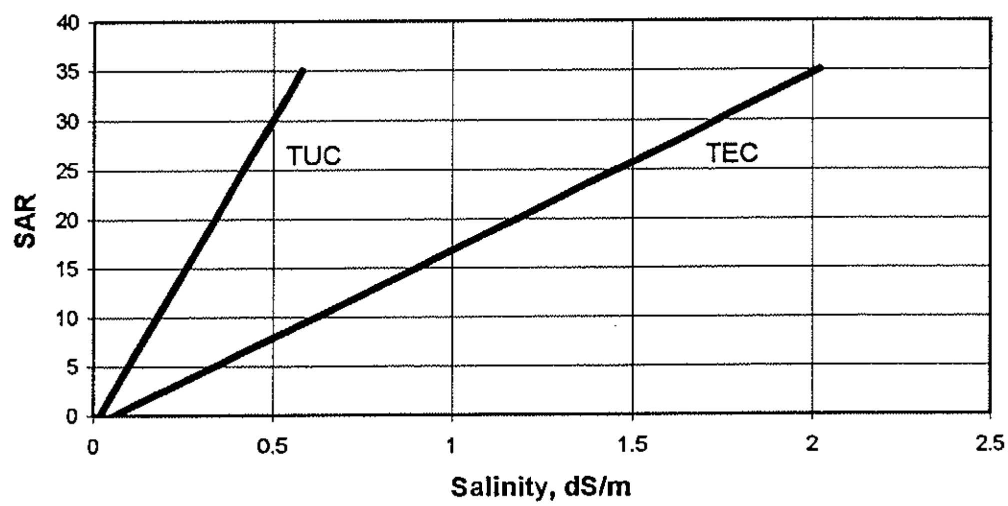


The salinity effect occurs at ESPs as low as zero as documented by research studies conducted since 1955 (Sumner, 1993).

Quirk choose a 15 percent reduction in the rate water moved through the soil as the first discernible deterioration of soil structure, and defined the concentration where this occurred as the threshold concentration (TEC). Further, Quirk observed the water that drained from the column became turbid at a quarter of the threshold concentration, indicating the presence of dispersed clay crystals. He called this the turbidity concentration (TUC). In Fig.1, the threshold and turbidity concentrations for an ESP of 21 are indicated at A and B respectively.

Both TEC and TUC increased linearly with increasing ESP (Fig. 2). Each of the lines in Fig. 2, divide the figure into two parts. Salinity levels to the right side of the TEC line were sufficient to maintain the hydraulic conductivity of the Sawyer soil (Quirk and Schofield, 1955). Salinity levels on the left side of the TEC line resulted reduced hydraulic conductivities, with the reduction increasing as salinity decreased (Fig. 1) for a given ESP (or SAR when ESP < 40). A similar situation occurred for TUC, but at much lower salinity levels than for TEC. Salinities levels to the right side of the TUC line were sufficient to prevent turbidity, whereas those to the left of the TUC line were not.

Figure 2. Dependence of the threshold electrolyte (TEC) and turbidity (TUC) concentrations on the SAR and salinity of the soil solution (Adapted from equations given in Quirk and Schofield, 1955 and Quirk, 1971).



In a forthcoming review article, Quirk (2001) describes the mechanisms that cause a decrease in the ability of the soil to conduct water as follows:

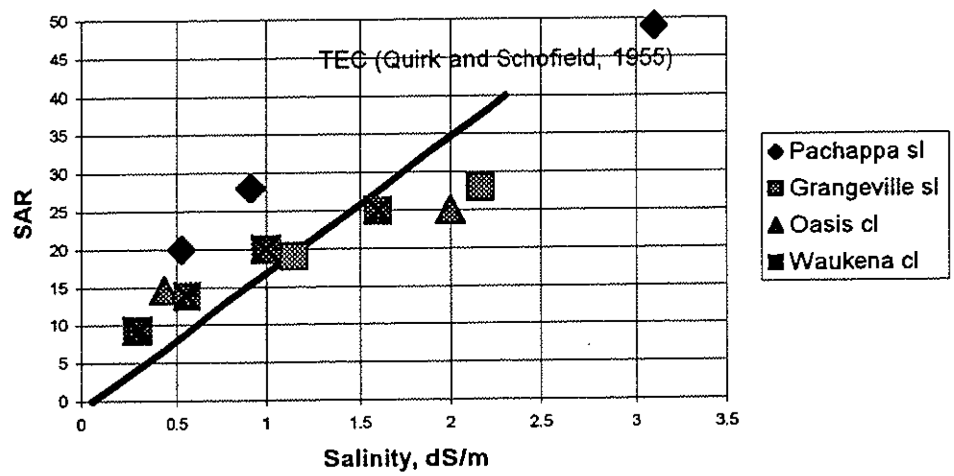
1. "Swelling results in the blocking or partial blocking of the larger conducting pores, and as flow through a pore is proportional to the fourth power of the radius, then appreciable decreases in permeability may result where the swelling is small."
2. "Failure of the soil aggregates is brought about by stress resulting from unequal swelling throughout the soil mass. In this connection organic matter is capable of acting to prevent failure."
3. "Deflocculation can be regarded as occurring when the charged plates, which are moving apart in the process of swelling, have reached such a distance of separation that the attractive forces are no longer strong enough to oppose repulsive forces."

Since the velocity of flow was small during the permeability studies on the Sawyer soil, Quirk (2001) considers the TUC relationship given in Fig. 2 to correspond to spontaneous dispersion, or deflocculation, of soil aggregates that occurs in the absence of mechanical agitation. Quirk believes that between the TEC and TUC, the microstructure progressively deteriorates but that this deterioration is probably reversible upon drying to a significant extent. However, below the TUC, the microstructure is irreversibly dismantled.

Starting in about 1960, Brian McNeal conducted experiments with California soils, using Quirk's techniques. The resulting data (McNeal and Coleman, 1966) were in reasonable agreement (Fig. 3) with those reported by Quirk and Schofield (1955).

Along the Westside San Joaquin Valley, the salinities of the drainage waters range from 6 to 20 dS/m, SAR's range from 6 to 35. Should one expect degradation in the rate water redistributes within the soil as a result of irrigating with these waters? The answer is no, assuming the soil salinity and sodicity will reflect that of the irrigation water. These salinities are more than adequate (Fig. 3) to maintain existing hydraulic conductivities. Furthermore, the hydraulic conductivity may increase because of the high salinities (Fib. 1).

Figure 3. Comparison of the combinations of SAR and salinity that resulted in 25 % reductions in hydraulic conductivity of California soils (McNeal and Coleman,1966) to those that resulted in a 15 % reduction in the Sawyer soil (Quirk and Schofield, 1955).

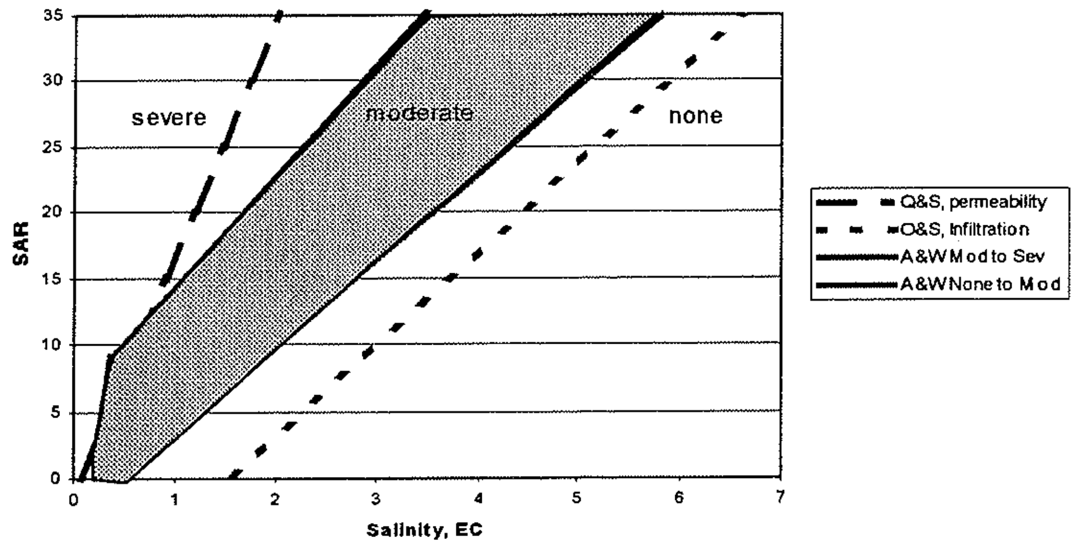


Infiltration rates

"Any agitation in addition to that of flow through pores would result in a more rapid loss of permeability and structure (Quirk 2001)." Agitation at the soil surface occurs because of the mechanical and stirring action of falling water drops and overland water flow. Seal formation at the soil surface results from two processes: (1) physical disintegration of soil aggregates and soil compaction caused by the impact of water, especially water drops; (2) chemical dispersion and movement of clay particles which results in the reduction in the pore size distribution in the surface layer of soil and plugging of conducting pores below this layer. Both processes occur simultaneously, with the first enhancing the second. Consequently, infiltration rates are particularly sensitive to SAR and salinity. And, at the soil surface both are closely linked to the SAR and salinity of the irrigation water.

When Ayers and Westcot (1985) developed their water quality guidelines they were aware that infiltration rates were particularly sensitive to SAR and salinity. Fig. 4 shows how their guidelines relate to that for TEC (Figs 2 and 3) and to the combinations of SAR and salinity of the irrigation water that resulted in 25 % reductions in steady state infiltration (Oster and Schroer, 1979) of cropped, undisturbed columns of Heimdal loam.

Figure 4. Ayers and Westcot (1985) water quality guidelines compared to the threshold salinities for hydraulic conductivity (Quirk and Schofield, 1955) and for infiltration rates (Oster and Shroer, 1979).



Rainfall or irrigation with nonsaline irrigation water, on soils previously irrigated with saline-sodic drainage water, will lower the soil salinity at the soil surface to a greater extent than it will lower the SAR. For example, if the soil salinity were 8 dS/m and the SAR were 20, rain could reduce the salinity to 1 dS/m but the SAR would likely remain above 10. Under this circumstance, a severe reduction in infiltration rates could occur if the soil surface were bare, particularly if it had been recently tilled. If gypsum was applied to the soil surface before rain or irrigation with a non-saline water, the reduction in infiltration rates would be smaller (Frenkel and Hadas, 1981). Gypsum dissolution would increase salinity of the soil solution and provide a source of calcium to reduce ESP. A full crop cover would be another management technique to help stabilize soil aggregates and maintain infiltration rates. For example, long-term pasture cropping stabilizes aggregate stability; the increase in aggregate stability being associated with the increased organic matter content (Greacen, 1958; Greenland et al, 1962), and the protection against agitation of the soil surface provided by the crop cover. Cropping strategies, the timing of cultivation, method of water application, and the use of chemical amendments provide management options that can significantly change how infiltration rates are impacted by SAR and soil salinity.

Reclamation by bioremediation

Along the Westside San Joaquin Valley, the saline-sodic drainage water will be chemically saturated with respect calcite, and likely also with gypsum. The soils are calcareous and usually also gypsiferous and will remain so when irrigated with saline-sodic drainage water that are in chemical equilibrium --- "saturated" --- with calcite and gypsum. Under these circumstances irrigation of salt tolerant crops with nonsaline water, bioremediation, would be the preferred method of reclamation (Kelley and Brown, 1934; Kelley, 1937). Reclamation by bioremediation relies on the dissolution of calcite within the rootzone to provide the calcium needed to reduce the ESP. This dissolution is enhanced by the elevation of the partial pressure of carbon dioxide that occurs within the rootzone as a result of root respiration (Robbins, 1986).

Subsurface drainage would be essential for any reclamation method to work. It could be natural with discharge into the strata underlying the land. However, more than likely, it would need to be a tile drainage system, with the drainage water discharged into an evaporation basin.

It would be helpful, if the salt tolerant crop were able to grow when the soil is very wet, if cropped conditions could be maintained year round, and if tillage were not necessary. For example, Bermuda grass grown during the summer top seeded with rye grass during the winter would be a good cropping strategy. As for harvesting, one could use periodic grazing, or harvesting by green chop for direct feeding or ensiling, or haying and baling. Periodic drying would be desirable to facilitate deeper root activity and a deeper depth distribution of reclamation. This forage cropping strategy could continue until the soil has been reclaimed to a level where more salt and boron sensitive crops can be grown. "Field crops, particularly barley, wheat, sorghum, cotton, and sugar beet, are real tools for use in reclamation, or as transition crops to "get acquainted" with soils and to get from "where we are" to "where we want to be" from the standpoint of soil salinity, Na, and B. By utilizing more water on these crops than is actually needed, salts, Na, and B can be leached beyond the reach of roots, and the soils can be prepared for later plantings of more sensitive high-income crops." (Dean's Committee, Univ. California, 1968). In addition to cropping, surface application of gypsum at rates from 1 – 3 tons/acre, particularly after tillage, would be appropriate. Or one could apply an equivalent amount of sulfuric acid. Both would improve the stability of the soil structure at the soil surface and accelerate its rate of reclamation. Since the soils are naturally gypsiferous, application of gypsum for reclamation of the soil in the rootzone doesn't make sense.

From a historical perspective, bioremediation has the distinction of being the oldest applied research conducted in California referenced in this paper. W.P. Kelley in the 1920s and 1930s (Kelley and Brown, 1934; Kelley, 1937) did it at the Kearney Ranch near Fresno. The soil was a calcareous fine sandy loam with the following chemical properties in the upper foot: pH = 9.2 – 9.7, $EC_{1:5}$ = 6.1 – 7.2 dS/m, ESP = 57 – 70. In the 1920s, these workers tested two reclamation strategies: gypsum (16.5 tons/acre in two splits: 10 tons/acre in 1920 and 6.5 tons/acre in 1927) in combination with cropping, and cropping only (bioremediation). The treatments were flooded for three weeks using well water (EC = 0.4 dS/m; SAR = 0.7), then cropped with barley, followed by 1-yr green manuring with clover, followed by five years of alfalfa. The ESP in the upper foot decreased from 70 to 5 in the gypsum-treated soil and from 65 to 6 in the bioremediated plots (Table 2).

In the 1930s, Kelley (1937) conducted a bioremediation experiment, without gypsum, over a period of eight years. Bermuda grass was the first crop and grown for two years. The following crops were barley (1-yr), alfalfa (4-yr) and oats (1-yr). The ESP of the upper foot of soil decreased form 57 to 1 (Table 2), and with a reduction to an average ESP of 6 in the profile to the depth 4 feet. This decrease in ESP was even greater than that brought about by the gypsum treatment of the earlier experiment, possibly due to the use of Bermuda grass at the start of the cropping sequence.

Table 2. Effect of gypsum and cropping on the ESP of Fresno soil (Adapted from Kelley and Brown, 1934 and Kelley, 1937).

Depth interval	1920 - 30				1930 - 37	
	Gypsum + Cropping		Cropping only		Cropping only	
	Initial	Final	Initial	Final	Initial	Final
ft	percent					
0 - 1	70	5	65	6	57	1
1 - 2	67	8	70	21	97	4
2 - 3	54	9	46	26	90	13
3 - 4	35	19	28	53	46	4
Average	49	10	52	27	73	6

Application of the Kelley findings to the finer textured soils of the Westside may be a reach. However, vineyards were planted on the Westside in the 1970s on soils where the bioremediation techniques referred to in the Dean's Committee report (1968) were used. In 1966, I saw Bermuda grass being grown to reclaim a field of fine textured soil in the Wellton-Mohawk Valley of southwestern Arizona. According the farmer, there was a market for both Bermuda grass hay and seed. In addition, he knew that it would grow well in salt-affected soils, and once it didn't, considerable reclamation had occurred. This is consistent with the effects of salinity on the growth of halophytes, a class of plants to which Bermuda grass belongs. Growth of Bermuda first increases with increasing salinity up to about an ECe of 8 – 10 dS/m; above these levels, growth declines as salinity increases.

CONCLUDING COMMENTS

Published laboratory and field research support the conclusion that saline-sodic drainage waters are a resource for crop production, particularly when used to grow salt tolerant forage crops. Cropping strategies that maintain a year-round ground cover would minimize the adverse impacts of rainfall, and periodic application of nonsaline-sodic irrigation waters, on infiltration rates and on the permeability of soil to both air and water. Dedication of lands to cropping systems that rely on irrigation with saline-sodic irrigation waters would eliminate concerns about reclamation. However, if for some reason these dedicated lands would need to be reclaimed, farmer experience, supported by published research, support the conclusion that reclamation is possible. I believe that through the use of appropriate crop and soil management practices, irrigation with saline-sodic drainage waters can be sustained over the long run without causing irreversible damage to soil permeability to water and air.

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OVERVIEW OF DAIRY LAGOON WATER NUTRIENT MANAGEMENT

C.A. Frate
University of California Cooperative Extension
2500 W. Burrel Avenue
Visalia CA 93291
Tele: 559-733-6483, FAX: 559-733-6720
e-mail: cafrate@ucdavis.edu

M. C. Mathews
University of California Cooperative Extension
3800 Cornucopia Way, Suite A
Modesto CA 95358
Tele: 209-525-6800, FAX: 559-525-6840
e-mail: mcmathews@ucdavis.edu

Most dairies in California have ponds, also often called lagoons, into which they put and keep "waste" water from the dairy facility. Wash water from holding pens prior to cows entering the milk barn comes into these ponds as well as all captured water from run-off during rainy periods. For those dairies with manure flush systems this water is also recycled to flush alleyways.

The fact that this water contains important crop nutrients such as nitrogen, phosphorus and potassium, as well as micronutrients, has been recognized for years. Pond water has been applied to cropland since pond systems were established. Testimony from growers about how lagoon water has improved marginal lands is common. However as farming becomes more intense, concentrated, and sophisticated, and as environmental concerns have increased, utilization of this nutrient resource is coming under scrutiny. And the fact of the matter is that pond water management in the future will have to be improved.

The two nutrients contained in the largest quantities in pond water are usually nitrogen and potassium. This paper primarily addresses the nitrogen aspect of improved lagoon water management because environmental concerns about dairy lagoon water use in California mostly focus on the potential of over application of nitrogen to crops and subsequent leaching of nitrate to groundwater. In other parts of the country, phosphorus is becoming at least as much of a concern, if not more so, as nitrogen. Salts are also a concern; in the Tulare Basin they are more of a limiting factor for crop application than nitrogen.

Nitrogen exists in two forms in lagoon water: as ammonium ions and in organic compounds. Soil temperature is the primary factor for determining the rate that ammonium ions are converted to highly leachable nitrate ions. Organic nitrogen also is also converted to ammonium and then to nitrate but the rate at which this occurs with organic nitrogen from lagoon water is not understood at this time. Soil type and irrigation practices will also influence the likelihood of nitrate leaching below the root zone.

Currently, pond water application is mostly unmeasured with only a rough guess on the amount of nutrients applied. Timing of applications is often based more on when the pond is full rather than on crop demand. When pond water is pumped, very few dairies are measuring how much is being pumped or recording which field(s) is receiving the water. Therefore it is only a guess, at best, as to how much went on a field. Analysis of lagoon water to determine the concentration of nitrogen is not routinely done. Most users of lagoon water reduce applications of commercial nitrogen in fields receiving lagoon water, but they do so on a trial and error basis and tend to err on applying more than necessary rather than less.

Components Needed for Lagoon Water Nutrient Management

What is needed for improved utilization of the crop nutrients within lagoon water? The goal is to apply the nutrients in the lagoon water when crops need it and at the amounts they need. Lagoon capacity, available acres, nutrient analysis, water delivery to fields, irrigation distribution uniformity within fields, an understanding of crop nutrient requirements, a system of record keeping, and an evaluation method are all important components of a lagoon water management system.

Sufficient lagoon capacity is critical to provide flexibility for timing manure water applications to coincide with crop needs. For dairies that have limited lagoon storage capacity, timing applications to periods of crop demand is difficult. When push comes to shove and the pond is full, water has to be taken out and applied to crops even if they are not actively growing and are not taking up nutrients at the time. In December, crop growth and therefore crop nutrient demand is minimal in the San Joaquin Valley. If water needs to be let out of a lagoon during this time, the applied nutrients, especially nitrogen, may no longer be in the root zone for crop uptake when temperatures and crop growth increase in February. Leaching and volatilization are potential methods for nitrogen loss. Soil type and weather will greatly influence these processes.

Crop acreage and nutrient uptake need to at least match the potential nutrient application amounts in a lagoon. For example, if a lagoon over the course of a year holds the equivalent of 70,000 lbs. of nitrogen and the pond water is applied to only 100 acres, this represents an average of 700 lbs. nitrogen to each field, more than most crop systems will take up. In some cases, a dairy has sufficient acreage on paper but the need in the future will be to get the irrigation plumbing in place that allows delivery of lagoon water to the available acres. If, on the other hand, there is a shortage of nutrients in lagoon water to meet crop needs, supplemental fertilizer can be applied or lagoon water applications can be restricted to fewer fields.

There should be a way to dilute lagoon water with fresh water. Applying straight lagoon water often results in an over application of nutrients and can be harmful to crops if salt concentration is high. In addition, fresh and lagoon water must come together in a way that allows adequate mixing prior to field application. If the two meet head-to-head at the valve, one side of the irrigation set will have mostly lagoon water and the other side mostly fresh water, resulting in an uneven application of nutrients.

Because lagoon water is distributed in the irrigation system, be it flood, furrow, sprinkler, or possibly even drip, the distribution of nutrients will only be as uniform as the distribution of water in the field. In this regard application of lagoon water can be as effective as any water-run fertilizer application but, depending on the irrigation system, may be less efficient than broadcast or injected applications. Fields in which water infiltration is much higher at the head or tail end of the field will have higher nitrogen applications in those areas. Different soil types within a field can make for less uniform applications.

To determine the amount of nutrient applied during an irrigation, the amount of water applied to a given acreage and the concentration of the nutrient in that water must be known. Measurement of lagoon water presents a challenge. Propeller meters, which are inserted into pipelines, have been the most commonly used tool for measuring applied water in agriculture. However they do not work in water that has lots of solids and foreign materials, such as cow hairs, string, parts of plants, and a lot of other "stuff" that may blow or fall into an uncovered lagoon. In the last few years, people have looked at the types of meters used in human waste treatment plants to find what will work with dairy water. Most are based on electromagnetic measurements (magmeters) or sound measurements (Doppler meters). Most have no, or very minor, protrusions into the pipeline for "stuff" to snag on and accumulate. These meters are more expensive than people in agriculture are used to paying, costing $1500 to $3000 more than propeller meters.

There are other methods to measure lagoon water use but none provide the accuracy and relative ease of a meter. Measuring pond drop, for example, may seem straightforward but the results are often inaccurate due to pond inflows, sides that are not straight or are not uniformly sloped, and reading the drop during a night irrigation. Another method is pump discharge and the hours of pump operation. Discharge, however, will vary with the level of the lagoon, the amount of solids being pumped, and if there is wear or debris on the impeller. For accuracy and ease of management, flow meters will probably become the most common method of measuring lagoon water applications despite their cost.

Flow meters, to be accurate, have to be placed correctly relative to bends, valves, intersecting pipes, and anything else that can disturb an even flow, or a uniform velocity across the cross section of the pipe where the meter is located. A general rule is that flow meters should be placed at least 10 pipe diameters downstream and 5 pipe diameters upstream of any elbow, tee, or pipe junction. Valves distort water flow even more than elbows and tees and should be placed downstream of a meter or a minimum of 25 pipe diameters upstream of a meter.

Flow meters also only give correct readings for pipes that are full so a pipe on a level or downhill slope will need modifications to ensure that the pipe is full at the location of the meter. One way to be sure that a pipe is full is to have a rise in the pipeline equal to 1 pipe diameter downstream from the meter. If the meter is located near the highest point of the pipeline, air pockets could be a problem.

A number of producers have installed lagoon meters and most have had to make at least one modification to their system. Some of these have included extending a pipe to make a straight run, adding a section of pipe to the flexible hose as it comes out of the lagoon, or adding an elevated area to ensure the pipe is full at the meter location.

Analysis of lagoon water to determine concentrations of nutrients is essential to calculating the amount of nutrients applied to fields. Sampling from lagoons may be difficult due to the physical layout and also due to variability of nutrient concentration within the lagoon. Samples from one part of the lagoon may not have the same concentration as the water being pumped. The easiest way to sample lagoon water is to install a sampling port in the outflow pipe from the lagoon. After collection, samples can either analyzed by a lab or by a "quick test" developed by UCCE Farm Advisor Marsha Campbell Mathews. When sent to a lab, results usually aren't available for several days and the amount of nitrogen applied would be calculated after the irrigation was finished. With this information subsequent irrigations with or without lagoon water can be planned. For example, if the irrigation applied 150 pounds of readily available nitrogen, then the decision might be to not use lagoon water in the next irrigation. On the other hand, if the irrigation only resulted in an application of 25 lbs. of readily available nitrogen and the corn is in its rapid growth stage, additional fertilizer may be necessary. This type of strategy is based on hindsight and is reactive

The development of a quick test for ammonium nitrogen allows the determination of ammonium nitrogen concentration in lagoon water in a matter of minutes. With this quick information, one can know in advance what rate the irrigation is going to apply or, if the flow from the lagoon can be regulated, a desired rate can be applied.

A method of regulating lagoon water flow is necessary for proactive lagoon water management and nutrient application. A valve on the outflow pipe or a variable frequency drive (VFD) on the lagoon pump will allow the amount of nutrient application to be regulated. Knowing the nutrient concentration, the best estimate for the time duration of the irrigation set, and the number of acres to be irrigated, the needed flow rate from the lagoon in order to apply a specific nitrogen application can be calculated. The valve or VFD can be adjusted to achieve the calculated flow rate and the desired application rate. With this system, nitrogen rates can be tailored to crop demand, with lower rates applied during periods of low crop uptake and higher rates applied when crop demand is high. Proactive management may be necessary on soils with high infiltration rates and shallow groundwater where the possibility of nitrate leaching to groundwater is high. In these situations, the matching of nutrient application rates to crop demand at the time is very important. Soils with less potential for leaching may not need to be managed as intensively as lighter soils.

For dairies where the design of the irrigation system allows fields to be irrigated with lagoon water one at a time, having one meter at the pond and testing straight lagoon water is a relatively easy way to track nutrient applications. In situations where lagoon water is pumped into the pipeline, fresh water comes from more than one source, and more than one field is irrigated at a time, it is not so easy. In these cases, the fresh/lagoon water mixture that is being applied to each field needs to be analyzed and the volume of the mixed water being applied to the field needs to be measured. This will require more meters or the use of portable meters that can be inserted in various spots in the pipeline. In these situations, targeting application rates will also be more difficult as adjustments to lagoon water flow in the pipeline will impact the rate applied to more than one field.

The goal of using lagoon water is to provide the amount nutrients a crop needs without reducing yield and also to avoid over-application. In-season plant tissue testing can help confirm if plants have sufficient nitrogen, hopefully in time to allow additional applications if needed. From the yield and nitrogen content of the harvested crop, the amount of nitrogen removed from the field can be calculated. Soil testing can provide information useful in evaluating if over applications have been made and for determining needs of following crops. All of this information will be useful in assessing if the goal of providing crop needs while avoiding excessive rates is being achieved.

Obviously, record keeping of lagoon water use, irrigations, nutrients applied to specific fields, crop yields and nitrogen content will be critical to manage the system. For each dairy/farm this will entail developing useful and practical ways of information input and organization that can be integrated into the way the dairy producer/grower and employees, including irrigators, do business.

Summary

In summary, the management of lagoon water nutrients will involve changing not only some of the infrastructure of lagoons and pipelines to fields but also changing the mindset of lagoon water users. When contemplating the manipulation of entire lagoon and irrigation systems, it is hard to know where to start. There are generalized rules for estimating lagoon water and nitrogen output for a dairy but, when considering some major changes in irrigation systems and their management, more accurate information is needed. The placement of a meter at the lagoon and the nutrient analysis of lagoon water over a 12-month period may be the best "first step" for any dairy. The information gained, taking into account the rainfall and lagoon management for that year, will provide the dairy with the most accurate picture of the total amount of water and nitrogen available. With this information, the amount of acres needed for nitrogen utilization can be determined, which will assist in evaluating pipeline capacity and water delivery strategies.

Lagoon Water Composition, Sampling and Field Analysis

M. Campbell Mathews[1], C. Frate[2], T. Harter[3], S. Sather[4]

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

[2]Tulare County U. C. Cooperative Extension, Visalia

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

INTRODUCTION

A large part of the manure generated on California dairies is handled using a flush system, where large volumes of water are used to wash manure from alleys and holding pens into a storage basin, commonly called a lagoon or pond. Typically, the water in the pond is recycled many times before being applied to cropland. In order to properly apply the nutrients and salts in dairy lagoon water to cropland, it is essential to understand the constituents in lagoon water and how they may vary over the course of a season or irrigation. Because the nitrogen content of dairy lagoon water cannot always be expected to remain constant, methodologies for rapidly determining the nitrogen content of the lagoon prior to and during irrigation are important tool to facilitate proper application of nutrients.

COMPOSITION OF NUTRIENTS AND SALTS IN DAIRY LAGOON WATER

Methods: During 1999 and 2000, samples of lagoon water were collected from over 60 dairies in the San Joaquin Valley. On many of the dairies, samples were collected on multiple sampling dates. On a few locations, samples were collected over the course of an irrigation so that more than one sample per day was collected. In data sets designated as "unique" in this paper, one sample was chosen at random to represent each sampling date if the composition of the lagoon water remained relatively constant during that period. This was done to insure that survey data was not unduly influenced by a disproportionate number of similar samples from the same sampling time and location. Samples were collected during all seasons of the year and represent dairies mainly in the Stanislaus/Merced and Tulare areas. Most of the ammonium determinations were done at a commercial laboratory using a distillation method. In some cases where laboratory ammonium nitrogen values were unavailable, ammonium was determined using the colorimetric method described in this paper. All total Kjeldahl Nitrogen (TKN) determinations were performed at a commercial laboratory using standard wastewater methods.

Nitrogen in Dairy Lagoon Waters

Nitrogen exists in dairy lagoons in two main forms, organic and ammonium. Nitrate nitrogen concentration can be expected to negligible in an anaerobic lagoon (Zhang, 2001). Out of 63 samples where NO3-N was determined, only one had a concentration over 2.12 mg/L. This sample had a NO3-N concentration of 14 mg/L and was from an unusually dilute lagoon where fresh water was being added at the time of sampling.

Total nitrogen (as measured by TKN) in 179 samples ranged from a low of 47 to a high of 2420 with an average of 560 mg/L (table A). In 87.2% (n=156) of the samples nitrogen concentration was less than 1000 mg/L total N. In those samples with concentrations less than 1000 mg/L TKN, which is presumably the majority of lagoon water used for irrigation during most of the year, about one third (33.5%) of the nitrogen was in the organic form (figure 1). Of the remaining 13% of samples with total N over 1000 mg/L, two-thirds (66.3%) of the nitrogen was in the organic form. Usually lagoon water in this category is drawn from the bottom of lagoons and can be difficult to apply at low rates because of problems with plugging of pipelines and valves. Although mineralization rates for lagoon water organic nitrogen are not known at this time, there is evidence that the ignoring this fraction can result in application of excessive amounts of nitrogen (Meyer, 2001).

The average NH_4-N in all 179 unique samples was 299 mg/L. The highest four NH_4-N concentrations were 606, 662, 791 and 942 mg/L. The highest value came from treatment lagoon. All other samples were less than 550 mg/L. This would suggest that the majority of San Joaquin Valley dairy lagoons are not so heavily loaded that the activity of methanogenic bacteria is inhibited.

Table A. Nitrogen concentration (mg/L) in San Joaquin Valley dairy lagoons, 1999-2000

All Samples (n=179)			TKN<1000 (n=156)			TKN>1000 (n=23)		
NH_4-N	Org-N	Total	NH_4-N	Org-N	Total	NH_4-N	Org-N	Total
299	262	560	274	151	425	466	1016	1482
942	2080	2420	942	613	980	791	2080	2420
13	11	47	13	11	47	340	540	1020

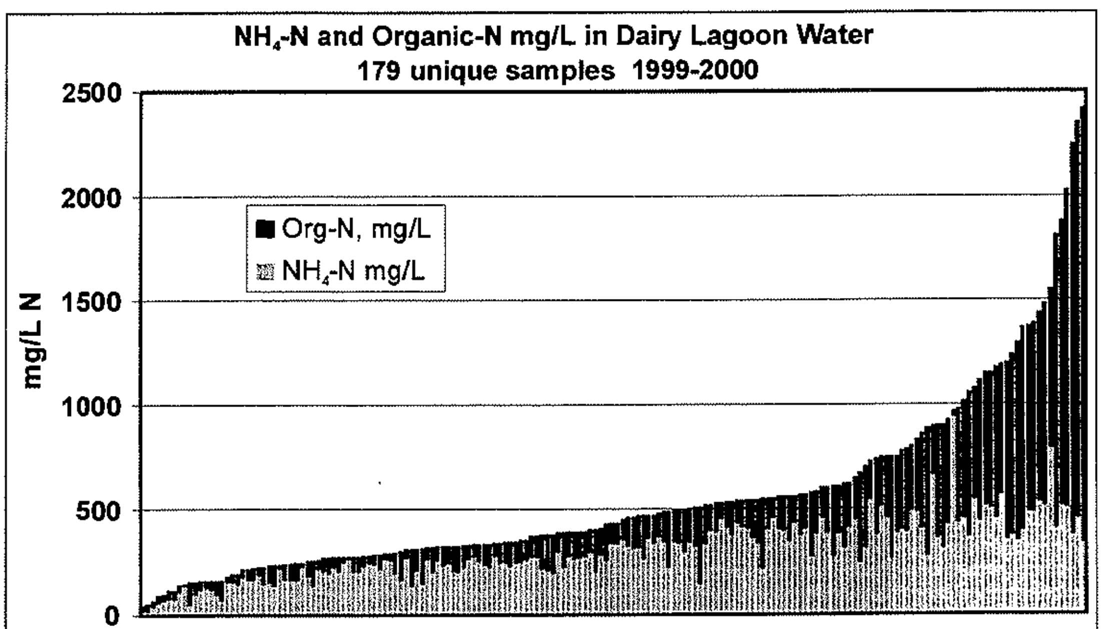


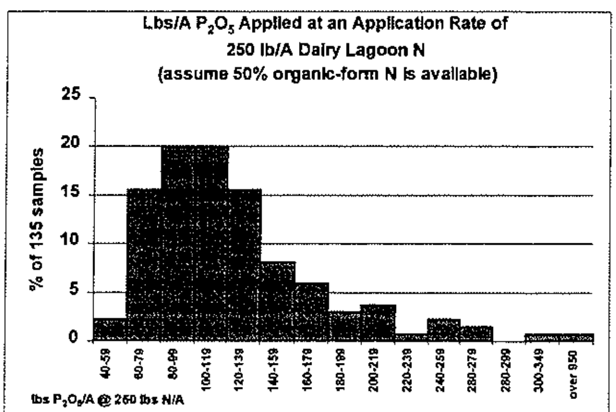
Figure 1. Relative fractions of total nitrogen (TKN) in San Joaquin Valley lagoons

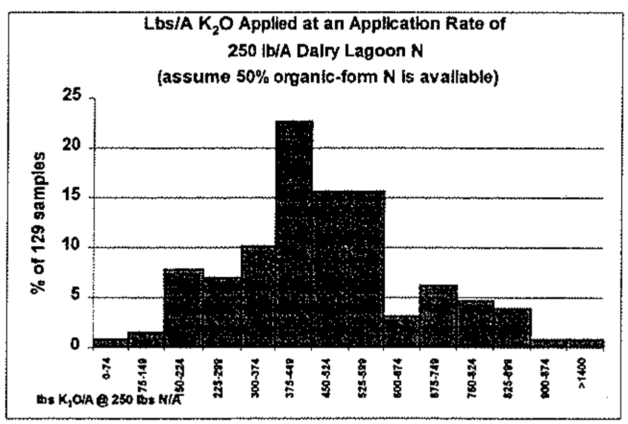
Other Nutrients and Salts in Dairy Lagoon Waters

Dairy lagoon water contains other crop nutrients in addition to nitrogen, as well as salts such as sodium and chloride which are not considered to be crop nutrients. There is potential for any of these to degrade ground or surface waters if applied in excess amounts. To determine the potential application rates of other nutrients and salts from lagoon water if the lagoon water nitrogen is applied at agronomic rates, calculatons were made based on lagoon samples analyses.

The accepted values for uptake of phosphorus and potassium by a 30 ton/A silage corn crop are 105 lbs P_2O_5 per acre and 250 lbs K2O per acre, respectively (CFA, 1985). Fifty percent of the lagoon waters would have provided inadequate amounts of phosphorus and 16% would have provided sufficient amounts (106-131.5 lbs P_2O_5/A). Thirty-one percent of the applications would have resulted in application of amounts exceeding 125% of crop uptake. Phosphorous application was higher (average 194 lbs P_2O_5/A) in samples containing more than 1000 mg/L total nitrogen than in the majority of samples with a total nitrogen content of less than 1000 mg/L (average 110 lbs P_2O_5/A). This suggests that a majority of pond water applications will not be result in excessive amounts of phosphorus application if nitrogen rates are reasonable, but that if the pond water has a high nitrogen content (these also tend to have elevated organic nitrogen contents), then phosphorus applications can exceed potential crop uptake.

Projected application rates of potassium at agronomic rates of lagoon water nitrogen application exceeded crop needs in all but 14% of the samples. Many crops, including corn, will take up more potassium than required. Even accounting for 100 lbs /A of luxury consumption, 75% of lagoon water samples exceeded crop uptake for K_2O. Samples with a total nitrogen content of less than 1000 mg/L had higher potassium applications than those higher than 1000 mg/L (table B) not because the concentration of potassium is different but because less lagoon water is needed to meet the crop nitrogen needs. Projected application rates of sodium and chloride are shown in figures 4 and 5 and in table B.



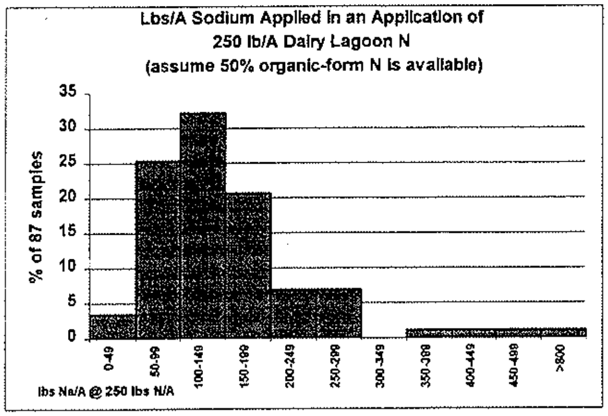


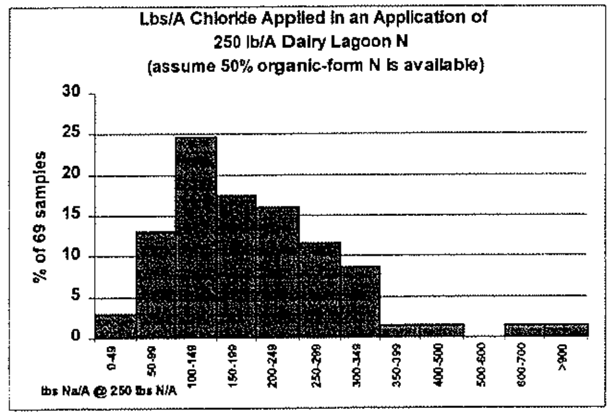
Distribution of samples projected to apply incremental ranges of lbs/A of P_2O_5 (Fig. 2) and K_2O (Fig. 3)

Table B. Pounds per acre of crop nutrients applied when 250 lbs/A lagoon nitrogen is applied (assuming 50% of the organic-form is available)

	Extra Org-N	total P_2O_5	soluble P_2O_5	soluble K_2O	Ca	Mg	Na	Cl	SO_4-S
Pounds per acre nutrient or salt									
avg <1000 mg/L TKN	54	119	74	512	127	71	186	220	30
avg >1000 mg/L TKN	125	194	30	227	57	31	69	68	5
Avg of all samples	63	128	67	477	118	66	171	207	28
Number of samples									
<1000 mg/L TKN	122	118	70	113	95	95	95	63	61
>1000 mg/L TKN	18	17	14	16	14	14	14	6	6

Total num. of samples 140 135 84 129 109 109 109 69 67





Percent of samples projected to apply incremental ranges of lb/A of sodium (Figure 4) and chloride (Figure 5)

Of the positively charged cations that contribute to the measured electrical conductivity (EC) of dairy lagoon water, an average of 34% of the cationic charge was contributed by ammonium, 24% by potassium, 14% by calcium, 12% by magnesium and 17% by sodium. It can be expected that, once applied to the soil, all of the ammonium will be taken up by the crop or converted to nitrate, and that a large percentage of the potassium will also be taken up by the crop. Since ammonium and potassium comprise over half (58%) of the total cationic charge, it can be expected that the long term impacts on the soil of irrigating with high EC lagoon water would be less than would be expected from a normal irrigation water of comparable conductivity.

EC as a predictor of lagoon water ammonium

It has been reported that EC, commonly measured by stick or pen type EC meter, is correlated with ammonium concentration in liquid manure (Van Kessel, 1999, 2000). In a sample set of 169 unique lagoon water samples representing over 55 San Joaquin Valley dairy lagoons, EC was only moderately correlated (r^2=.69) with ammonium concentration, even when disregarding samples with an EC greater than 7.5 dS/m (figure 6). Even when considering only one dairy lagoon (figures 7 and 8), the correlation was too poor to make using EC a reliable predictor of lagoon water ammonium. There are several possible reasons why EC has failed to accurately predict ammonium nitrogen in lagoon water. First, the percentage of lagoon water ammonium ions as a percentage of total cation charge averaged about 34% with a range from 9.3% to 65% in a set of 109 San Joaquin Valley samples. For EC to

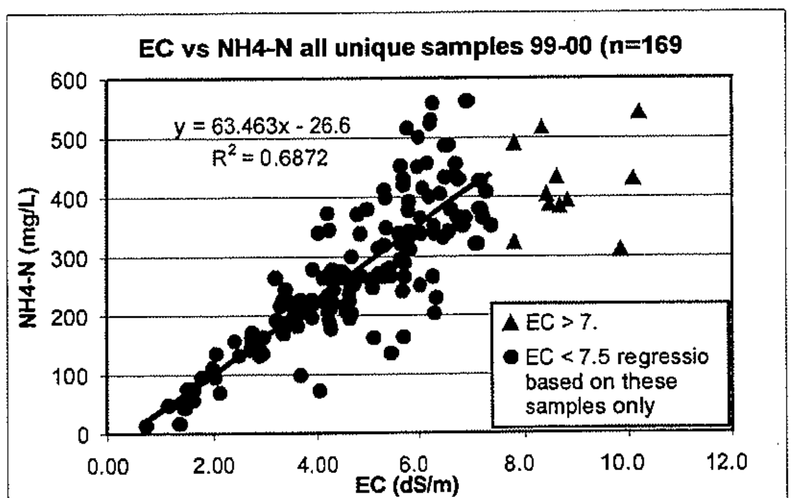
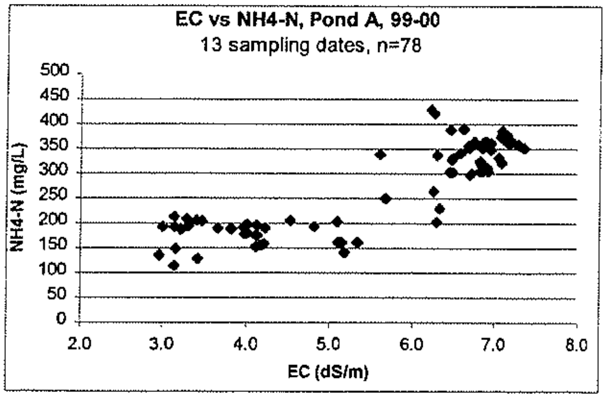
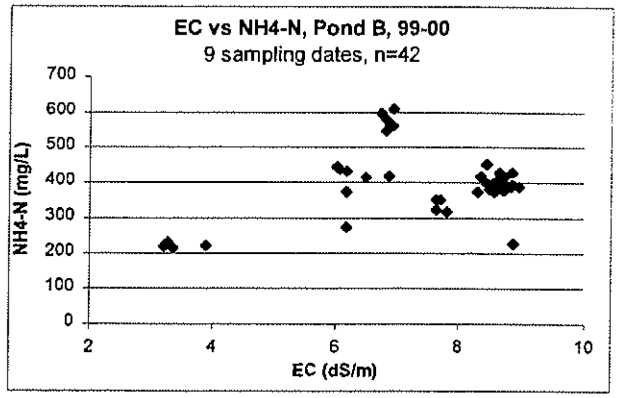


Figure 6. Correlation between electrical conductivity and ammonium concentration in dairy lagoon water. 169 samples representing over 50 San Joaquin Valley dairies, many with multiple sampling dates.

predict ammonium concentration, the relative proportion of charge coming from ammonium must be relatively stable. Adding dilution water that has a high EC of its own also can add charge to the blend without adding ammonium. A second issue is the inherent variability in the measurement of dairy lagoon EC. Particulate matter can interfere with EC measurement and can add to unavoidable variability in the measurement, especially under field conditions and with thick samples.





Figures 7 and 8. Correlation of EC with lagoon water ammonium concentration in two different ponds.

Colorimetric determination of lagoon water ammonium using Nesslerization

Nesslerizaion was for many years one of the standard methods of determining ammonium in water samples. We have modified this method to function as a reliable quick test procedure for in-field measurement of ammonium concentration in dairy lagoon water. A syringe is used to accurately dilute a 1cc sample of lagoon water in 200 cc of water. Dispersing and mineral stabilization reagents are added to minimize interferences. Nessler's reagent is added to a subsample and, after the appropriate time for color development, the absorbance is read using a hand-held 420 nm colorimeter. Because lagoon water also absorbs light at 420 nm, a reading of the absorbance of the diluted lagoon water is taken prior to adding the Nessler's reagent and this reading is subtracted from the final absorbance figure. This procedure is simple enough for many growers to perform, and the cost per determination is low. A small amount of dilute mercuric waste is produced by each test which must be disposed of at a hazardous waste receiving facility.

To develop a prediction equation for ammonium from absorbance, samples were collected from many lagoons in the San Joaquin Valley, from the flush, during irrigation, or in some cases by sampling the lagoon beneath the lagoon surface. The quick test procedure was performed immediately prior to and, if the samples took more than a few days to return from the lab, immediately after, the laboratory procedure was performed. If more than one quick test was made, the results were averaged. Samples were kept refrigerated at all times at

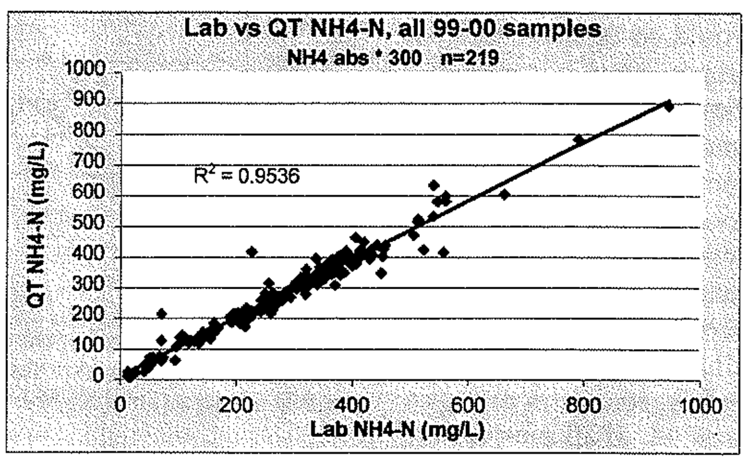


Figure 9. Correlation between ammonium concentrations as measured by laboratory and colorimetric quick test procedures

approximately 40°F. The samples were analyzed by a commercial laboratory using a standard method for determination of ammonium by distillation. Because different laboratory procedures for determining ammonium in lagoon water may not give comparable results, distillation was chosen as the method most similar to the nesslerization reaction.

In a comparison of laboratory and colorimetric quick test ammonium results from 219 samples representing over 60 different lagoons, 83% were within 10% (or <10 mg/L difference for dilute samples) of each other, 93% were within 15% (or <15 mg/L difference), and 5% were more than 20% or 20 mg/L different. Differences between lab and quick test results may be the result of anomalies in either the quick test or laboratory procedure or both.

In most lagoon water samples, organic-form nitrogen comprises about a third of the total nitrogen and can be much higher. Relying solely on ammonium-form nitrogen when determining application rates will likely result in overapplication of nitrogen. It is therefore important to determine the concentration of both ammonium and organic form nitrogen in lagoon water. Because diluted manure absorbs light at the same wavelength as the Nessler's reagent, one of the steps in the ammonium quick test procedure is to record the absorbance of the diluted manure prior to the addition of the reagent. Both the manure absorbance and the reagent blank absorbance are subtracted from the final absorbance obtained after addition of the Nessler's reagent. Because it was observed that samples with higher organic nitrogen content tended to also have the highest diluted manure absorbance, we developed an equation that could be used to estimate organic form nitrogen using a value already obtained in the process of determining lagoon water ammonium nitrogen.

Most of the samples used in the development of a prediction equation for ammonium based on absorbance were also used in the organic nitrogen sample set. Samples which had more than a 17% difference between lab and quick test ammonium concentrations were excluded from the sample set. Samples which obviously contained old sludge or which came from a pond receiving treatment to reduce solids were not used in developing the prediction equation for organic nitrogen from diluted manure absorbance. In these types of samples, it would be expected that the proportion of nitrogen in the sample would be smaller due to more complete digestion of the solids through microbial activity. If these types of samples are excluded, correlation between diluted manure absorbance and organic-form nitrogen was .94. If all samples are included, the overall correlation is .83 (figure 10). Of the 245 samples tested, 43% were within

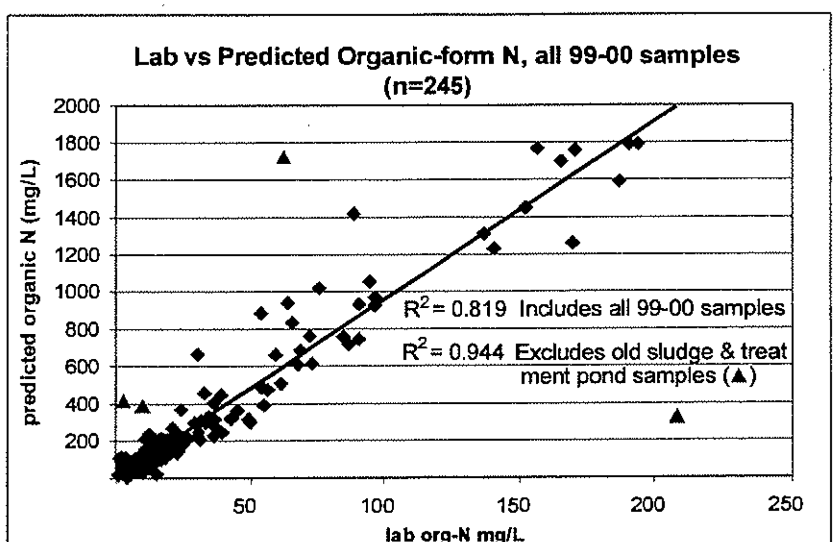


Figure 10. Correlation between organic nitrogen predicted from diluted manure absorbance (manure abs x 2100) and laboratory determination of organic nitrogen (Total Kjeldahl Nitrogen-NH4-N)

15% of laboratory values, 54% were within 20%, 73% were within 30%, and 89% were within 50%. Although the prediction equation for relating diluted manure absorbance to organic nitrogen can be only be considered an estimate, it may be sufficiently accurate for farm use to prevent gross overapplication of nitrogen in many cases by allowing at least some of the organic nitrogen to be accounted for when determining application rates. Additional study is needed to determine if it is possible to predict which types of lagoon water samples are not suitable for this method of organic nitrogen estimation.

During the summer of 2000, this quick test procedure was used, along with a flow meter and throttling valve, to apply targeted amounts of lagoon water nitrogen in each of at least 5 irrigations on each of several commercial silage corn fields which received a total of between 250 and 450 lbs total lagoon N/A. In every case, the amount of ammonium nitrogen applied as determined by the quick test was within 15 lbs/A of the amount as determined using laboratory values. For the same fields, differences between laboratory and quick test organic nitrogen applied were between 2 and 47 lbs/A. This quick test procedure can be a valuable tool for applying appropriate rates of lagoon water nitrogen to crops.

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Lagoon Water Analyses, 1999 and 2000

code	sample date	EC dS/m	pH	% total solids	TKN mg/L	NH4-N mg/L	Organic N mg/L	Total P mg/L	Soluble P mg/L	Soluble K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Cl mg/L	Zn mg/L	Cu mg/L	SO4 mg/L	NO3-N mg/L
A	Large new pond, with settling basin & pre-pond. Irrig with floating pump. Fresh water added in summer.																	
A	5/26/99	5.10			278	247	30.8	61	30.4	480	168	74	373					
A	6/18/00	5.63	7.00	5.75	405	294	111.5	55.86	18.2	626	156	105	455	398	0.93	0.08	36.7	0.56
A	6/27/00	6.01	7.00	5.23	348	250	98	48.67	16.4	591								
A	7/12/00	5.67	7.00	5.18	338	240	97.9	47.2	22.8	516	124	96	386	337	0.61	0.08	36.8	0.39
A	7/26/00	5.69	6.80	3.46	223	162	60.8	35.02	17.9	369								
A	8/2/00	5.45	7.00	4.27	311	135	175.7	63.88	21.7	251	84	67	223	185	0.19	0.03	21.1	<0.05
B	Undersized pond until spring, 00 when added 2 new ponds. Most irrigations are from bottom of middle pond of a series of 3, or mix of pond 2 and 3.																	
B	3/16/99	7.15				426												
B	5/7/99	7.25			863	409	454.4	152	35.7	765	296	118	393					
B	5/26/99	6.76				366												
B	6/19/99	6.21			1370	399	970.7	334	57.1	1255	224	120	285					
B	6/29/99	6.60			1377	488	889.2	442	51	755	236	123	304					
B	7/9/99	10.10			927	427	500.4	208	28.6	1209	222	85	591					
B	7/19/99				1391	482	909.5	507	44	670	270	106	593					
B	7/28/99	3.36			349	228	121	101	50.3	762	120	62	393					
B	5/29/00	6.92	7.00	9.49	2128	561	1567.4	504.6	34	1078	336	198	432	515	0.49	0.86	32	1.13
B	7/3/00	8.50	7.20	7.81	507	382	125	69.7	21.4	1218	242	211	483	568	0.35	0.96	46	0.85
B	7/13/00	8.45	7.40	7.78	514	399	114.9	72.4	23.4	1273	274	222	501	593	0.4	0.96	50.4	1
B	7/24/00	8.86	7.20	7.86	591	389	202.7	75.6	23	1330	262	217	520	628	0.42	1.02	51.1	1.13
B	8/2/00	8.71	7.20	7.40	561	378	182.4	81	26	1361	264	226	527	625	0.42	1.07	58.9	1.26
B	8/22/00	8.65	7.20	7.51	608	429	179	72.8	35.7	1330	274	187	529	604	0.52	0		2.11
B	9/4/00	7.82	7.20	6.70	568	318	250	74.3	33	1340	280	188	531	568	0.52	0		2.12
C	8/3/99	3.62			256	182	74.2	64	58.9	378	150	84	230					
D2	Huge pond, 6 mo capacity. Pre-pond is D1, below.																	
D2	5/26/99	4.87				266	132.9	38	27.2	641	186	81	163					
D2	6/21/99	5.44				266												
D2	7/3/99	5.27				265	131.4	48	30.1	760	172	101	189					
D2	7/8/99	5.28				265												
D2	7/17/99	5.37				276												
D2	7/28/99	3.85				235												
D2	7/29/99	3.88				227												
D2	5/31/00	4.56	6.80	4.31	321	264	57.4	57.7	20.6	644	154	98	166	217	0.2	0.13	41.3	0.33
D2	6/13/00	4.32	7.00	4.96	328	258	69.3	53.64	17.4	664								
D2	6/23/00	4.73	7.00	5.49	338	252	86.1	51.87	15.2	712								
D1	Pre-pond to D2. Milk cow flush water is separated, heifer flush is not. This sample series during dewatering and refilling with fresh water.																	
D1	7/14/00	8.35	6.80	9.41	1885	514	1371.4	313.6	34.9	743	156	135	184	259	0.88	0.29	19.2	0.99
D1	7/27/00	4.67	6.80	3.65	334	264	70.9	50.5	14	769								
D1	8/15/00	4.69	6.80	5.13	280	203	77.7	50.15	29.2	590	102	105	150	192	0.16	0.03	29.4	0.21
D1	8/15/00	4.31	6.60	4.33	345	267	77.7	48.97	14.9	763	126	112	193	245	0.18	0.08	43	0.4
D1	9/25/00	4.98	7.00	9.65	2250	378	1871.4	240.5	83	595	138	102	150	213			21.9	0.9
C1	9/26/00	4.65	7.20	5.25	385	196	189.2	68	69	515	170	100	219	291			21.8	0.7
C	Moderate size pond with separator. 4/29 pond had turned, 5/4 had settled again.																	
C	4/29/99	6.24			1441	530	910.9	342	30.2	799	182	81	221					
C	5/4/99	6.07			535	414	121	102	22.6	804	184	72	223					
C	6/25/99	6.17			752	457	294.8	132	17.6	831	154	78	242					
C	7/28/99	5.68				431												
C	8/17/99	6.63				379												
C	8/18/99	6.78				362												
D	Moderate size pond drawn down frequently small amounts at a time. Separator only.																	
D	5/4/99	3.75			271	205	66.4	44	40.3	360	174	90	200					
D	3/15/99	5.21				270												
D	4/6/99	4.11				225												
E	Large new pond with settling basin.																	
E	3/15/99	4.63				238												
E	5/26/99	4.21			313	207	106	55	30.4	503	174	102	219					
F	4/6/99	6.04			474	338	135.9	54	20.3	599	254	113	251					
G	5/4/99	2.75				170												
G	6/12/99	2.99			221	162	58.7	44	42.2	246	122	62	133					
H	Moderate size pond, sample drawn from bottom.																	
H	4/6/99	5.98			1155	500	654.9	299	47.9	557	314	128	258					
H	5/4/99	5.96			1177	450	726.7	176	58.2	807	290	138	276					
I	Double pond, undersized, frequently emptied. Irrig from bottom.																	
I	8/3/99	3.88			299	196	102.8	45	34.1	436	136	88	193					
I	5/19/00	6.43	6.80	10.3	1813	405	1407.9	83.43	31.8	244	94	68	97	96	0.05	0	19.6	0.29
I	7/14/00	6.29	7.00	9.0	1203	351	851.3	342.2	55	534	248	148	242	330	0.5	0.89	22.1	2.48
I	7/25/00	4.31	6.80	4.5	432	257	175.7	94.85	27.9	560								
I	8/7/00	4.21	7.00	8.6	1243	372	871.5	388.7	63	503	164	131	228	291	0.16	0.06	9.1	<0.05
I	8/18/00	3.47	6.80	5.5	493	223	270.3	126.8	44	497	158	111	214	266	0.16	0.18	16.5	0.54
I	8/27/00	3.67	7.00	4.3	385	209	175.7	63.1	71	462	176	101	198	146			17.1	0.83
I	9/26/00	3.39	7.20	6.4	676	243	432.4	63.5	41	311	138	70	136	146			31.4	0.7
J	Undersized pond, frequently emptied.																	
J	3/15/99	3.91				220												
J	4/6/99	3.22			324	192	132	70	53.8	293	126	77	108					
K	Pond had recently been drained and refilled with fresh water.																	
K	8/9/00	2.12	6.80	1.68	101	68	33.7	36.67	32	179	86	59	71	67	0.04	0	12.6	0.15

code	sample date	EC dS/m	pH	% total solids	TKN mg/L	NH4-N mg/L	Organic N mg/L	Total P mg/L	Soluble P mg/L	Soluble K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Cl mg/L	Zn mg/L	Cu mg/L	SO4 mg/L	NO3-N mg/L
L	Moderate pond had been completely emptied and dredged in the spring. Fresh water added.																	
L	7/12/00	3.21	6.00	5.44	328	263	64.4	44.45	28.2	421	126	84	140	163	0.05	0	21.6	<0.05
L	7/12/00	4.32	7.50	2.60	341	277	64.2	53.2		439	120	88	145	249			22.2	0.27
L	7/24/00	3.67	7.00	5.17	282	226	55.8	46.48	26	374								
L	8/2/00	3.56	6.80	4.55	279	203	76	43.68	23.5	332	112	72	124	121	0.03	0	25.8	<0.05
L	4th irrig	4.24	7.00	3.32	226	189	37.1	44.88	26.6	293								
L	5th irrig	3.29	6.80	6.59	291	216	74.3	57.84	38.5	502	142	99	205	280	0.34	0.29	15.8	0.93
L	6th irrig	4.56	6.80	3.89	264	216	47.3	43.1	322	602	162	104	159	217			21.4	0.15
M	4/6/99	4.68			392	299	92.9	28	24.2	488	186	72	193					
M	5/26/99	2.50				132												
N	Undersized pond																	
N	10/2/00	4.24	7.00	4.61	493	345	148.6	63.1	56	453	152	82	163	188			30	1.14
O	Undersized pond, frequently emptied. Drained completely 4/30/99. Refilled fresh water.																	
O	3/15/99	5.67				289												
O	4/6/99	5.21				314												
O dm1	4/30/99	5.76			1155	515	640.2	376	71.6	755	212	99	200					
O dm2	4/30/99	5.78			570	377	193.5	48	35.5	757	192	68	200					
O dm3	4/30/99	5.79			792	392	399.6	127	39.6	781	194	70	200					
O	6/21/99	2.9				131												
O	7/6/99	5.33				267												
O	7/29/99	4.11				264												
P	Undersized pond. Agitated. Fresh water added in summer.																	
P	3/15/99	7.81				487												
P	4/6/99	6.51			834	485	348.6	109	41.7	875	206	68	200					
P	5/4/99	6.71				436												
P	5/26/99	5.32				318												
P	6/12/99	4.74				256												
P	6/21/99	5.42				279												
P	7/30/99	3.68				214												
Q	4/5/99	5.35			563	348	214.7	92	31.3	656	250	93	366					
Q	6/7/99				513	323	190.5	75	28.5	641	214	99	382					
R	Large new pond																	
R	9/26/00	4.69	7.20	4.45	358	250	108.2	39.3	38	469	196	113	235	327			40.7	1.32
S1	5/4/99	1.97			142	111	31	210	30.8	226	82	40	76					
S1	6/21/99	1.61			121	76	45.4	23	23.1	160	66	29	53					
S2	Very large pond, receives irrigation drain water.																	
S2	5/4/99	4.20			328	234	93.7	34	24.5	577	174	81	186					
S2	6/21/99	2.02			164	95	69.5	33	34.5	227	86	40	64					
T	Undersized pond with separator thru spring 99, mainly draw from bottom of 1st pond																	
T	3/16/99	5.75				334												
T	5/4/99	5.82				311												
T	5/26/99	5.70				265												
T	6/12/99	5.71				287												
T	6/14/00	7.35	7.00	6.49	493	351	141.9	66.8	19.4	907	230	174	336	401	0.28	0.44	38	0.68
T	7/14/99				756	261	494.7	138	36.4	675	84	100	361					
T	7/24/99	4.22			271	194	77.2	50	36.7	539	124	92	274					
T	8/2/99	3.35			385	220	164.8	87	60.1	572	146	100	304					
T	6/22/00	6.60	7.20	5.74	466	341	125.1	57.1	27.3	939	218	144	338	462	0.34	0.55	40	0.98
T	7/1/00	7.09	7.20	5.80	463	321	141.9	62.6	25.1	963	210	146	347	497	0.34	0.49	42.7	1.04
T	7/6/00	6.31	7.00	5.61	446	338	108.1	70.86										
T	7/6/00	6.28	6.80	5.42	2419	557	1861.6	357.2										
T	7/11/00	9.86	7.20	6.56	500	304	195.9	73.4	26.4	971	200	145	350	497	0.39	0.55	38.7	1.15
T	7/14/00	6.35	7.00	6.20	341	230	111.5	41.8										
T	7/31/00	5.12	7.20	6.98	405	162	243.3		33.4	1330	262	173	506	781	0.54	1.3	54	1.77
T	8/9/00	2.97	7.80	4.86	176	135	40.6	30.8	21.8	453	94	95	179	224	0.07	0.18	21.5	0.24
U	Settling basins																	
U	10/2/00	4.28	7.00	4.29	338	277	60.9	57.6	65	453	156	66	122	146			18.9	0.35
V	Separator, no settling basins.																	
V	5/26/99	6.49			520	331	189.1	54	31.1	563	250	89	476					
W	Large pond, med-large dairy, first pond use since fall																	
W	6/2/00	5.72	7.50	2.98	544	426	118.2	51.7		611	114	70	194	213			23	2
X	Small pond, small dairy, no flush																	
X	5/26/99	4.28			221	178	43.4	46	40.1	353	190	90	370					
X	7/26/99	3.47				188												
Y	Very small pond, small dairy, frequently drained completely.																	
Y	5/26/99	3.91			892	279	613.3	158	61.1	282	250	81	212					
Y	6/26/99	4.27				213												
Y	7/26/99	4.64				225												
K1	Sludge from pond bottom. K1 is straight, K1 dil was diluted with water as it was being land applied.																	
K1	9/25/99				1191	1085	105.6	465	22.3	750	146	110	244					
K1 dil	9/25/99				556	458	98.5	81	22.1	692	142	106	239					

code	sample date	EC dS/m	pH	% total solids	TKN mg/L	NH4-N mg/L	Organic N mg/L	Total P mg/L	Soluble P mg/L	Soluble K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Cl mg/L	Zn mg/L	Cu mg/L	SO4 mg/L	NO3-N mg/L
BD1	5/11/00	10.21			1080	540	540											
BD1	5/13/00	7.60			780	405	375											
BD1	7/3/00	6.77			980	430	550	230		800								
BD2	6/16/00	1.47			116	50	65.9	18.8		78.9								
BD2	7/14/00	1.43			159	49	110.5	24.9		110								
BD3	9/26/00				238	140	98.4	24.4		300								
BD3	9/28/00	5.05			360	260	100	33.9		400								
BD4	5/23/00				120	103	17											
BD4	7/25/00	3.66			160	97	62.9	23.4		150								
BD5	5/13/00	1.59			95	55	40.2											
BD6	7/21/00	0.74			57	13	44	4.8		29								
BD9	9/29/00	1.45			71	42	29.5	17.9		95.4								
BD10	8/12/00	4.79			1060	370	690	220		730								
BD10	9/1/00	4.02			2420	340	2080	380		880								
BD10	9/5/00	5.64			470	320	150	48.9		650								
BD11	7/24/00				320	150	170	67.5		370								
TC 01	Large pond, with no mechanical seperator, taken from different locations																	
TC 01	6/27/00	2.74	7.00		304	162	141.9	39.51		271	158	44	94	114			32	0.53
TC 01	6/27/00	2.73	7.50		196	142	54	42.91		279	108	38	92	114			25.1	0.22
TC 01	6/27/00	2.75	7.00		182	152	30.4	44.4		271	110	38	97	117			24.6	0.26
TC 01	6/27/00	1.76	7.50		105	95	10.1	18.82		138	74	17	78	78			16.7	0.07
TC 02	Small pond, with a mechanical seperator, and from the settling basin																	
TC 02	6/27/00	2.88	7.50		514	145	368.2	96.25		216	70	24	101	117			10.9	0.15
TC 03	Sampled from the flush																	
TC 03	6/27/00	2.40	7.00		193	155	37.1	27.55		289	130	44	168	138			22.6	0.4
TC 04	Small pond, with no mechanical seperator, no settling basin																	
TC 04	6/27/00	4.47	7.50		311	270	40.6	38.94		507	136	68	131	167			21	0.31
TC 05	Medium pond, with a mechanical seperator and settling basin																	
TC 05	6/27/00	5.33	8.00		520	399	121.6	57.9		714	148	84	179	241			24.8	0.73
TC 06	Large pond, with a mechanical seperator and settling basin																	
TC 06	6/27/00	6.52	8.00		564	432	131.7	66.2		745	180	109	276	273			29.7	0.85
TC 07	Small pond, with no mechanical seperator, no settling basin																	
TC 07	6/27/00	2.03	7.00		260	135	125	41.42		104	100	18	90	64			11	0.13
TC 08	Sampled from the flush																	
TC 08	6/27/00	6.02	7.50		473	365	108.1	71.78		686	138	93	294	288			29.3	0.75
TC 09	Medium pond with no seperator																	
TC 09	6/28/00	4.04	7.50		324	71	253.4	50.54		565	92	37	115	195			28.3	0.31
TC 10	Large pond, with no mechanical seperator																	
TC 10	6/28/00	5.63	7.50		534	453	81	85.38		671	136	61	101	163			27.9	0.96
TC 11	From the irriagation valve at the field, pumped from sludge at the bottom of the pond and mixed with fresh water																	
TC 11	6/28/00	4.58	8.00		405	206	199.3	50.27		259	88	31	113	138			15.2	0.21
TC 12	Large pond, no seperator, with settling basin																	
TC 12	6/28/00	4.51	7.00		378	274	104.7	40.66		471	144	68	138	117			32.7	0.6
TC 13	Large pond, with mechanical seperator, and settling basin																	
TC 13	6/28/00	4.86	7.50		439	338	101.3	70.55		524	90	49	175	195			29	0.75
TC 14	Barn water																	
TC 14	6/28/00	1.50	7.00		122	74	47.3	20.65		102	46	4	60	46			7.9	0.13
TC 15	Medium pond, with no seperator or settling pond																	
TC 15	6/28/00	3.80	7.50		277	223	54	37.31		358	130	33	177	202			16	0.49
	Large pond, with mechanical seperator and settling basin																	
TC 16	6/29/00	3.35	7.50		243	169	74.3	37.29		234	124	63	191	195			74.7	0.48
TC 16	From the settling basin into which sulfuric acid was being added																	
TC 16	6/29/00	1.34	7.00		47.3	17	30.4	10.76		25	78	32	108	121			54.2	<0.05
TC 17	Medium pond, with mechanical seperator, and 5 agitators in the pond																	
TC 17	7/10/00	5.31	7.50		628	412	216.2	106.8		538	74	90	186	213			26.6	0.72
TC 18	Settling basin:																	
TC 18	7/10/00	4.29	7.50		331	223	108.1	63.4		521	116	83	168	213			16.7	0.33
TC 18	From the large pond, with no mechanical seperator:																	
TC 18	7/10/00	4.34	7.00		284	243	40.6	54.2		509	80	81	163	178			18.4	0.29
TC 18	From the large pond, with no mechanical seperator																	
TC 18	7/10/00	1.15	6.50		61	47	13.5	12.8		101	32	27	53	107			6	13.95
TC 19	Small pond, with no mechanical seperator																	
TC 19	7/10/00	4.27	7.00		291	240	50.7	35.6		501	134	67	140	249			19.3	0.35
TC 19	7/10/00	5.79	8.00		497	341	155.4	76.7		625	134	109	313	355			17	0.31
TC 19	7/10/00	5.83	7.50		439	334	104.7	68.3		635	130	110	324	391			16.2	0.28
TC 20	Large pond, with mechanical seperator and settling basin																	
TC 20	7/10/00	6.73	8.00		608	456	152	88.1		832	106	98	324	213			28.2	0.59
TC 21	Very large pond with no mechanical seperator or settling basin																	
TC 21	7/10/00	4.48	7.50		611	274	337.8	128.9		593	56	72	200	320			20.8	0.39
TC 21	7/10/00	4.45	7.50		581	274	307.4	109.1		578	68	72	198	320			15.9	0.35

Engineering Dairy Lagoon Water Application Systems

Eric Swenson, P.E.

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General:

The intent of this paper is to outline several approaches to handling the application of dilute dairy lagoon water to field crops and orchards. Most of the approaches described in this paper have been designed by the author and in many cases are operating on an existing dairy site. Some of the irrigation systems described were designed by others and witnessed by the author. Through working with a number of dairy operators it is clear that there is a wide variation in approaches to dairy lagoon water application. One recurring theme is that the irrigation system used must be simple and reliable. This paper is not intended to be a complete design guide for the design of dairy lagoon water application systems, but rather an overview of a number of approaches used in central California.

Existing Dairy Layout:

Figure 1 shows the layout for a simplified dairy in central California. The dairy is often adjacent to an access road so that feed can be easily delivered and milk hauled away. Adjacent to the dairy consisting of a milking barn, freestalls and corrals, is a manure water storage lagoon. Surrounding the dairy site is irrigated acreage typically with field crops planted. A common planting scheme is to have a silage corn/silage oat rotation on a portion of the fields and alfalfa on the balance of the farm ground. Manure water is often distributed through a series of concrete pipelines and/or open ditches to the field. Low areas of each irrigated field collect tail water that is often returned to storage or applied immediately for irrigation.

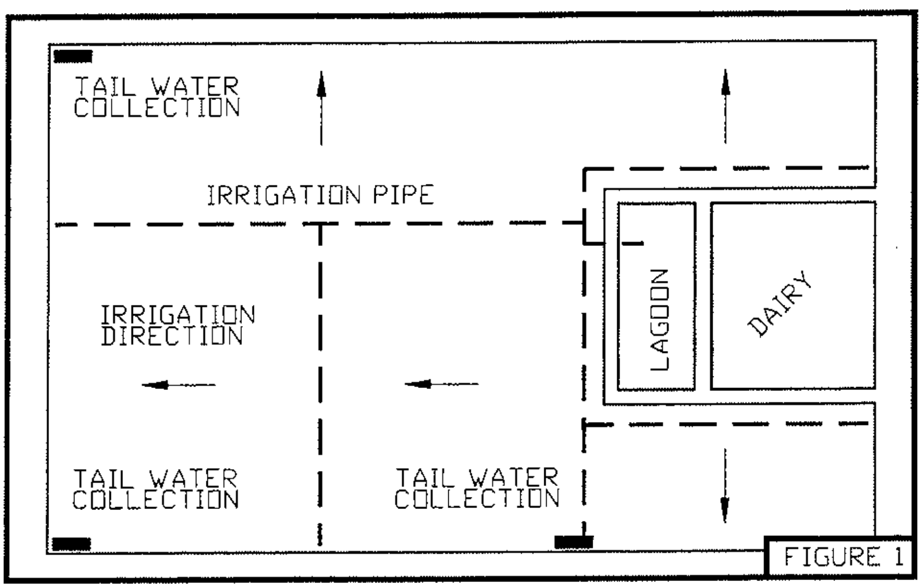

FIGURE 1

It is often difficult or impossible at some dairies to evenly distribute manure water to all irrigated acreage using existing manure water distribution system. Pipelines from storage lagoons are often being utilized to convey surface or well water for irrigation and are not available to also carry manure water. This can lead to the excess application of nutrient rich manure water on fields close to the storage lagoon.

Some dairies do not have settling basins for solids prior to storage lagoons. This allows for a large portion of nutrient rich solids to also be conveyed with the manure water. Currently, the nutrient management of the nutrient rich solids appears to be more difficult to control than the ammonia rich liquid fraction.

Nutrient Management Improvements:

Figure 2 shows the same dairy as shown in Figure 1 with a number of significant changes which improve the sites ability to manage its nutrient rich manure water.

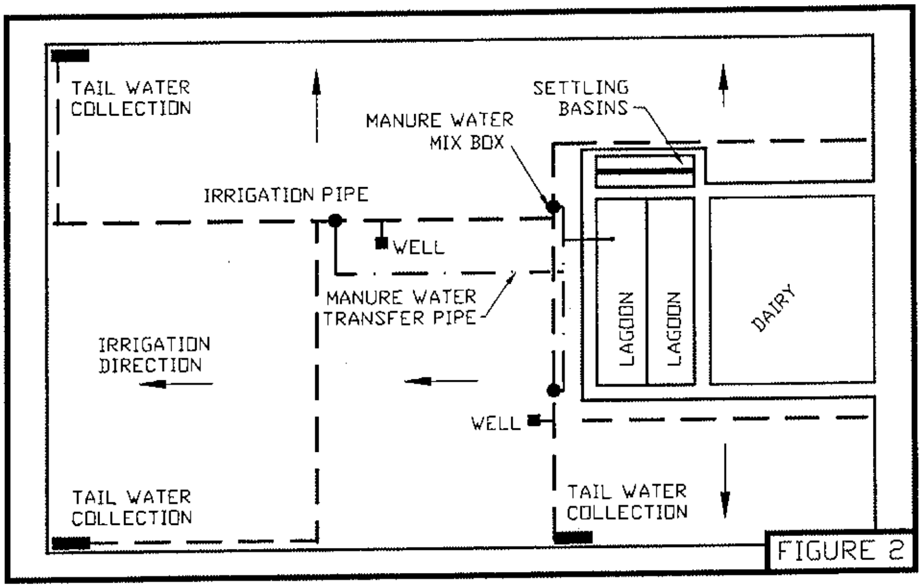

FIGURE 2

Settling Basins:

A pair of settling basins has been added prior to the storage lagoon(s). The settling basins allow the removal of significant quantities of suspended solids in the manure water. The removed materials will be removed, dewatered, and either directly land applied by mechanical spreading or first composed and then spread.

Lagoon Storage Capacity:

In many counties, 120 days of liquid storage is required in lagoons. Some operators are constructing facilities with up to 160 days of storage. An existing facility may or may not have 120 days of storage. A dairy storage lagoon may have floating pumps or pumping systems that do not allow for the full use of all the lagoon storage capacity. Storage capacity must be calculated from the maximum allowed operating level (usually 2 feet of freeboard to top of berm) to the minimum operating level often dictated by operation of flush lane pumps. If less than the required usable storage is available, additional storage should be constructed.

If a dairy operation had the minimum required farm ground for its herd population, but needs to add settling basins and/or increased storage capacity, then additional farm ground may have to be added for manure application. This additional ground would offset the area occupied by the new settling basins and storage lagoon(s). In some cases changing crops, number of rotations per year, timing of manure water applications, or other options to increase plant nutrient uptake per acre, can compensate for decreased farmed acreage.

Tail/Storm Water Collection and Pumping:

It has been suggested that to optimize flood irrigation of land with border check irrigation systems that 15% of supplied irrigation flow be collected at the end of the check.[i] In order to achieve high irrigation distribution uniformities with most flood or furrow irrigation systems, some tail water will collect in the low areas of the field. Rainfall on many manured fields will also result in runoff to low collection areas of fields. At these locations tail water collection and transport systems must be constructed. These systems must be sloped to avoid standing water. If standing water remains at tail water collection basins, then these basins must be constructed to the same standards as manure water storage lagoons. Often it is necessary to provide a pumping system that will lift the tail/storm water and convey it through a pipeline. It is convenient to the dairyman if this water can be applied to the field that is currently being irrigated. Storm water collected from manured fields must be conveyed to an appropriate storage location until it can be irrigated on ground that will allow it to infiltrate.

Tail/storm water collection and transfer systems must be properly sized to collect and transport the required flows of water. Often a civil engineer is utilized to calculate the anticipated runoff from various storm events and make recommendations on rates and volumes of water that can be anticipated. There is additional collection of storm water from corrals and feed storage facilities that should be integrated into this system. Irrigation specialists who are familiar with the local soil type and irrigation methods can assist landowners with the design of tail water collection and transport systems for irrigation water.

Irrigation Water Supplies:

One of the first steps in designing a manure water irrigation system is to understand the capabilities of the existing fresh water irrigation supplies. Water may be available from surface facilities (such as canals or rivers), private wells, or treated effluent from processing facilities. The quality, quantity, and time availability of the water sources is important. Characteristics of the soil and proposed cropping are very important. For flood and furrow irrigation in the San Joaquin Valley in California it is probably desirable to have a minimum of 10 gpm/acre of water available for irrigation. Peak ET is typically during late July and August. For irrigation systems other than flood and furrow, one is primarily trying to insure that peak ET can be reliably be met.

In some cases it may be necessary to increase fresh water irrigation supplies to make optimum management of manure water and farmed acreage.

Manure Water Transfer Systems:

Manure Water Transfer to Field: Once a knowledge of the known fresh water irrigation supplies is determined, soil types are known, and cropping patterns are established, then one must calculate what the maximum application rate of nutrients from manure water would be. For instance it might be determined that the maximum desired application rate of nitrogen is 100 pounds per acre per irrigation. Let us further assume that based upon irrigation water supply scheduling and availability that 5 inches of water are to be applied with this irrigation. Next the minimum anticipated nitrogen available from the manure water would be estimated (this might be something like 250 ppm available nitrogen). This information taken together will allow the irrigation designed to establish a maximum application rate for manure water. Manure water can be transferred by pumping or gravity flow (if sufficient elevation difference exists).

Pumping of Manure Water: Pumps are utilized to transfer manure water when gravity head is not available. An irrigation designer should establish the required flow and pressure characteristics of the pump. Pumps designed for "trash" type services should be employed. These pumps are often called "Non-clog" pumps. The best service has been experienced with pumps having submerged impellers such as submersible or vertical turbine style pumps. Many of these pumps do not have high discharge heads. In-line, end suction, non-clog pumps may be needed following lagoon pumps for long manure water transfer operations or where large uphill piping runs are needed. Self-priming, end suction, non-clog pumps are not recommended for lagoon pumps due to the foaming nature of some manure water which can negatively impact pump priming and operation.

Flow Measurement of Manure Water: In order to accurately apply a known amount of nutrients from manure water to farmland the concentration of these nutrients in manure water must be established and the rate of application of these materials must be measured. Experience and testing has shown that a real-time, continuous measurement of the flowrate of manure water can be reliably made using magnetic flow meters such as have been employed for many years in the municipal waste water industry. Some success has also been shown with acoustical flow meters (such as doppler flow meters). Gravity flow situations may provide the opportunity for the use of open channel flow metering systems. Unfortunately, the author is not aware of any testing of manure water with open channel metering systems. Electronic metering systems easily provide instantaneous flow readout and totalizing of flow delivered and provide many options for additional data acquisition if desired.

Most manure water flow metering installations require a straight run of pipe which is full of fluid. A typical installation is shown is figure 3. Optimum installation of the meter is at least 10 pipe diameters immediately downstream of the pump discharge. This would be followed by approximately 5 pipe diameters of straight run of pipe. Two 45 degree elbows can be installed after the 5 diameter long straight section to insure that the pipe is always full of water. An air vent is provided after the rise to insure that all air has been vented from the pipe. It is generally more challenging to design gravity irrigation metering runs due to the difficulty of insuring that the pipe is always full of water.

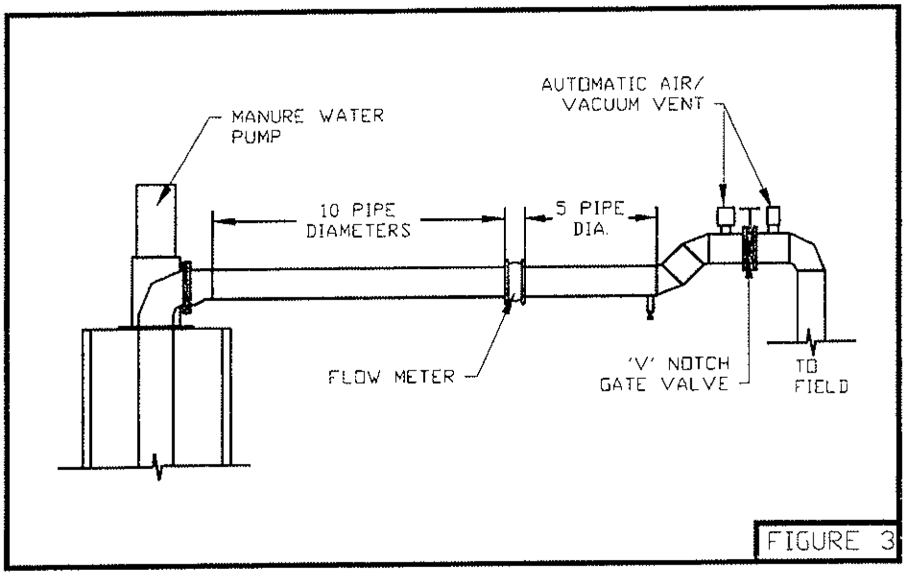

FIGURE 3

Flow Control of Manure Water: A flow control device is needed to regulate the flow of manure water to the field. Dairymen to date have primarily been interested in a device that is low in cost, easy to install, and works reliably. The best device that fits this criteria appears to be a gate valve with a 60 degree 'V' shaped notch (see figure 4). This 'V' shaped valve orifice allows throttling of the flow while still providing a large cross section opening for solids and debris to travel through. These valves are only somewhat more expensive than a standard gate valve and are available in a wide range of sizes. Valve opening is normally adjusted by turning a handwheel. For convenience the flow meter display is often mounted where it can be read when adjusting the handwheel.

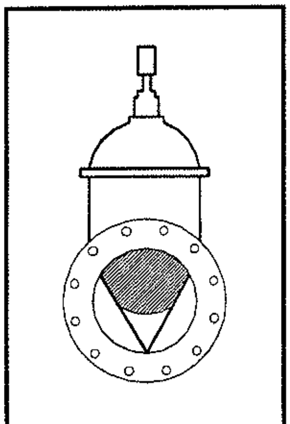

FIGURE 4

Variable frequency drives (VFDs) can be used in place of a valve to control manure water flow. These control flow by changing the speed of the pump that results in a varying flow output. The electronics that run VFD need to be protected from excessive temperatures. Pumps that are driven by variable frequency drive must be carefully selected to insure adequate pumping head (pressure) is available at all anticipated pumping rates. An alternative means to variable speed pumping and flow control is through the use of an engine driven pump. Most variable speed pumping systems will result in lower energy usage than a throttling valve.

Manure/Fresh Water Mixing:

It is desirable to fully mix manure and fresh water prior to application to the field. This can be done in a number of fashions. One simple approach that has been employed is to discharge the manure water into an open pipe stand at the beginning of an irrigation system, prior to the first irrigation outlet in the field. Another approach that has been used successfully is to construct round, pressure rated, steel, mixing chambers with automatic air vents where manure and fresh water mix prior to field application.

Some older manure water application systems only have one location for mixing manure water with fresh water. For land application areas in excess of approximately 300 acres for a single dairy, which have multiple sources of fresh water it may be difficult to uniformly apply manure water during the peak irrigation season. One approach to increasing the flexibility of manure water application is to distribute manure water through a dedicated distribution system to multiple fresh water mixing points around a farm. This allows manure water to be applied at a distant field while still applying fresh water only at a field close to the manure water source (see figure 2).

Alternate Manure Water Application Systems:

Impact Sprinklers: Impact sprinklers with a wide range of orifice sizes have been used for manure water application. These systems can pump raw undiluted manure water or some mixture of manure water and fresh water. "Big Gun" large orifice sprinklers with large attached hose reels are used in some areas with success. Center pivot and linear move sprinklers have also been used for animal holding facility manure water applications. All pressurized impact sprinkler systems have the potential for increasing downwind odor over other application systems due to small droplet formation.

FanJet Micro Sprinklers: The author has designed one system which filters manure water to approximately 150 mesh equivalent filtration level and injects this material into an existing FanJet, pressure compensated, micro sprinkler system. All filtration is done with commercial sand media filtration equipment. Filtered manure water is mixed with fresh water, re-filtered, and then applied to approximately 40 acres of almonds. Approximately 1 part manure water is mixed with 3 parts fresh water. The system has successfully operated for 2 seasons with minimal problems. This system will probably only work when less than half of the applied acreage uses filtered manure water.

Drip Irrigation: The author has been involved with two drip irrigation projects with manure waters from large animal holding facilities. The first is located in California at the same location as the FanJet system described above. Manure water is filtered and then mixed with fresh water, re-filtered, and then applied to approximately 131 acres of wine grapes.[ii] The mixture is applied with an above ground in-line pressure compensating dripper. Approximately 1 part manure water is mixed with 5 parts fresh water. The system has successfully operated for 2 seasons with minimal problems. This system will probably only work when less than half of the applied acreage uses filtered manure water.

Another related project that involves cattle feedlots is located in Garden City, Kansas. Kansas State University started a small test plot using filtered feedlot runoff water to irrigate corn through subsurface drip tape.[iii] The author was able to design an expanded system encompassing 34 acres using commercial irrigation equipment. This system does not use fresh water dilution and has successfully completed it first growing season. This system will probably only work when less than three quarters of the applied acreage uses filtered manure water. Subsurface injection of the lagoon water virtually eliminates any potential for surface runoff of nutrients.

Other work along these same lines is on going in various areas of the country and this is not an exhaustive description of all current and past efforts.[iv]

Summary:

In central California manure water irrigation systems are being designed, constructed, and operated that allow controlled application of manure water in ways that allow beneficial utilization of nutrients by farm crops while minimizing negative impacts to the environment. These systems utilize components with a proven history in this or a related industrial application. Special systems are also being designed and operated which allow for application of manure water through micro sprinklers and drip systems when required. Application of solid manures must also be incorporated into the overall management approach. Attention to details of tail water and storm water handling must be addressed to have a manure management approach that is complete. Irrigation systems currently on the drawing board will refine the schemes outlined in this paper over the next 1 to 2 years.

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[i] Comments by Terry Pritchard, UC Davis, made during Spring 2000 Seminar at UC Extension shortcourse entitled: **Using Dairy Lagoon Water Nutrients for Crop Production.**

[ii] **Innovation Turns Dairy Water into Vineyard Asset,** by Melinda Warner, Grape Grower Magazine, January 2000.

[iii] **Microirrigation Advances: Irrigating Corn with Subsurface Drip Irrigation and Lagoon Water,** by T.P. Trooien, et.al, Irrigation Journal, July/Aug. 1999.

[iv] **Waste Water? Not!,** by J.C. Garrick, Irrigation Journal, Jan./Feb. 1999.

Dairy Nutrient Management Effects on Groundwater Quality: A Case Study

Project Leaders: *T. Harter*[1], *M. C. Mathews*[2], *R. D. Meyer*[3]

[1]Corresponding author:
Dept. of Land, Air, and Water Resources
University of California
Davis, CA 95616-8628
telephone: 530-752-2709 fax: 530-752-5262
e-mail: thharter@ucdavis.edu

[2]Stanislaus County Cooperative Extension, Ceres

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

INTRODUCTION

California's dairy herd of 1.5 million milk cattle produces large amounts of liquid and solid waste. Freestall facilities with a flushing system for manure removal are now commonly used in the San Joaquin Valley, which houses most of the state's dairy herd. At a typical freestall dairy with approximately 1,000 adult cows, an estimated 7,000 - 10,000 cubic-feet of liquid manure are generated daily from animal manure and wash water (VanEenennaam, 1997; Shultz, 1997; Meyer and Schwankl, 2000). After separating out solids, the liquid manure is typically stored in storage ponds (lagoons), recycled through the flushing system for manure removal from the freestalls, and eventually applied to adjacent crop land. The handling and safe disposal or reuse of liquid and solid manure has recently come under critical scrutiny with respect to the environmental impacts to surface water, air quality, and groundwater resources.

Proper nutrient management is one of several environmental aspects of manure handling. Planning and documentation of nutrient management practices is part of proposed federal regulations for concentrated animal feeding operations to control water pollution (EPA, 2000). Implementation of appropriate nutrient management practices is critical to protecting groundwater resources from excess leaching of salts, nitrates, and pathogens. Groundwater serves as the primary source of drinking water in California's rural areas. It is also an important source of irrigation water. In some areas of California, groundwater recharged on dairy facilities will eventually discharge to surface waters. Therefore, groundwater quality may sometimes play a critical role in the ecological health of streams and estuaries.

The guiding principle of proper dairy nutrient management is to balance the nutrient cycle without excessive loss to the environment: Nutrients in the animal manure are recycled by applying the manure as a crop fertilizer, matching the nutrient application to the field with the nutrient uptake by the forage crop, thereby returning the nutrients back to the animals via the forage grown around the dairies. The nutrient cycle on a dairy is a delicate and complex system of checks and balances, which are difficult to equilibrate in practice. The nutrient cycle includes all three major nutrients, nitrogen (N), phosphorus (P), and potassium (K), each of which partitions at different rates through the many interfaces of the nutrient cycle. Feed quality, feeding practices, milk production, heifer production, wash water handling, manure handling and storage within the dairy, manure application to crops, soil quality in the field, and agronomic practices (including irrigation practices) all influence the balance of the nutrient cycle. In turn, any of these elements have potentially significant impacts on air, surface water, and groundwater quality. One of the elements of the nitrogen cycle for which relatively few California specific data exist is the nitrogen balance in forage fields receiving liquid manure water through irrigation (Mathews et al., 1999; Meyer and Schwankl, 2000). A better understanding of the nitrogen balance in manure treated fields is critical to developing proper nutrient management practices. These practices should accommodate the climatic, soils, and agronomic conditions of California dairies while protecting the water resources that California's agricultural communities depend on.

Objectives. The objectives of this paper are: a) to determine the nitrogen mass balance for two demonstration fields prior to and during a period of targeted nutrient management; b) to predict impact on groundwater quality and compare predictions to measured groundwater quality data. The case study serves as a demonstration of the intrinsic link between nutrient management and groundwater quality. Results reported in this summary are considered preliminary. Work on this project is ongoing.

METHODS

We selected a set of two adjacent fields at a typical, cooperator-owned freestall dairy operation in the San Joaquin Valley. The nutrient management field study was initiated in May 1998, while the groundwater monitoring adjacent to these fields began in May 1993. The period prior to 1998 is considered an example for "conventional manure management" practices (control data). Beginning in 1998, manure applications were managed to better match crop uptake (targeted manure nutrient management, TMNM). Two different protocols were established for TMNM. An initial protocol was established in May 1998 and implemented for two years (TMNM 1998/99). The protocol was adjusted in May 2000 to further improve the nutrient balance in these fields (TMNM 2000). Because of the timing of the study, we designate a "crop year", which begins with the corn planting in May and ends with the winter forage harvest in April of the following year. Hence, a March fertilizer application in the "crop year" 1998 actually occurred in March 1999.

In this section, we briefly summarize the manure nutrient management practices, the elements of the nutrient cycling in the field and how they were measured, and the groundwater monitoring. Detailed descriptions of these methods can be found in Harter et al. (1999) and Mathews et al. (1999, 2001).

General Setting: The two fields are located on the low alluvial plains and fans east of the San Jóaquin Valley trough in the north-central part of the valley (Merced County). The soils are loamy sand to sand with rapid drainage in the surface soil and low water holding capacity. The groundwater table is very shallow (6 – 10 ft.). As on most dairies in this region, the two fields are used to grow two crops per year for silage, summer corn (*Zea mays* L.) and a winter cereal crop. The fields are border check flood irrigated during the summer. Crop plantings and harvest dates vary from year to year to year. Corn is typically planted in late April through early June and harvested between mid-August and late September. Winter forage is planted in October and harvested in April. Surface water originating from the Sierra Nevada and distributed through the local irrigation district is used for irrigation water during the summer. Late fall irrigations and winter precipitation (annual average: 15 inches) provide moisture for the winter forage crop. In 1998 and 1999, measured annual irrigation applications were approximately 44 acre-inches per acre. Annual average crop water uptake is 27 inches (corn) and 12 inches (winter grains). Estimated net recharge rates under these fields are nearly two feet per year due to the high soil drainage. Irrigation efficiencies of approximately 50% - 60% are similar to those observed elsewhere in the San Joaquin Valley (Meyer and Schwankl, 2000).

Conventional Manure Management (1993-1997): Conventional manure and nutrient management practices on freestall dairies in the northern San Joaquin Valley have three components: 1. Application of pond water (liquid manure) blended with irrigation water occur in the spring and fall preirrigations (prior to corn and winter forage plantings, respectively). 2.Commercial fertilizer is applied during the growth period of the corn (June and July) and occasionally on winter grains (February or March). 3. Excess pond water is disposed to fields during the winter due to the limited holding capacity of the storage pond. Winter disposals of pond water and preirrigations with blended pond water have typically been applied only to a limited crop acreage of the dairy. This type of manure management largely ignores the nutrient value of the manure because of the perceived difficulties in managing the manure as a fertilizer. Crop nutrient management relies on commercial fertilizer applications during the summer.

Targeted Manure Nutrient Management 1 (1998-1999): Beginning with the planting of the corn crop in May 1998, the following changes were implemented to better match nitrogen applications with crop uptake: Preirrigations were run without addition of liquid manure (pond water). Winter disposals of liquid manure were also discontinued (this required the expansion of available pond capacity). Spring fertilization at a rate of 80 – 120 lbs/acre was implemented with commercial fertilizer (crop year 1998) and with diluted liquid manure (crop year 1999). Commercial fertilizer applications in the summer were replaced by targeted liquid manure applications such that the *ammonia-N* (NH_4-N) content of the liquid manure would supply the necessary 250 lbs/acre. In this treatment protocol, no credit was given to the nitrogen available to the crop from the *organic N* in the liquid manure.

Targeted Manure Nutrient Management 2 (2000): In 2000, the treatment protocol was adjusted to not only credit all of the NH_4-N, but also 70% of the measured organic N in the pond water as being plant available fertilizer. Hence, the total amount of pond water applied was further reduced compared to TMNM 1998/99. This protocol required a reliable method for estimating the amount of organic N in the pond water immediately prior to irrigation.

Measurement of nitrogen application: The amount of pond water N applied is measured by determining the flow rate of pond water to the field during the irrigation, the duration of the irrigation, the size of the area being irrigated, and the concentration of NH_4-N and organic N in the pond water prior to and during the irrigation. NH_4-N is determined using a hand-held colorimeter to read the color change resulting from mixing the diluted lagoon water with Nessler's reagent and later confirmed through laboratory analysis. Organic N is estimated from the absorbance reading of the diluted lagoon water and later confirmed through laboratory analysis.

Measurement of soil nitrogen and plant N uptake: Soil samples were taken soon after the winter forage crop was harvested, before most irrigations throughout the corn growing season and after the corn was harvested. Soil samples are taken in one or two subplots within each of three or four irrigation checks. Each composite sample consisted of 12 core samples taken from each of five depths to 4 feet. Ammonia-N and nitrate-N (NO_3-N) is determined after equilibrium extraction of soil with one molar potassium chloride and subsequent determination by diffusion-conductivity (Carlson, 1978). At each of the locations where soil samples are collected, 25 feet of one corn row is cut, weighed, subsampled and weighed, dried and weighed to determine moisture content, ground and submitted to the laboratory for nutrient analysis. These samples are collected on each soil sample date after the corn reaches a height of 12-15". Final harvest samples were collected as field chopped silage blown on the ground at the site of the soil sampling location and sampled for nutrient analysis (Gavlak et al., 1994).

Monitoring of groundwater nitrate: Soil nitrate levels and nitrate levels in the shallow-most groundwater within 15 – 20 feet of the water table is used to validate the estimated nitrogen leaching losses from the root zone. Groundwater nitrate is determined from water samples taken at monitoring wells between and adjacent to the two fields. From 1993 to 1999, two monitoring wells were located downgradient of the two fields (Harter et al., 1999). In April 1999, four additional monitoring wells were constructed downgradient of the two fields for a total of six monitoring wells. The monitoring wells are 25 feet deep for measuring water quality within the upper 15 feet of groundwater. Based on a simplified hydraulic analysis, groundwater sampled from these monitoring wells can be shown to originate predominantly from recharge that percolates from the two fields to the water table (Harter et al., 1999).

RESULTS AND DISCUSSION

Information about the manure management practices on the demonstration fields for the period from 1995 through 1998 was obtained from the operator. He had recorded the date and approximate amount of pond water applied to the two fields and of the amount of commercial fertilizer applied. Commercial fertilizer in the spring, at a rate of approximately 50 – 80 lbs/acre, was applied only in years when no winter disposal of pond water had occurred. Commercial fertilizer applications with liquid ammonia injected into the irrigation water during the summer typically occurred in five separate irrigations at a rate of approximately 50 lbs/acre per irrigation (total: 250 lbs/acre).

The amount of manure N shown for the years of conventional practices (crop years 1993 – 1997) were not measured and are based on estimates of the volume of pond water applied and of the nutrient content of the pond water. The grower reported an average of four diluted or straight pond water applications per year on each of the two fields between late 1995 and early 1998 (crop years 1995 – 1997). Applications include (a) preirrigations with blended pond and irrigation water in the spring and fall prior to crop planting during most (but not all) years, (b) applications during the winter months (usually undiluted), and (c) occasional applications during the corn growing season. Pond water applications varied in the amount but typically ranged from

1 to 4 acre-inches per acre per application. Reported ranges of pond water nitrogen concentration range within an order of magnitude (Meyer and Schwankl, 2000; Mathews et al., 2001), making it difficult to estimate the exact amount of applied N. One third to three quarters of the total N is reported to be in form of NH_4-N. For 1999 and 2000, reliable pond water NH_4-N and organic N measurements are available at our site. Measured pond water concentrations of total N at the time of irrigation averaged 400 mg/l and ranged from less than 200 mg/l in late summer irrigations to over 500 mg/l in the spring and early summer irrigations. NH_4-N to organic N ratios ranged from 1:1 to 2:1. Assuming that pond water N concentrations were similar in previous years, we estimate that the average amount of manure N applied during 1993-1997 was 300 lbs per acre in a typical spring preirrigation (April or May), 200 lbs per acre in a typical fall preirrigation (September or October) and at least 300 lbs per acre in a winter disposal (anytime between December and February, Figure 2a). These estimates should be interpreted very carefully. Actual values and actual average annual N applications may differ substantially due to the large variations in manure N composition and annual scheduling of pond water applications. Commercial fertilizer applications are estimated to average 250 lbs per acre, which is the agronomic rate targeted by the grower. Actual fertilizer applications varied, partly as a result of what the grower perceived as nutrient value of summer pond water applications at that time.

Substantially lower amounts of nitrogen were applied during the 1998-99 crop years (Fig. 1) due to omitting the winter disposals of pond water and by replacing commercial fertilizer with targeted manure applications that explicitly accounted for the NH_4-N content in the liquid manure. Further reduction in nitrogen application has been achieved during the current crop year (2000) by also accounting for the organic nitrogen and assuming that 70% of the organic N is plant available (Fig. 1). Total nitrogen applications dropped from an estimated minimum of 1050 lbs N/acre prior to targeted manure management to 670 lbs N/acre in 1998 and 1999, and 420 lbs N/acre in the current crop year. Our preliminary estimates indicate that the margin of error for the 1998-99 and 2000 totals is 10% - 20% based on the accuracy of flow rate and nitrogen concentration measurements.

Corn yields (for silage) averaged 33 tons per acre in 1998 and 31 tons per acre in both 1999 and 2000. These yields are comparable to yields achieved under conventional management practices in nearby control checks (Mathews et al., 1999). Monthly plant nitrogen uptake is estimated from plant samples taken in the corn crop in 1999 and 2000, and in the winter grains at time of harvest. Because yields did not change significantly, it is assumed that plant N uptake patterns are similar between the three treatments. Monthly N applications and plant N uptake are compared for each treatment in Figure 2. Total crop N uptake averages 290 lbs/acre for corn and 150 lbs/acre for winter grain in crop years 1998 and 1999. Winter grains are assumed to have taken up higher amounts of N prior to 1998 due to the manure applications but without difference in crop yield. We estimate that plant N uptake in 1993-1997 averaged 200 lbs/acre. Based on these data, the annual N balance for the two fields, computed as the difference between applied total N and plant N uptake is +560, +230, and –20 lbs N/acre for the conventional, the 1998-99, and the 2000 treatments, respectively. If we assume that ammonia volatilization losses during the irrigation and in the soil are negligible (within the margin of error of the total N application), and that all applied nitrogen eventually converts to nitrate, the long-term average nitrate-N concentration in the leachate from the field is 106 mg/l under conventional management and 43 mg/l under 1998/99 treatment (at two acre-feet per acre net annual recharge).

These long-term field integrated nitrate leaching estimates can be compared with soil N levels at the bottom of the root zone and with groundwater nitrate-N concentrations observed in two wells between and downgradient of the two fields (six wells after April 1999, Fig. 3). In the soils, total available nitrate- and ammonia-N in the top 4 feet averaged 240, 230, and 170 lbs/acre in April-September of 1998, 1999, and 2000, respectively. In the lower root zone (3ft. – 4 ft. depth), average NO_3-N concentrations for the same three time periods are 73mg/l, 53 mg/l, and 46 mg/l. These concentration estimates are obtained from total available soil nitrate measurements assuming saturated conditions. Because soils are not actually saturated, these concentrations are minimum estimates of soil nitrate concentrations at the bottom of the root zone. Also, because of large variations in soil nitrate concentrations between preplanting and mid-summer, the differences in soil nitrate concentrations between the three summers are not as significant as it may seem. These data are considered preliminary and data analysis is ongoing.

Average shallow groundwater concentrations increased between 1993 and 1995 and reached levels between 80 and 120 mg/l during 1995 through 1997. After the last winter pond water application in crop year 1997, the nitrate-N concentrations significantly decreased. Average nitrate-N concentrations fell below 50 mg/l during the crop year 2000 with individual well concentrations ranging from 30 to 65 mg/l during the summer and fall of 2000. The decline in groundwater nitrate concentration agrees with preliminary groundwater modeling results that are based on the assumption that nitrate concentrations in recharge are 106 mg/l prior to April 1, 1998, and 43 mg/l thereafter (i.e., according to N field budget estimates, above; Fig. 3).

Measured groundwater concentrations, like the deep soil nitrate concentrations, are within a factor 2 of the concentrations predicted from the overall field nitrogen budget. Direct comparison of groundwater concentrations and field N budget, however, is difficult and the results should be interpreted very carefully: (A) Significant amounts of N are stored from year to year in the soil. Organic N pools in the soil that accumulated as a result of years of excess manure applications may only slowly decay as management practices change. The organic N pool may provide a residual source of nitrate in percolating water. (B) Travel times across the individual field to the monitoring wells are on the order of one to several years. Hence changes in the amount of nitrate percolating from the soil may not be detected in groundwater for months or years (Fig. 3). (C) Denitrification and dilution may reduce groundwater nitrate concentrations relative to the nitrate concentration in the percolating water. (D) The installation of subsurface tile drains below the two demonstration fields at the beginning of crop year 1999 may have influenced the nitrate concentrations in the wells through local changes in the groundwater dynamics. We are currently evaluating these impacts.

For 2000, the computed net nitrogen budget within the margin of error of its individual budget components. From a practical point of view, inputs and outputs are therefore balanced. However, a balanced budget at the field or farm scale is – by itself - not a guaranty for either environmental compliance or sufficient crop fertilization. Within a field, significant local imbalances may exist due to irrigation nonuniformity, N application nonuniformity (a result of variable pond water N concentrations, and settling of organic suspended solids during manure irrigations), and due to variable irrigation practices from application to application. Continued soils and groundwater monitoring will be necessary to evaluate the actual long-term impacts of the improved management practices on crop yields and groundwater quality.

CONCLUSIONS

- Management of manure as the almost exclusive source of crop nitrogen is feasible without short-term impacts on crop yields. Substantial capital improvements in pond storage and pond water delivery to the fields (pump, pipeline extension, flow meter, throttling valve, field test supplies for ammonia and organic N determination) and significant efforts in monitoring the applications are needed to successfully implement these practices.
- Significant reductions in shallow groundwater nitrate concentrations have been achieved. These changes occurred over a relatively short time period due to the high net recharge rate, the high soil permeability, and the extremely shallow water table (less than 10 feet. In areas with deeper water table (50 feet and more), similar changes in groundwater nitrate concentrations near the water table may not be observed until several years after management practices have changed.
- Organic nitrogen must be accounted for to balance the nutrient inputs and outputs to and from the field.
- Long-term studies are needed to evaluate the intermediate and long-term agronomic, environmental, and economic feasibility of the proposed management practices.

ACKNOWLEDGMENTS

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FIGURES:

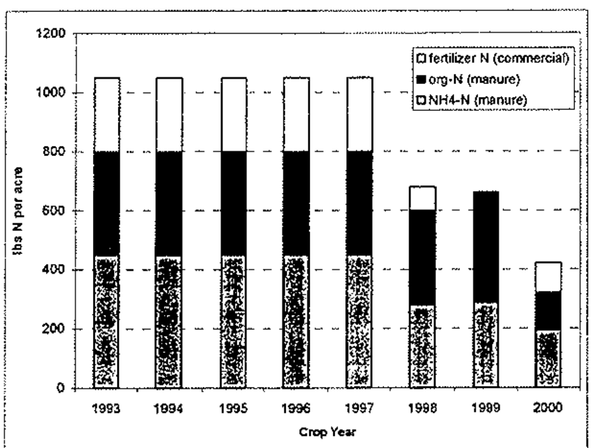
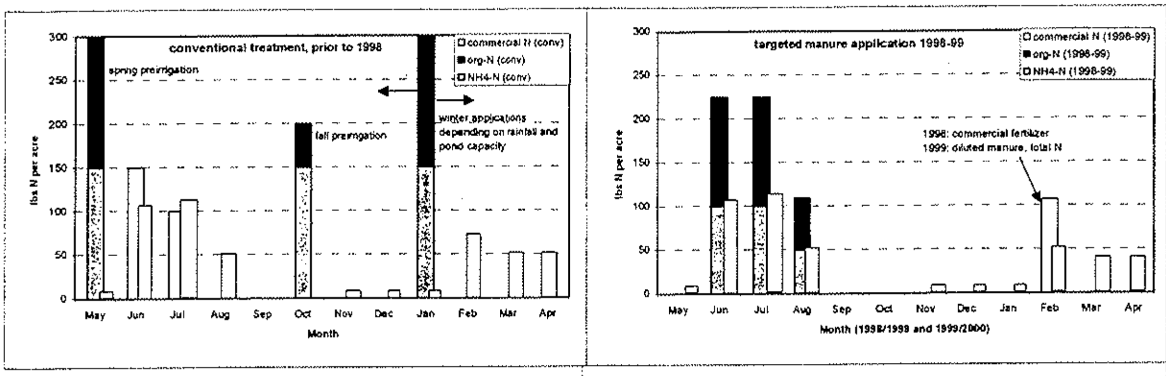


FIGURE 1: Annual nitrogen applications from manure (NH_4-N and organic N) and from commercial fertilizer from 1993 – 2000. Applications for 1993 – 1997 are preliminary estimates based on management practices reported by the cooperator and based on estimates of the NH_4-N and organic N in pond water.



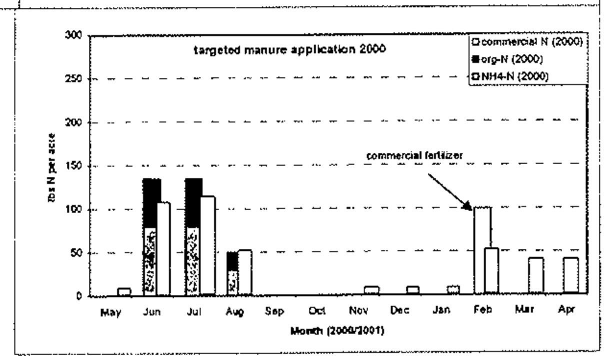


FIGURE 2: Typical monthly nutrient applications (lbs/acre per month) for conventional (a), 1998-1999 (b), and 2000 (c) treatments. In white bars: typical plant N uptake (lbs/acre per month), assumed to be similar throughout all treatments.

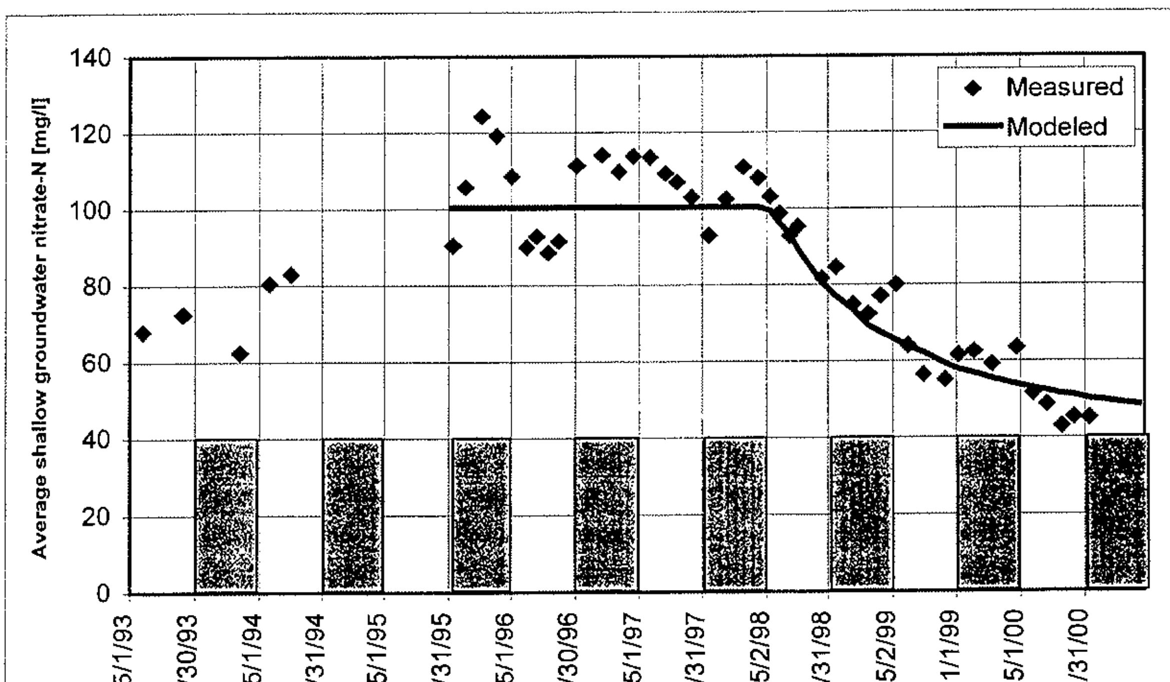


FIGURE 3: Average measured and modeled groundwater nitrate-N from 1993 through 2000. Two wells were monitored throughout that period. Four additional wells were installed in April 1999 and are included in the average. Shaded areas represent winter periods (November through April).

NRCS ASSISTANCE IN PREPARING AND IMPLEMENTING MANURE MANAGEMENT PLANS

Dan Johnson
State Water Management Engineer
USDA Natural Resources Conservation Service
Davis, California
Ph: (530) 792-5625
Fax: (530) 792-5791
Dan.johnson@ca.usda.gov

The NRCS provides voluntary technical assistance to private land users in their management of soil, water, air, plants, and animal resources. With offices located in most counties, NRCS takes an interdisciplinary approach in helping producers identify resource concerns, develop alternatives for improvement, and plan and design needed conservation practices. NRCS also administers the Environmental Quality Incentive Program (EQIP) that can provide cost share funds to producers for the installation of practices.

Increasing national, state, and local concerns about manure handling at confined livestock facilities are encouraging NRCS to broaden and accelerate our work in this area. NRCS will move beyond simply helping producers design and build manure storage ponds and other individual components to a process where all components will be evaluated and planned as a manure management system. Additionally, the potential impacts of proposed practices on other resources will also be evaluated.

Manure Management Plans

Whether we call them manure management plans or Comprehensive Nutrient Management Plans (CNMPs) NRCS, by policy, follows a "conservation planning process" whereby we look at the producer's entire operation and the surrounding environment as a system. Steps in the process include:

- Weighed against the producer's objectives and NRCS Practice Standards, each component of existing manure management systems will be evaluated. Producer's objectives may include getting into regulatory compliance, environmental stewardship, or simply making the operation easier to run. Typical components include manure production, collection, transfer, storage, treatment, and utilization.
- Assisting the producer in deciding on a list of improvements needed to address identified problems.
- Assisting the producer in scheduling the implementation of improvements and in developing a written strategy on how he/she will operate the system from cow to crop. It's at this point that EQIP or another funding program can be pursued to help offset the cost of planned practices.
- Assisting the producer in implementing new methods and follow-up as needed to address problems along the way.

Nutrient Management Plans

Although there are several alternatives for utilizing manure, land application will continue to be a common method employed. In order to take full advantage of the nutrient value of manure and to avoid the environmental pitfalls of over application, manure needs to be treated as a resource as opposed to a byproduct. Unfortunately, in comparison to commercial fertilizer, manure is difficult to handle, its total nutrient content varies, and its available nutrient content is difficult to predict. A nutrient management plan must address these challenges to be effective and is likely to include:

- Results of a farm wide nutrient budget to let the producer know the status of his/her potential to apply manure to farmland with minimal threat to groundwater. With this information he/she can consider the need to access more farmland, haul manure off site, treat it, or to utilize it in some other way.
- Confirmation that adequate facilities are in place to allow good manure application decisions to be made. Storage ponds need to be large enough to provide flexibility in timing of application. Appropriately designed pipeline systems must be in place to convey liquid manure to fields planned to receive it. Facilities are needed to meter the planned amount of manure to each field.
- An inventory of fields, soil types and properties, and facilities used to convey manure to points of application. Usually produced in the form of a map, this tool is used by the producer to plan annual cropping patterns and to budget manure applications between fields based on crop needs and his irrigation and manure application system.
- Crop water requirements and nutrient uptake characteristics. Crop nutrient uptake characteristic information is limited. Further research is needed. However, the best available information can be used so producers can make application decisions.
- Guidance on how to determine or estimate the amount of nutrient available in manure at the time of application and in the future as mineralization occurs. Researchers need to continue work on developing manure quick- tests and accounting for nutrients made available through mineralization.
- In irrigated areas, information regarding good irrigation practices will be provided. The best nutrient management will not keep nutrients from leaching if poor irrigation management produces excessive deep percolation of water.
- Guidance on how to include soil nutrient monitoring into a nutrient management strategy.
- Record keeping system that serves as a manure application decision-making tool for current and future applications.
- Guidance on the operation of manure storage, transfer, and measurement systems.
- A proposed manure application schedule for the current season.

Technical assistance in implementing the plan will be critical. It will take some time, perhaps years, before producers work out inevitable bugs in the new system. There will be a lot of trial and error. NRCS will be available to assist with adjustments.

Lots To Do

To reach this level of management it will take a great deal of time on the part of those providing assistance. NRCS will prepare ourselves and deliver this level of assistance, however, we know that we will not have the staff to meet the need. It will take a partnership between NRCS, Cooperative Extension, private industry and others to collectively contribute the time necessary. The California Dairy Quality Assurance Environmental Stewardship Program, for example, is educating producers about environmental regulations and the basics of good manure management. Producers who participate in this program will be more willing to consider new technologies and more intensive manure management strategies.

For a partnership to work, we'll need to work toward common agreement regarding practice standards, acceptable planning data, evaluation procedures, and tools.

In the National USDA/EPA "AFO Strategy", NRCS has been given the task of developing or overseeing the development of a voluntary certification program for those who provide manure/nutrient planning management assistance to confined livestock producers. It's likely that a manure management training program will be developed to help prepare people for certification. A certification program should benefit producers and those who assist them by encouraging quality work and uniformity in expected results and data used.

Biology and Engineering of Animal Wastewater Lagoons

Ruihong Zhang
Associate Professor
Biological and Agricultural Engineering Department
University of California, Davis
Phone: (530)754-9530, Fax: (530)752-2640, Email: rhzhang@ucdavis.edu

Introduction

Wastewater treatment lagoons are earthen impoundments that are engineered and constructed to treat as well as temporarily store wastewater. In practice, the terms *lagoons and ponds* are used interchangeably. The wastewater treatment lagoons are different from wastewater storage or holding lagoons in that they are designed to function as biological reactors that allow effective degradation of organic compounds contained in the wastewater by various microorganisms. Through the biodegradation process, solid particles in the wastewater are broken down and liquified, and organic compounds are converted into inorganic compounds, resulting a reduced organic content in the wastewater effluent. Meanwhile, organic nutrients, such as nitrogen and phosphorus, are mineralized into inorganic nutrients in the forms of ammonia and orthophosphate, respectively. If designed and opereated properly, treatment lagoons are capable of achieving siginificant reduction of suspended solids and mineralization of nturients in the wastewater, which is desirable for wastewater irrigation and reuse.

The physical, chemical, and biological environments in the treatment lagoons are controlled to achieve the intended purposes of wastewater treatment. Depending on the specific designs, some treatment lagoons are built with wastewater storage volumes as well as treatment volumes. In comparison, wastewater storage lagoons are designed only to provide the temporary storage of wastewater. Even though natural degradation of the wastewater by indigenous microorganisms does occur during the storage period, the waste degradation rate in a storage lagoon is not controlled, and therefore degradation is less efficient and often unpredictable. Treatment lagoons are not pumped down below their treatment volume elevation except for maintenance purposes whereas storage lagoons are emptied regularly when the wastewater is pumped out for irrigation.

Wastewater treatment lagoons have been widely used for the treatment of human, industrial, and animal wastewaters due to their low capital costs and simple operational and maintenance requirements compared with other biological treatment systems. In the United States, use of treatment lagoons for human waste has the longest history, about 100 years. At present, the lagoons are mainly used in small community and rural areas where sufficient land areas are available. Animal wastewater lagoons have about 30 years of history. Early animal wastewater lagoons were designed primarily based on the experiences with human wastewater lagoons. After years of experimental evaluations, agricultural engineers and scientists have gained a better understanding of the biochemistry involved and have developed engineering design standards specific to animal wastewater lagoons. Due to the high contents of nutrients and organics in the animal wastewater, the treatment capacity of wastewater lagoons is often limited, and effluent from the lagoons is not suitable for direct discharge into surface waters. In this paper, I will discuss the biology/biochemistry and the engineering designs of animal wastewater lagoons.

Biology/Biochemistry of Wastewater Lagoons

Wastewater treatment lagoons range in depth from shallow to deep and often are categorized by their mode of biodegradation, as determined by the presence or absence of dissolved oxygen (aerobic or anaerobic), source of oxygen, and other design features. Biological degradation and sedimentation are the primary means for removal of organic and inorganic compounds from the wastewater in the lagoons. Based on the presence of oxygen, the lagoons are classified as aerobic, anaerobic, and facultative lagoons. Bacteria are the primary microorganisms responsible for waste degradation in all types of lagoons. Algae live symbiotically with bacteria in aerobic and facultative lagoons and play an important role in removing nutrients from the wastewater.

Aerobic lagoons

Aerobic lagoons contain dissolved oxygen in the water to sustain aerobic bacteria. The dissolved oxygen can be supplied naturally or artificially. Natural aeration is achieved by air diffusion at the water surface, by wind- or thermal gradient-induced mixing, and by photosynthesis. The photosynthetic microorganisms include algae and cyanobacteria (blue-green algae). Artificial aeration is achieved by mechanical aeration. Thus, there are two types of aerobic lagoons, naturally aerated lagoons and mechanically aerated lagoons.

Naturally aerated lagoons are quite shallow, typically 1 to 2 feet, to allow sunlight to penetrate the full lagoon depth to maintain active algal photosynthetic activity during daylight hours. The oxygen produced from the photosynthesis process is used by aerobic bacteria to degrade the organic waste. The dissolved oxygen level in the lagoon increases and decreases throughout the day, depending on the solar irradiation available. The general chemical reaction for aerobic degradation of organic compounds is as follows:

$$\text{Organics compounds (C, H, O, N, S)} + O_2 \text{ ---> } CO_2 + H_2O + NH_4^+ \text{ (or } NO_3^- \text{)} + S \text{ (or } SO_4^{2-} \text{)}$$

Natural air diffusion and algal photosynthesis require that naturally aerated lagoons be shallow and have large surface areas. Mechanically aerated lagoons (Figure 1), however, do not have the depth requirement. They are usually built with much more depth and a smaller surface areas than the naturally aerated lagoons. Since oxygen is supplied through mechanical means, algal photosynthesis in the mechanically aerated lagoons plays an insignificant role.

Under aerobic conditions, the nitrogenous compounds (proteins, peptides, and amino acids) are first converted to ammonium (NH_4^+) by heterotrophic bacteria. If sufficient oxygen is available and the chemical environment is right, nitrification bacteria may be established and oxidize ammonium into nitrite and then into nitrate. Therefore, the end products of nitrogen oxidation can be ammonium, nitrite, or nitrate, depending on how complete the oxidation is carried out by the bacteria. Organic carbon is oxidized into carbon dioxide. Sulfur compounds (sulfur-containing protein) in the wastes are converted to elemental sulfur (S) or sulfate (SO_4^{2-}) in the aerobic environment instead of odor-causing sulfides in the anaerobic environment. The degree of oxidation depends on the amount of oxygen provided and the reaction time allowed in the treatment process.

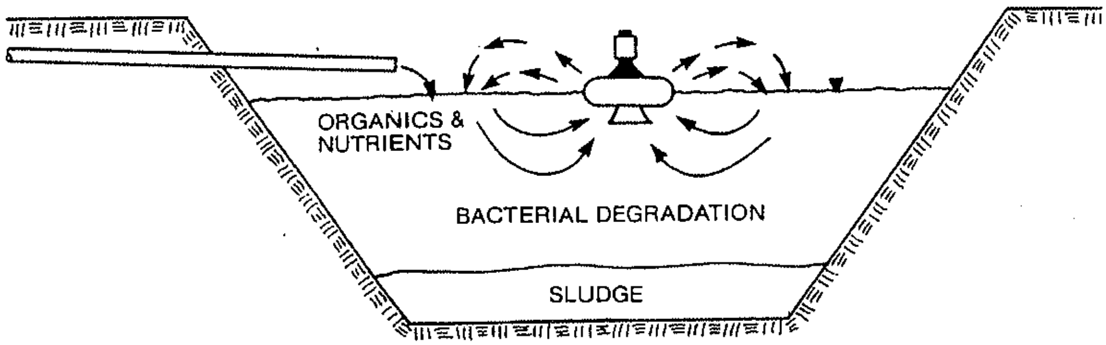


Figure 1. Mechanically aerated lagoons (adapted from NZAEI, 1984)

Facultative lagoons

The facultative lagoons are deeper than aerobic lagoons, varying in depth from 5 to 8 feet. Waste is treated by bacterial action occurring in an upper aerobic layer, a facultative middle layer, and a lower anaerobic layer. Aerobic bacteria degrade the waste in the upper layer where oxygen is provided by natural surface aeration and algal photosynthesis. Settleable solids are deposited on the lagoon bottom and degraded by anaerobic bacteria. The facultative bacteria in the middle layer degrade the waste aerobically whenever dissolved oxygen is present and anaerobically otherwise. Figure 2 shows microbial interactions and waste degradation pathways in a facultative lagoon. The facultative lagoons are more common than naturally aerated lagoons. They have more depth and smaller surface areas but still have good odor control capabilities because of the presence of the upper aerobic layer, where odorous compounds such as sulfides produced by the anaerobic degradation in the lower layer, are oxidized before emission into the atmosphere. Biochemical reactions in the facultative lagoons are a combination of aerobic and anaerobic degradation reactions.

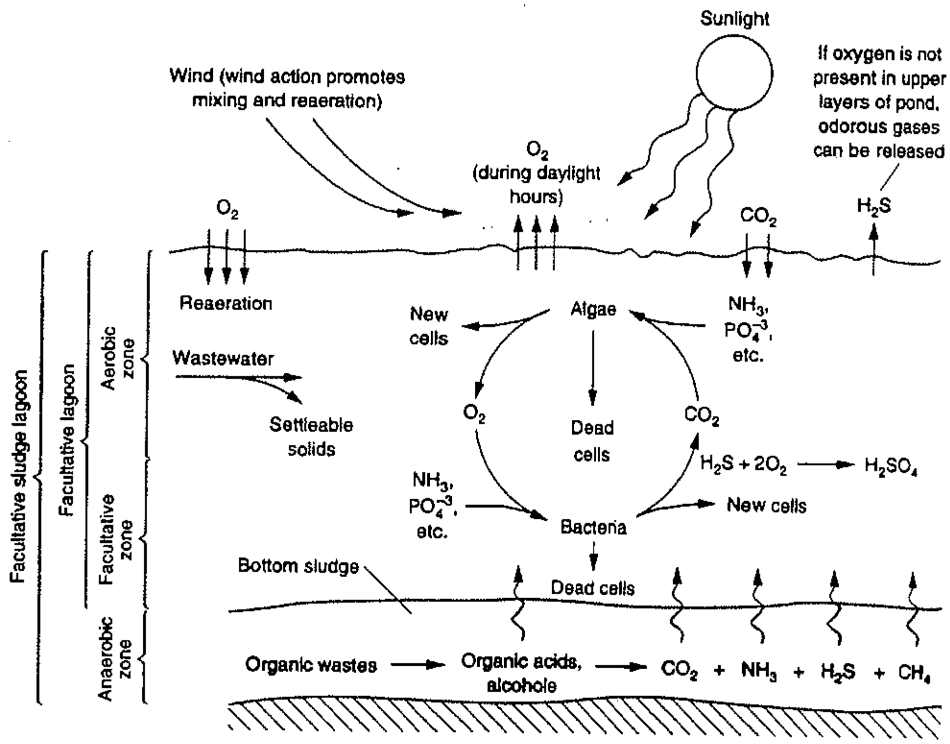


Figure 2. Facultative lagoons (adapted from Crites and Tchobanoglous, 1998).

Anaerobic lagoons

Anaerobic lagoons are used mostly for high-strength wastewater treatment, such as animal wastewater. They vary in depth from 8 to 30 feet and are built as deep as the local geography allows to minimize the surface area and reduce odor emissions. The top layer may contain dissolved oxygen depending on wind, temperature, and organic loading rate. In general, however, the aerobic layer is very thin, less than 50 cm, and the contribution of aerobic bacteria to the overall waste degradation is insignificant. Due to the high organic content of animal wastewater, all the primary lagoons used for animal wastewater treatment are essentially anaerobic lagoons, unless mechanical aeration is added to artificially render the lagoons facultative or aerobic.

Under anaerobic conditions, two distinct reactions occur. In stage one, hydrolysis of organic compounds and conversion to intermediate organic acids are achieved by acid-forming bacteria called acidogens. Then in stage two, the organic acids are converted by methane and carbon dioxide by methane-forming bacteria called methanogens as illustrated in Figure 3.

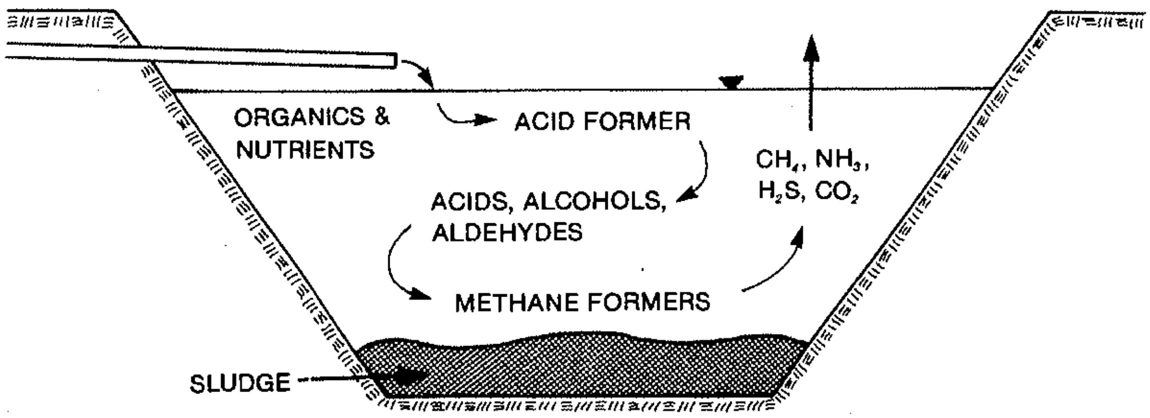


Figure 3. Degradation of organic compounds in anaerobic lagoons (adapted from NZAEI, 1984).

The overall complete reaction of anaerobic degradation is:

$$\text{Organics(C, H, O, N, S)} \longrightarrow CH_4 + CO_2 + NH_4^+ + H_2S$$

Methane (CH_4) and carbon dioxide (CO_2) are produced as the end products of organic carbon degradation. Methane has very low solubility in water and is readily emitted into the atmosphere as soon as it is formed. Ammonium (NH_4^+) and hydrogen sulfide are the end products of nitrogen and sulfur degradation, respectively. Ammonium (NH_4^+) exists in equilibrium with ammonia (NH_3) in the wastewater. Carbon dioxide, ammonia, and hydrogen sulfide are three soluble gases. Their potential for emission into the atmosphere is largely dependent on the pH and temperature of the lagoon water. A high pH (>8) favors more ammonia emissions while a low pH (<6) favors more hydrogen sulfide and carbon dioxide emissions. Between the two major groups of anaerobic bacteria (acidogens and methanogens), methanogens are more environmentally sensitive and fastidious. They have stricter pH and redox potential requirements. They are obligate anaerobes, i.e., they can not tolerate any molecular or ionic oxygen in the water. The redox potential of water must be below –300 for the methanogens to thrive. The optimum pH for methanogens is 6.8 to 7.5, with the lowest pH being 6.2. In comparison, acidogens are more versatile and have much wider working pH range, 5 to 8, with the optimum level being 5 to 6. Therefore, one way to suppress the methane production in anaerobic lagoons is to control the pH below 6.2. However, when methanogens are suppressed, the anaerobic degradation will not be carried to completion, yielding much organic acids that may cause strong odor problems. Volatile fatty acid (VFA) in the lagoon water has been used by researchers as an indicator for measuring how complete the anaerobic degradation is in anaerobic digesters and lagoons and for correlation with odor levels. A well functioning anaerobic digester usually has a VFA below 800 mg/L. In comparison, a heavily loaded anaerobic lagoon can have a VFA above 3,000 mg/L. The exact correlation of VFA with odor level from anaerobic lagoons has not been well established by researchers. It is currently a researchable question.

In most anaerobic lagoons, anaerobic degradation is not complete due to the fact that conditions such as organic loading rate, temperature, and retention time are not optimum for bacterial reactions. High concentrations of intermediate degradation compounds, such as organic acids, amino acids, aldehydes, sulfides and others are present in the lagoon water and contribute most of the foul odors. Well-designed and operated lagoons can effectively lower the concentrations of these odorous compounds and keep odors to a minimum. However, high emissions of methane from open lagoons may be expected. Gases produced at the bottom of anaerobic lagoons often lift sludge to the top surface forming a layer of floating solids. Adding gental mechanical mixing in the anaerobic lagoons has been found to help prevent this solids-rising phenomena (Rice, 1977). Covering lagoons is a good way to recover the methane gas as a fuel and also to control emissions of ammonia and other odorous gases.

In addition to acidogens and methanogens, other types of bacteria also live in the anaerobic lagoons. One with particular environmental significance is purple sulfur bacteria. Lagoons containing such bacteria turn pink, purple, or red in the warm months. Purple sulfur bacteria are phototropic anaerobic bacteria that use sunlight as an energy source and are capable of oxidizing sulfides, therefore reducing odors from anaerobic lagoons. Due to their capability of suppressing odors from the anaerobic lagoons, they have recently become the subject of research. Research is underway at several universities to understand the right conditions for growth of purple sulfur bacteria in the lagoons. The USDA-ARS and University of Nebraska researchers (Gilley et al., 2000) have found that the zinc in swine diets enhanced the growth of purple sulfur bacteria, whereas copper inhibited their growth. Temperature and solar radiation are other factors that affect the growth of purple sulfur bacteria.

Even though lagoons are generally considered to be simple treatment systems, the biology and biochemistry involved are very complex, involving many forms of biological reactions. Anaerobic lagoons are mostly suitable for treating animal wastewater. Facultative and aerobic lagoons may be used as secondary lagoons after the anaerobic lagoons to provide further biological degradation and produce relatively odor-free water for recycling and irrigation. Thus, different types of lagoons can be combined into multiple-stage lagoons to achieve the best treatment if the land area is available. Since they are operated at ambient temperature, lagoons function well only in mild or warm climates.

Design and Engineering of Lagoons

As mentioned earlier, lagoons are designed to be bioreactors that should provide suitable environmental conditions for microorganisms to degrade the organic wastes. Major factors affecting the performance of animal wastewater lagoons include temperature, organic loading rate, retention time, pH, and the presence of inhibitory or toxic chemicals. Ammonia is one of the chemicals that needs special consideration. At high concentrations, ammonia can become inhibitory or toxic to the bacteria in the lagoons. Generally, total ammonia nitrogen in the lagoon water should be kept under 1,500 mg/L. Therefore, animal manure needs sufficient dilution to reduce the ammonia concentration to a safe level before entering the lagoons.

Lagoons are sized based on organic loading rate or retention time. Organic loading rate and retention time are related to the temperature of the lagoons, which in turn are decided by the local climatic conditions. The allowable organic loading rate is higher for the lagoons located in warmer climates. According to the current engineering design standard published by American Society of Agricultural Engineers (ASAE) and the design method published by USDA-NRCS, the organic loading rate of lagoons is defined as follows. For anaerobic lagoons, the organic loading rate is the volumetric loading rate of volatile solids, which is the amount of volatile solids in pounds loaded per 1,000 cubic feet of lagoon treatment volume per day (lb VS/1000 ft^3.day). For facultative and naturally aerated lagoons, the organic loading rate is the area-loading rate of 5-day biochemical oxygen demand (BOD_5), which is the amount of BOD_5 in pounds per acre of surface area per day (lb BOD_5/ac.day).

ASAE has an engineering design standard for anaerobic lagoons (ASAE, 1999). USDA-NRCS also has an engineering design standard (USDA-NRCS, 1992). Each design standard has a set of organic loading rates recommended for different regions of the United States, with higher values for warmer regions. However, the two sets of the organic loading rates show different values for the same regions. For example, for California from the south to the north, the ASAE standard recommends the maximum loading rate to be 5.5 to 4.5 lbVS/1000 ft^3.day, while the USDA standard recommends 6.5 to 5.5 lbVS/1000 ft^3.day. Since the ASAE standard is the most recent standard developed and the authors are from USDA-NRCS, it is recommended that the ASAE standard be used as the first reference. Figure 4 shows the loading rate of anaerobic lagoons for the different regions of the United States as published by ASAE. In either standard, the organic loading rate is given as the recommended maximum loading rate. The actual loading rate that should be used depends on the treatment objectives being stressed, such as maximizing pollutant reduction, reducing odors, or minimizing sludge production. The ASAE standard recommends a minimum 50-day retention time for primary anaerobic lagoons. Figure 5 shows a diagram of a single-stage anaerobic lagoon, which contains wastewater treatment volume and storage volume.

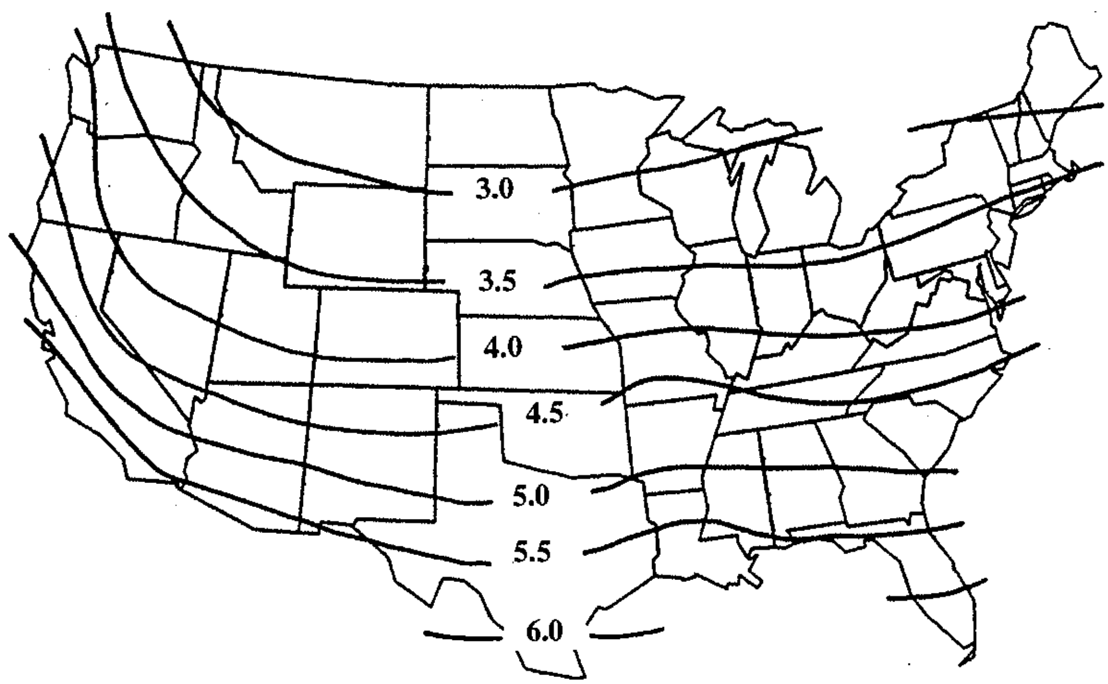


Figure 4. Loading rate of anaerobic lagoons in lb/1000 ft^3.day (adapted from ASAE, 1999).

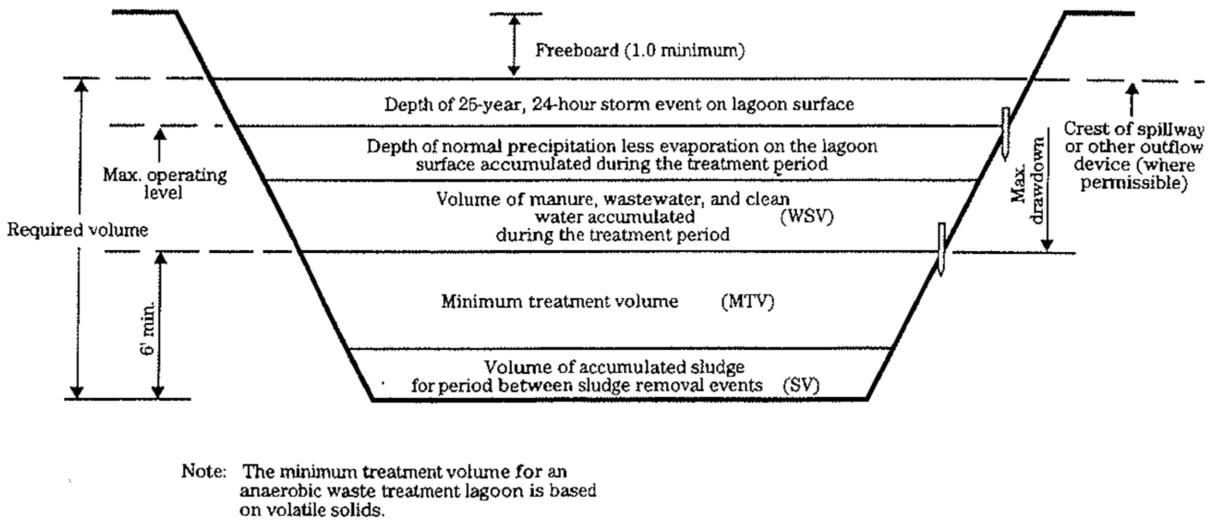


Figure 5. Design volumes of an anaerobic lagoon (adapted from USDA-NRCS, 1992).

Two-stage anaerobic lagoons are sized based on the criteria that the first stage contains the treatment volume and the second stage contains the storage volume. Both stages must have the volumes for net precipitation and 25-year/24 hour storm on the lagoon surface and freeboard. If wastewater is recycled on the farm for manure flushing systems, a two-stage lagoons is recommended over a single-stage lagoon. The recycling wastewater should be pumped from the second-stage..

The detailed design procedures for anaerobic lagoons are given in both the ASAE Standards and USDA-NRCS Design Method. The ASAE Standards list various engineering considerations for construction of lagoons, including sitting, groundwater protection, depth, shape, earth embankment and excavation, inlet and outlet, effluent utilization, water supply, safety, and visual appearance. It also outlines the operation and maintenance procedures, such as start-up, operational depth and loading, salt build-up, crust, sludge removal, and inspection.

Design procedures for aerobic and facultative lagoons are given by USDA-NRCS method (1992). The engineering considerations for construction, operation, and maintenance are similar to anaerobic lagoons.

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FERTILIZER USE EFFICIENCY AND INFLUENCE OF ROOTSTOCKS ON UPTAKE AND ACCUMULATION OF N IN WINE GRAPES GROWN IN THE COASTAL VALLEYS

Larry E. Williams
Department of Viticulture and Enology
University of California – Davis, and
Kearney Agricultural Center
9240 S. Riverbend Ave.
Parlier, CA 93648
e-mail: williams@uckac.edu

There are approximately 284,000 ha of grapevines grown in California with 42% of that acreage devoted to wine grape production. Presently, the most rapidly growing segment of the wine industry is the sale of premium wine. The majority of grapes used to produce premium wine are grown in the coastal valleys of California. Unfortunately, a large portion of the vineyards in those areas is having to be replanted on rootstocks resistant to Phylloxera, a root feeding louse. Most of the fertilization recommendations for grapevines in California were developed for vines growing in the San Joaquin Valley on their own roots. Thus, there is an urgent need to develop fertilization recommendations for premium wine grape cultivars grown on different rootstocks in the coastal areas of California.

The primary fertilizer used in California vineyards is nitrogen. Therefore, the timing and amounts of an N fertilizer application are critical in optimizing its uptake to avoid leaching below the root zone and possible ground water contamination. The only direct way to measure fertilizer use efficiency is with the use of ^{15}N labeled N fertilizer. ^{15}N is a non-radioactive isotope of N and can be quantitatively measured in plant tissue. This study was conducted to determine fertilizer use efficiency, using ^{15}N labeled fertilizer, in four different vineyards (two Chardonnay and two Cabernet Sauvignon vineyards) growing on different rootstocks, and at different locations in California.

Materials and Methods:

The study was conducted in four commercial vineyards. The Chardonnay vineyards were located in the Carneros district of Napa Valley and east of Gonzales in the Salinas Valley. The Cabernet Sauvignon vineyards were located at Oakville in Napa Valley and east of Paso Robles. The rootstocks used in the study are shown in Table 1. Subsequent to berry set (two to four weeks after full bloom) in 1997 $^{15}NH_3{}^{15}NO_3$ fertilizer (5 atom % excess) was applied to six, individual vine replicates for each rootstock at all locations. The amount of N applied per vine was determined by estimating yield at each site and the corresponding amount of N that would be removed in the fruit at harvest. This ranged from 30 to 50 kg N/ha, depending upon location. The fertilizer was dissolved in water and placed beneath an emitter while the vines were being irrigated.

Fruit of the data vines were harvested and weighed at each location when the sugar levels indicated that a particular vineyard would be harvested within one week. After harvest the fruit was taken to the Kearney Ag Center where the clusters were dried. Senescent leaves were removed from the data vines at each location beginning shortly after fruit harvest, transported back to the Kearney Ag Center and dried. It was assumed that the leaves removed weekly were about to naturally fall from the vine. All leaves remaining on the vines the first week of December were removed and dried. Leaves from each vine replicate on the different harvest dates were combined and total leaf dry weight determined. Subsequently, leaves from each vine were subsampled and ground. The remaining leaves were then taken back to each respective vine and placed on the ground beneath each replicate in 1998 and 1999. This was accomplished when the vines were pruned. Data vines were pruned during the dormant portion of the growing season. Fresh pruning weights were taken and then subsampled. The subsamples were transported back to the Kearney Ag Center, fresh weights taken and then dried. The prunings left in the vineyard were cut into short pieces and then distributed on the ground around each vine replicate.

The dried vine material was ground to a fine powder. All ^{15}N labeled vine parts were sent to a commercial laboratory to determine the amount of total N and ^{15}N of each organ for data collected each growing season. Data were analyzed via analysis of variance. Differences among means were determined using Duncan's multiple range test.

Results:

The total amount of ^{15}N taken up by the vine over the three year period of the study was determined (Table 1). There were significant differences among rootstocks at the Paso Robles location, no differences among rootstocks at the other locations. The sum of Total N as a function of rootstock in the same organs over three years differed significantly only at the Oakville location but this may have been due partly to significant differences in biomass production among rootstocks at that site. The average N concentration of biomass produced by the scion (total vine N divided by total vine dry weight) was significantly affected by rootstock at three of the four locations. A comparison of the two rootstocks (5C and 110R), common to all experimental locations, showed that percent N was significantly greater for 5C at Gonzales, significantly greater for 110R at Oakville, but no significant differences between the two at Carneros and Paso Robles.

Fertilizer use efficiency (FUE) (ratio of applied ^{15}N to ^{15}N taken up by the vine) was calculated for all scion/rootstock/location combinations each year and then summed at the end of the study (Table 2). With the exception of the Paso Robles site, there were no significant differences in FUE among rootstocks. This may be due to the fact that all rootstocks were culturally treated the same (i.e. vertical trellis system, shoot positioned, hedged at a certain height and drip irrigated according to best estimates of vine water requirements). All fertilizer applications were such that the nitrogen was applied directly beneath an emitter while irrigating. The 110R rootstock had a significantly higher FUE than the 5C rootstock at Paso Robles and it was higher than 5C at the other three locations (although not significantly). The FUE of Freedom was greatest among rootstocks at Paso Robles but lowest at Gonzales.

There were somewhat larger differences in FUE among locations. Fertilizer use efficiency, when averaged across rootstocks, was 12.0, 4.9, 14.0 and 6.6% at the Carneros, Gonzales, Oakville and Paso Robles sites, respectively. There are several explanations for the differences among sites. The extremely high petiole nitrate-N levels in 1997 at the Paso Robles vineyard may indicate an abundance of soil nitrogen at that site thus diluting the uptake of fertilizer N. At the Gonzales site, the cooperator applied a NPK fertilizer without my knowledge again diluting the ^{15}N fertilizer applied at berry set. The higher FUE at the Carneros and Oakville sites may have been due to the fact that neither vineyard had been fertilized since planting. In addition, the Oakville vineyard had very low petiole nitrate levels when sampled at bloom in 1997 and 1999. Lastly, the proportion of labeled fertilizer taken up the first year at Carneros, Gonzales, Oakville and Paso Robles was 87, 84, 79 and 60% of that found in the vine over three years.

The amount of N required to support the growth of the fruit, leaves and canes each year the study was conducted as a function of rootstock and location (Table 3) and location (Table 4) is shown. Differences in N uptake from year to year were related to differences in yield from year to year. Over the course of the study N requirements ranged from 163 kg N per ha (145 lbs./acre) to 110 kg pr ha (98 lbs./acre). The lowest amount of N per tonne of fruit was 0.98 kg (1.96 lbs./ton) at the Oakville site in 1997 (Table 4).

Discussion and Conclusions:

This study quantified the uptake of nitrogen as a function of scion, rootstock and location for three growing seasons. As has been found in other studies on grapevines, the fruit is the major sink for nitrogen. Summed over the three growing seasons the amount of N found in the clusters at harvest, leaves as they fell from the vine and the pruning canes ranged from a low of 100 to a high of 163 kg N per hectare (98 to 145 lbs./acre). The actual amount of N removed from the vineyards (by harvesting the fruit) ranged from approximately 1.0 to 1.6 kg N per tonne of fruit (2.0 - 3.2 lbs. N per ton).

The data collected would indicate that the efficiency of N fertilizer utilization (FUE) by the various rootstocks differs only slightly. It is often assumed by many in the grape industry that rootstocks with greater petiole nutrients (such as higher nitrate levels) are more efficient than rootstocks that generally have lower values. The data collected in this study would indicate that not to be the case. The small differences among the rootstocks at three of the locations may be due to how the rootstock affected vine growth and that the growth then drove the uptake of the N fertilizer. The significant differences in FUE at the Paso Robles site could be due to differences in root distribution within the soil profile. Those rootstocks with higher FUE may have a higher concentration of roots in the wetted zone beneath the emitter (where the ^{15}N fertilizer was applied), thus having greater access to the fertilizer. The differences among rootstocks at Paso Robles could also have been due to the movement of the labeled fertilizer into the wetted zone at each site the fertilizer was applied. Perhaps some of the labelled fertilizer moved into the soil where little of the vine's roots were present.

Another indicator of a rootstock to absorb N more efficiently would be whether it had a higher concentration of N in the biomass of the scion. There were significant differences (albeit small) at three of the locations among rootstocks in total vine N concentration (Table 2). This would indicate that a particular rootstock took up greater N in relation to the amount of biomass it produced (i.e. more efficient). However, there was no apparent relationship between FUE and the N concentration in the dry biomass.

The above fertilizer use efficiencies seem quite low compared to a FUE of approximately 40% the PI found on Thompson Seedless grapevines grown in the San Joaquin Valley. It should be pointed out that the FUEs presented in this summary were based upon N found in the fruit, leaves and pruning canes while those on Thompson Seedless also analyzed the root system, trunk and fruiting wood. Those three organs contained approximately 40% of the total ^{15}N labeled fertilizer taken up by the vines in that study. It was anticipated that the labeled fertilizer in the trunk, cordons and root systems of the vines used in this study would be remobilized and found in the in the clusters, leaves and pruning canes in 1998 and 1999. The data found in Table 2 indicate the majority of ^{15}N found in those organs was taken up the first year. Other possible reasons for the differences between the Thompson Seedless study and this one are: 1.) the vineyard site in the Thompson study had a hardpan at a depth of 1.0 m, which may have prevented any leaching of the fertilizer below the root zone, 2.) vines in this study were irrigated at estimated full ET, which may have leached the fertilizer below the rooting zone and 3.) other reasons for the low FUE at the Gonzales and Paso Robles have been explained above in the **Results** section. In support of reason 2, an additional treatment was established at Carneros where vines were irrigated at 50% of estimated full ET and fertilized with a combination of potassium nitrate and ammonium sulfate labeled with ^{15}N (left over from my Thompson study). The FUE was twice (approximately 23%) that of the full ET treatment (unpublished data).

Table 1. The amount of labeled N (^{15}N), total N, total dry biomass and percent N of the biomass accumulated by the data vines over the course of three growing seasons (1997, 1998 and 1999). The ^{15}N (5 atom % excess) fertilizer was applied at berry set in 1997 at all locations.[1,2]

Location	Rootstock	Applied ^{15}N Fert	Total ^{15}N	Total N	Total Dry Wt.	Percent N
		------------------------(g vine^{-1})	------------------------	------------------------	------------------------	(% dry wt)
Carneros	5C	12	0.066	44.1	6255	0.71
	110R	12	0.078	52.7	7482	0.70
Gonzales	5C	20	0.049	52.7	6694	0.79a
	110R	20	0.051	54.5	7591	0.72 b
	Freedom	20	0.047	49.9	7889	0.73 b
Oakville	5C	6	0.039	26.6a	4480a	0.59 b
	110R	6	0.043	24.0ab	3760 b	0.64a
	3309C	6	0.044	20.6 b	3761 b	0.62ab
Paso Robles	5C	17	0.035 c	65.3	8261	0.79 c
	110R	17	0.049 b	67.5	8394	0.80 bc
	Freedom	17	0.074a	69.7	8701	0.80 bc
	140Ru	17	0.051 b	79.7	9171	0.87a
	1103P	17	0.072a	74.0	8949	0.83 b

1) The cultivar used at Carneros and Gonzales was Chardonnay while Cabernet Sauvignon was used at the other two locations.

2) Values for the rootstocks within a column at a given location are significantly different ($p < 0.05$) if followed by a different letter. If no letters appear within the column, there are no significant differences among rootstocks.

Table 2. The relationship (expressed as a percentage) between the amount of ^{15}N labeled fertilizer found in each rootstock/scion combination and the amount of ^{15}N fertilizer applied at berry set in 1997 at the end of the growing seasons in 1997, 1998 and 1999 and the total percentage after three years.

			^{15}N in vine/^{15}N applied			
Location	Cultivar	Rootstock	1997	1998	1999	3 Years[1]
			(%)			
Carneros	Chardonnay	5C	9.7	1.1	0.2	11.0
		110R	11.1	1.2	0.7	13.0
Gonzales	Chardonnay	5C	4.0	0.6	0.3	4.9
		110R	4.3	0.5	0.3	5.1
		Freedom	4.0	0.4	0.3	4.7
Oakville	Cabernet	5C	10.4	1.5	1.1	13.0
		110R	11.2	2.1	1.0	14.3
		3309C	11.5	2.1	1.1	14.7
Paso Robles	Cabernet	5C	2.1	1.2	0.7	4.0 c
		110R	3.2	1.8	0.8	5.8 b
		Freedom	6.1	1.7	0.9	8.7a
		140Ru	3.5	1.6	0.9	6.0 b
		1103P	4.8	2.2	1.5	8.5a

[1)] See Table 1 "Total ^{15}N" column illustrating differences among rootstocks with regard to fertilizer use efficiency.

Table 3. Total N in the leaves, canes and clusters at the end of the 1997, 1998 and 1999 growing seasons. Each value is the mean of six individual vine replicates multiplied by the number of vines per hectare.

		Total N (kg ha^{-1})			
Location	Rootstock	1997	1998	1999	3 Year Total
Carneros	5C	53[1]	40	43	136
	110R	65	45	53	163
Gonzales	5C	44	27	45	116
	110R	52	29	39	122
	Freedom	46	24	40	110
Oakville	5C	56	45	48	149
	110R	43	44	41	128
	3309	36	39	35	110
Paso Robles	5C	39	41	37	117
	110R	36	48	36	120
	Freedom	48	41	35	124
	140Ru	48	53	41	142
	1103P	49	48	35	132

1) To convert kilograms per hectare into pounds per acre multiply by 0.89.

Table 4.The total amount of N in the fruit at harvest, leaves as they fell from the vines and prunings taken during the winter and N per tonne of fruit at the four vineyard locations. Each value is the mean (averaged across rootstocks) at each location each year. Other information as found in Table 4.

Location	Total N (clusters, leaves & prunings) (kg ha^{-1})			Total N (kg $tonne^{-1}$ fruit)		
	1997	1998	1999	1997	1998	1999
Carneros	58.7	42.6	47.8	1.34[1]	1.25	1.29
Gonzales	47.2	26.5	41.2	1.24	1.28	1.44
Oakville	44.7	42.9	41.5	0.98	1.24	1.35
Paso Robles	43.7	46.1	36.6	1.58	1.51	1.38

1) To convert from kg per metric tonne of fruit to pounds per English ton multiply by 2.0.

ASSESSMENT OF NITROGEN, PHOSPHORUS, AND POTASSIUM UPTAKE CAPACITY AND ROOT GROWTH IN MATURE ALTERNATE-BEARING PISTACHIO (*PISTACIA VEAR* L.) TREES.

Rosecrance, R.C[1]., Weinbaum, S.A[2]., Brown P.H.[2]
[1]College of Agriculture, California State University, Chico, Chico CA 95929
[2]Pomology Department, University of California, Davis, Davis, CA 95616

Abstract

We examined interrelationships between crop load, nitrogen (N), phosphorus (P), and potassium (K) uptake, and root growth in mature, alternate-bearing pistachio (*Pistacia vera* L.) trees. Pistachio trees bear heavy (on-year) fruit crops in alternate years. Uptake and partitioning of N, P, and K among tree parts were determined during the nut fill (late May to early September). Although root growth was reduced during nut fill in on-year trees compared with off-year trees, there was no relationship between root growth and the uptake of N, P, or K from the soil. Our data support the hypothesis that sink demand rather than root growth regulates the uptake of N, P, and K in pistachio trees.

Introduction

The large, woody biomass and storage of N over winter in perennial tree parts (branches, trunk, roots) make it difficult to assess the magnitude and dynamics of nutrient uptake by mature trees. The situation is further complicated by alternate bearing, because differential crop load influences the pattern of nutrient uptake and usage (Weinbaum et al. 1994).

Heavy fruiting has been shown to depress root growth in apple (Head 1969) in peach (Chalmers and van den Ende 1975) and in citrus (Golomb and Goldschmidt 1987). Little is known, however, about the relationship between root growth and nutrient uptake in mature trees. Many researchers have assumed that nutrient uptake and root growth are concurrent processes, with increased root growth resulting in greater nutrient uptake. This hypothesis, however, has not been adequately tested. The objectives of this study were: 1) To determine the seasonal patterns of N, P, and K uptake over the alternate bearing cycle, and 2) To relate the seasonal patterns of root growth of heavily cropping (on year) and lightly cropping (off year) pistachio trees with seasonal patterns of N, P, and K uptake.

Materials and Methods

Twelve full-sized 20-year-old 'Kerman" pistachio trees were selected for this experiment at S and J Ranch in Madera CA. Six of these trees were in their on-year cycle and nine were in their off-year cycle. Trees were fertilized at optimal levels and soils at the site were as sandy loams, pH 6.0.

Root growth. Root growth was determined using root observation boxes, with 6 boxes installed in the tree row between an on year and an off year tree, about 1.) m from each tree in the microjet spray zone. Each root box had 2 windows (61 x 92 cm), one facing an on year and the other facing an off year tree. Roots growing against the windows were counted and traced onto clear acetate sheets, the tracings were digitized, and lengths measured by computer. Roots from the 12 trees were measured every 2 weeks between fruit set and leaf senescence (April 15 to November 15).

Nutrient uptake. Six trees (3 on and 3 off year) were excavated following the spring growth flush (May 24), nut fill (September 8) periods. Trees were separated into eight fractions: 1) fine roots < 1 cm diameter; 2) roots > 1 cm diameter; 3) rootstock; 4) trunk; 5) canopy branches; 6) current year wood; 7) leaves; and 8) fruits (cropping trees only). The various tree fractions were weighed and subsamples were analyzed for N,P, and K contents. Total annual N, P, and K uptake was determined from the difference in tree nutrient contents from the sequential tree harvests. The trunk cross-sectional area was used to normalize tree of varying sizes, following procedures similar to Kappel (1991).

Results and Discussion

Root growth varied seasonally and was influenced by alternate bearing. On-year trees initiated root growth earlier in the spring that off-year trees and produced three times more white root growing against the rhizotron windows than off-year trees three weeks following anthesis (April 22, Figure 1). On-year trees, however, produced significantly lower numbers of white roots during nut growth (June 16) and at nut maturity (August 30) compared with off-year trees. During nut growth and development root length and root growth rates were significantly depressed in on- vs off-year trees (data not shown). The data support previous research in other fruit tree species that heavy fruiting reduced root growth.

Differential crop load also influenced nutrient uptake, particularly in the case of potassium (Figure 2). On-year trees took up 35% more N ($p<0.10$), 112% more K, and similar amounts of P than off-year trees during the nut fill period (late May to early September). This increased uptake occurred despite the fact that root growth was significantly reduced in on- vs off-year trees. On-year trees had 4 times fewer white roots were growing against the rhizotron than off-year trees during the nut fill period, yet N and K was greater in on- vs off-year trees.

For the decoupling between root growth and nutrient uptake to occur, the rate of nutrient uptake per unit of root length in fruiting tees must be higher than that of non-fruiting trees. Simulation models have shown that doubling root uptake kinetics is as effective as doubling root growth in increasing N uptake (Barber 1995). Thus, increases in root nutrient uptake rates can compensate for a lack of root growth.

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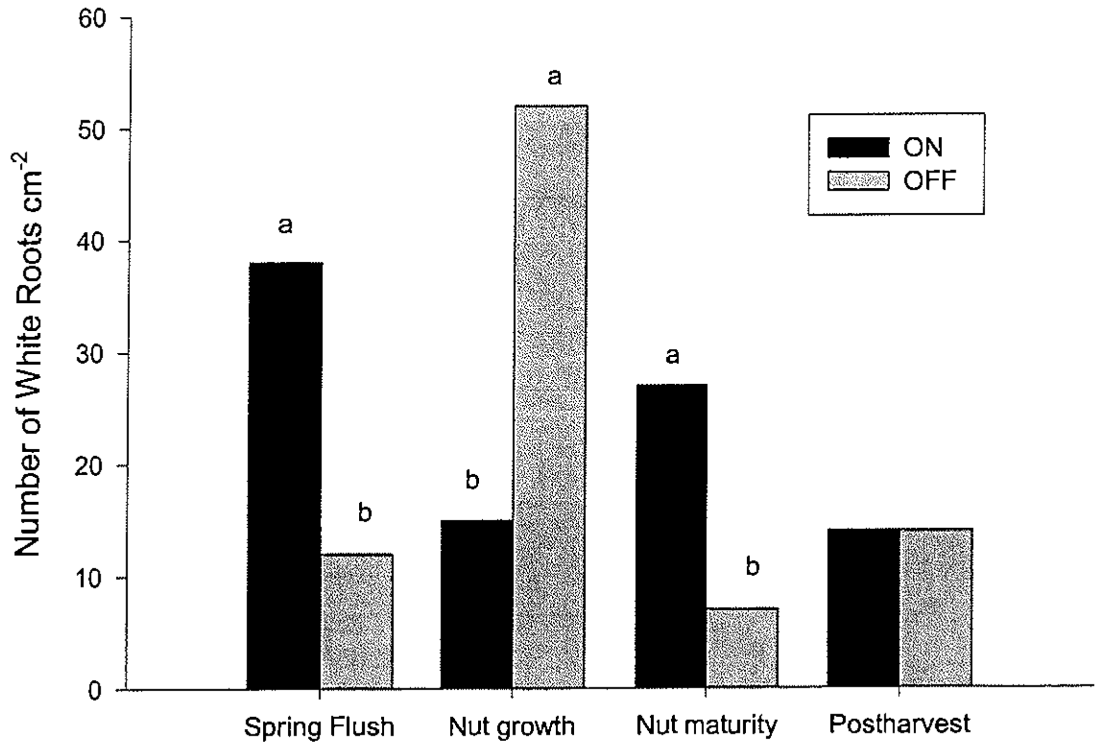


Figure 1. Effects of alternate bearing and season on the number of white roots growing against the rhizotron windows during spring flush (April 22), nut growth (June 16), nut maturity (August 30), and postharvest (October 13) periods.

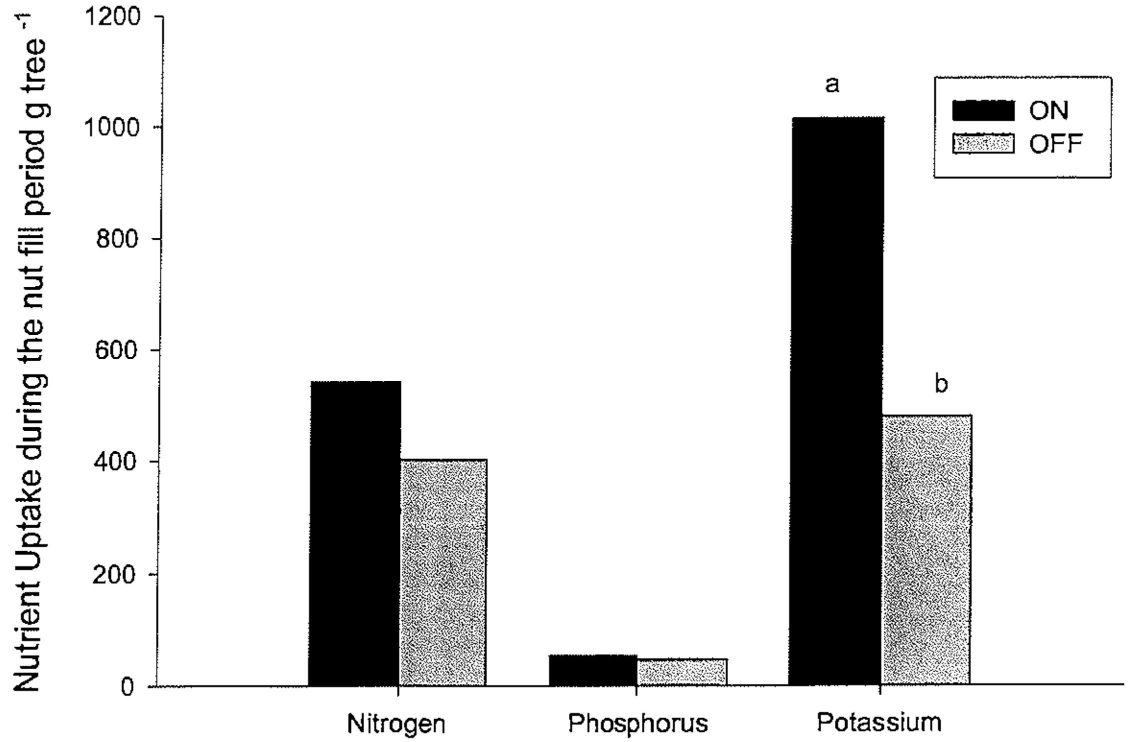


Figure 2. Uptake of N, P, and K (g per tree) during the nut fill period (May 24 to September 8) in on- and off-year trees.

THE ORGANIC TRANSITION PHENOMENON: MYTH OR REALITY?

R.F. Denison, E.A. Martini, D.C. Bryant
Dept. of Agronomy and Range Science
University of California
Davis, CA 95616
Tele: 530-752-9688 FAX: 530-752-4361
e-mail: rfdenison@ucdavis.edu

T.K. Hartz
Dept. of Vegetable Crops
University of California
Davis, CA 95616
Tele: 530-752-1738
e-mail: tkhartz@ucdavis.edu

J.S. Buyer
Soil Microbial Systems Lab.
USDA, ARS, SMSL
Beltsville, MD 20705 USA
e-mail: jbuyer@asrr.arsusda.gov

Recent research at UC Davis's Long-Term Research on Agricultural Systems project (LTRAS.ucdavis.edu) challenges two beliefs which are widely held (not always by the same people!), namely that:

1) organic yields are always lower than conventional yields
2) increases in yields of organic systems over years are due to increasing "soil quality."

In this first-ever comparison of identically-managed replicate plots differing only in the duration of organic management, there was no difference in soil N mineralization, tomato growth or fruit yield, between plots in their first versus sixth year of organic management. But both organic systems had higher yield, following a wet spring, than the most directly-comparable conventional system.

Farmers who switch to organic methods often report lower yields in the first few years, frequently followed by yield increases. This "organic transition effect" has been attributed to hypothesized, lingering negative effects of conventional methods on "soil quality," and gradual improvements in soil quality with organic methods. Although there have been many reports of differences in soil properties between organic and conventional systems, previous reports supporting soil quality changes as the principal cause of yield trends during the early years of organic farming have all been confounded by a second factor – increasing grower experience. No previous study has been designed to measure the relative contributions of soil quality trends versus grower experience.

LTRAS is now conducting the needed research, with a grant from the Kearney Foundation of Soil Science. Three replicate, one-acre plots, which are not part of the main, 100-year experiment, were managed conventionally since LTRAS began in 1993. But since November 1998 these plots have been managed identically to our organic system, which has been managed organically since 1993. This is the first, replicated comparison of plots differing only in the duration of organic management.

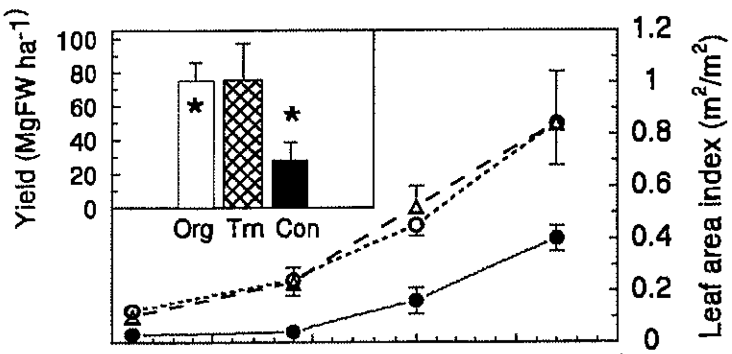
Under the prevailing, "organic transition" hypothesis, we would expect yields in the first-year "organic transitional" plots to be lower than those in either the "established organic" plots (farmed organically since 1993) or the comparable "conventional" plots. Neither prediction proved true, however. Instead, first year yields of tomatoes in the transitional organic plots were much *higher* than in the most directly comparable conventional system, but no different than in the established organic system. We also found faster plant growth in the two organic systems, relative to their conventional counterpart, even early in the growing season (Fig. 1). All three systems are two-year rotations of tomatoes and corn.

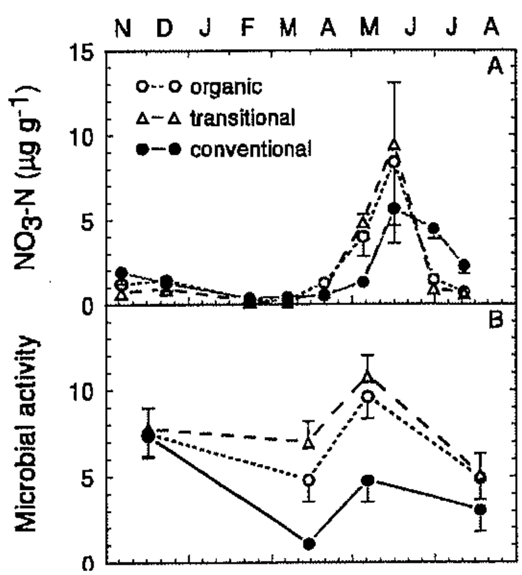
A possible explanation for the growth and yield differences between conventional and organic systems may come from the observation that a second conventional system, not shown, had higher yield even than the organic system. In the conventional wheat/tomato rotation, most field preparation can be completed in the late summer, after wheat harvest, when the soil is dry. But, because corn is harvested later, more work is often done in the spring, when the soil may be wet, as in the spring of 1999. Working wet soil can cause compaction, but the two organic systems appeared to be relatively immune to this problem, either because of the organic matter added by compost and winter legume cover crops, or because the cover crop itself used enough water to dry the soil. Further research may support or refute this hypothesis.

Another popular idea about the organic transition was also not supported by our data. Microbial communities in the transitional sys system were at least as effective in nutrient cycling (specifically, release of N from the compost and the leguminous "green manure") as those in the established organic system (Fig. 2A). Furthermore, overall microbial activity in the transitional system was not intermediate between the organic and conventional systems, as had been expected. Instead, the established organic systems were intermediate (Fig. 2B).

Our results are inconsistent with the hypothesis that there is a steady improvement in yield-limiting soil quality parameters during the organic transition. In wet years, there do seem to be some soil quality benefits of organic farming methods, as indicated by higher tomato yields. But it appears that these benefits can occur quite rapidly. The faster early growth of tomato plants in the transitional system, relative to its conventional counterpart, were seen less than 6 months into the transition period.

We do have very limited data suggesting that some other aspects of system performance may be more consistent with the "transition hypothesis." A small scale comparison of winter runoff after one year of organic management gave results that seem to be intermediate between the conventional and organic systems. The conventional system, which does not have a cover crop in the winter, had the highest runoff.





Ammonia Emissions From Nitrogen Fertilizer Applications - Field Sampling Methodology

Charles F. Krauter, Professor of Soils and Water
Plant Science Department and Center for Irrigation Technology
California State University, Fresno, CA 93740
(559) 278-5774, charles_krauter@csufresno.edu

Dave Goorahoo, Research Scientist
Center for Irrigation Technology
California State University, Fresno, CA 93740
(559) 278-8448, dgooraho@csufresno.edu

Christopher Potter
Ecosystem Science and Technology Branch, NASA-Ames Research Center, Mail Stop 242-4
Moffett Field, CA 94035 USA
(650) 604-6164, cpotter@mail.arc.nasa.gov, http://geo.arc.nasa.gov/sge/casa

Steven A Klooster
NASA Ames Research Center and CSU Monterey Bay
MS 242-4, Moffett Field, CA. 94035-1000
(650) 604-1063 Fax 650 604-4680, sklooster@gaia.arc.nasa.gov

The objectives of this project as funded by the California Air Resources Board included "determination of agricultural field sources, seasonal flux rates and a regional budget for atmospheric ammonia emissions related to applications of N fertilizer." Identification of sources, calculation of flux rates and a regional budget required the development of a database relating the crops, soils, type and application method of N fertilizer along with estimates of fertilizer use from annual sales data. The key to estimating atmospheric ammonia from the database was a value for the amount of the applied fertilizer nitrogen lost from the soil as NH_3 to the ambient atmosphere. This value, termed the emission factor by the atmospheric modelers, would be more familiar to agronomists as "percentage of volatile losses". Emission factor estimates by the Air Resources Board prior to this project were from 5% to 10% based on limited information from work done primarily in climates and on soils different from California. This project was funded by the Air Resources Board for data collection to support more accurate emission factors and a database more specifically related to agricultural practices in the state.

The field sampling phase of the project was to measure the magnitude of volatile NH_3 loss and its duration as a result of an N fertilizer application. The volatile loss percentage for a specific N application would be influenced by several factors that could be identified in the statewide database. The first step in the project was to list those factors in a matrix and then select representative combinations from the matrix cells to monitor in the field. The first factor identified was crop type. The database under development at NASA-ARC utilized county-based crop maps from the California Department of Water Resources. The second factor was soil. A simple separation of the state soils into four categories based on %clay (A= <5%, B=5%-10%, C=10%-20%, D=>20%) was used for the initial database. The most subjective selections for the sampling matrix were the fertilizer forms and application methods. Six combinations of a material and application method were selected as common to many of the crops and soils for the completion of the sampling matrix. The ten crops, four soils and six fertilizers resulted in a matrix of 240 cells. The sampling period for the ARB funded project was the calendar year, 2000. We planned to sample 15 - 20 individual applications during that time. The final matrix, developed prior to sampling, is shown below.

CROP	DWR category	Urea dry	UAN liquid	NH_4X dry	NH_3 injected	NH_3 water run	Dairy Effluent
Cotton	Field Crop	D				B	
Corn	Field Crop				C		C
Melons	Truck Crop			B		C	
Tomato	Truck Crop		B			C	
Lettuce	Truck Crop		C	B			
Citrus	Citrus			B			
Small Grain	Grain	C			B		
Vineyard	Vineyard		B	A			
Decid. Trees	Decid. Fruit	B		A			
Rice	Rice					D	

The actual sites sampled did not always match the initial plan but each site corresponded to a cell of the original matrix. Sites were chosen based on matching the matrix, accessibility, and available personnel and resources, in that order of priority. The sampling scheduled for the next two years will complete the original plan and add several additional cells. The actual sites sampled from December, 1999 to December, 2000 are shown below.

Field Sampling Sites for the Ammonia Emissions From Fertilizer Applications Project

SITE	CROP	Fertilizer	N lb/A	Application Method	LOCATION
A	Almonds	UAN-32	100	surface band, watered in	15 m West of Madera
B	Almonds	$(NH_4)_2SO_4$	100	surface band, watered in	16 m West of Madera
C	Almonds	Urea liquid mix	15	foliar with bloom spray	CSUF Farm
D	Citrus	NH_4NO_3	50	Broadcast - rained in	5 m North of Sanger
E	Almonds	UAN-32	100	Water Run-buried drip	7 m North of Sanger
F	Onions	UAN-32	40	Water Run-sprinkler	3 m South of Five Points
G	Tomato	UAN-32	100	Side dressed	3 m SW of Five Points
H	Garlic	UAN-32	50	Water Run-furrow	4 m SW of Five Points
I	Cotton	NH_3	100	Injected, 15cm shank	2 m SW of Five Points
J	Cotton	NH_3	100	Injected, 15cm shank	4 m West of Five Points
K	Almonds	21-21-21 liquid	9	Water Run-microspray	CSUF Farm
L	Pasture	effluent	200	Flood	CSUF Farm
M	Broccoli	NH_4NO_3	60*	Surface spray for weed control	8 m SW of Mendota
N	Cotton	defoliant	0	Aerial Spray	5 m South of Lemoore NAS
O	Lagoon	effluent	NA	Ponded	CSUF Farm
P	Broccoli	UAN-32	75*	Water Run-buried drip	8 m SW of Mendota
Q	Lettuce	UAN-32	60	Water Run-furrow	3 m SW of Five Points
R	Cotton	NH_3	80	Injected, 15cm shank	4 m SW of Five Points
S	Tomato	NH_3	100	Injected, 10cm shank	2 m South of Five Points

Once the sampling matrix had been determined, the next step was to select a field sampling procedure that would characterize the emission factor for each site in a manner suitable for the needs of the statewide database. The magnitude and duration of the volatile losses were the values needed to establish an emission factor. Duration could be characterized easily as long as a continuous sampling method was used. The initial plan was to sample for two days prior to an application to determine background levels. Sampling would proceed through the application of the fertilizer and continue for five days afterward to monitor the expected spike of atmospheric NH_3 from the application. This sampling schedule was used through the year and proved to be adequate to establish the duration of the NH_3 emission.

The selection of a sampling procedure to measure the magnitude of the NH_3 emission was a more difficult task. Monitoring of volatile NH_3 in commercial agricultural settings has not been a common practice in agronomic research. Closed chambers in the lab or greenhouse have been used but were not considered suitable for this project in which field monitoring was mandated. Field measurement of NH_3 has been done in air quality studies, primarily in urban settings. Two basic methods have been employed; denuders and open-path spectroscopy. The denuder is a medium through which an air stream is passed in the same manner as a filter for particulates. In the case of NH_3 it is a fibrous material, usually glass, treated with a substance (citric acid) that will react with NH_3 to form a solid. The denuder is usually an active sampler utilizing a pump to pull a known flow of air through a disk of the treated material in a filter holder located at the point of measurement. This requires a pump, power system and air flow measurement for each sampling point. Denuders can also be passive, depending on wind to move the air through the denuder medium. An active denuder was selected for the initial sampling season of this project because it represents an established method in air quality studies and it satisfied our requirement for continuous sampling. A 47mm disk of glass fiber filter paper was treated with citric acid (5% in 95% ethanol) and dried. A commercially available, 12 volt air sampling pump was used to pull air through the denuder disk at a rate of about four liters per minute. Previous work suggested differences in day and night levels of NH_3 in the air so the sampling was diurnal with the denuders changed at dawn and dusk. Samples were refrigerated and taken to the Graduate Laboratory of the CSUF College of Agricultural Science and Technology, to be analyzed by project personnel. The NH_4-Citrate was extracted from the denuder with distilled water and analyzed with Nessler's Reagent in a spectrophotometer. The amount of ammonia on the denuder disk was reported in μg NH_3. The concentration of NH_3 in the air at the sampling point could be determined by dividing the amount of ammonia on the disk by the volume ($meter^3$) of air through the denuder in the sampling period to get $\mu gNH_3/meter^3$ of air at the sampling point.

The denuder method of measuring NH_3 concentration proved to be appropriate for the needs of the project at the present stage. The second method of NH_3 monitoring in a field setting, open-path spectroscopy, was also considered. The method has a number of advantages for such a study. Similar to laboratory spectroscopy, an electro-magnetic signal is generated and detected at specific wavelengths. NH_3 absorbs very strongly at a specific near infra-red λ. The IR λ is propagated along a path in the air to a detector. The absorbence at the specific λ can be used to determine the amount of NH_3 in the air along the path just as it can in a cuvette in the laboratory. Two methods of open-path monitoring are Fourier Transform Infra-Red (FTIR) and Tunable Diode Laser (TDL) spectroscopy. Each can provide rapid, real-time data over paths of 1000m or more. They are also very costly and require a high level of operator expertise for reliable measurements. There was no real advantage over the active denuder for the long-term, continuous sampling required during the past year. Open path spectroscopy may be needed by the project in the next year for shorter term monitoring of NH_3 from dairy operations.

The measurement of NH_3 concentration at a particular sampling point was not sufficient to determine the emission factor for a particular field site. The amount of NH_3 in the atmosphere depends not only on the concentration but also the flow of air at the sampling point. The value necessary to characterize the sampling point was the flux in $\mu g NH_3/meter^2/second$. This ammonia flux is the amount of NH_3 passing through a 1meter^2 cross section of air per second. The measurement of the flux at a single sampling point is not enough to determine an emission factor. The initial assumption during the planning of the project was to monitor ammonia flux at several elevations above the field surface to characterize the gradient between the soil surface and the ambient atmosphere. Denuders and anemometers were to be located at 1, 2, 5, 10 and 20 meters above the soil surface. Initially, it was assumed that a positive NH_3 flux gradient from the soil surface, decreasing as the elevation increased could be used to indicate the magnitude of the emission factor for the sampling period. Prior to the application, it was suspected that negative gradients, with higher flux rates in the atmosphere, decreasing at elevations closer to the soil surface might be found due to ammonia absorption by foliage and/or a moist soil surface. The stomata and internal structure of the leaf that functions to absorb CO_2 from the air should be very effective as an absorber of NH_3 as well. If there was no source of NH_3 such as a fertilizer application at the surface, the sampling at a site might well exhibit a negative gradient as the field absorbed NH_3 from the air rather than contributed it. It was presumed that we might see a change from the negative gradient prior to the N application to a positive gradient reflecting volatile NH_3 loss from the applied fertilizer and then a change back to negative gradients to signal the end of the ammonia emission. As will be seen later, this second assumption was not entirely correct.

The requirement to sample and measure wind speed at five elevations for 7 to 10 days in different locations remote from electrical power made a self-contained, portable sampling system necessary. An instrument tower 15 meters in height that would telescope down to 5 meters was borrowed from a completed UC Davis (Ken Tanji) project for the duration of our study. The tower was mounted on a trailer constructed by the Farm Machinery Center at CSU Fresno. The trailer served as a base for the tower when erected and allowed the tower to collapse and pivot to a horizontal travelling position. Storage and instrument compartments mounted on the trailer held the air pumps, flow measurement devices, power monitors, controls, the datalogger for the meteorological instruments and the four golf cart batteries used for powering the sampling system. By the end of the first sampling season, the tower/trailer unit had been developed to the point where one person could tow the trailer to a sampling site, erect the tower, and begin sampling in two hours.

The first three sampling sites (A to C) were monitored during the developmental phase of the sampling system. The final configuration of the tower/trailer was complete for Site D though some changes in the air pump system were made prior to Site L. A single anemometer was used for wind speed at both 1 and 2 meters until Site K. Data analysis suggested the wind speed was, in fact significantly different at those two sampling elevations so the anemometer at 10 meters was shifted to the 2 meter height and the unit that had been at 1.5 meters was lowered to 1 meter.

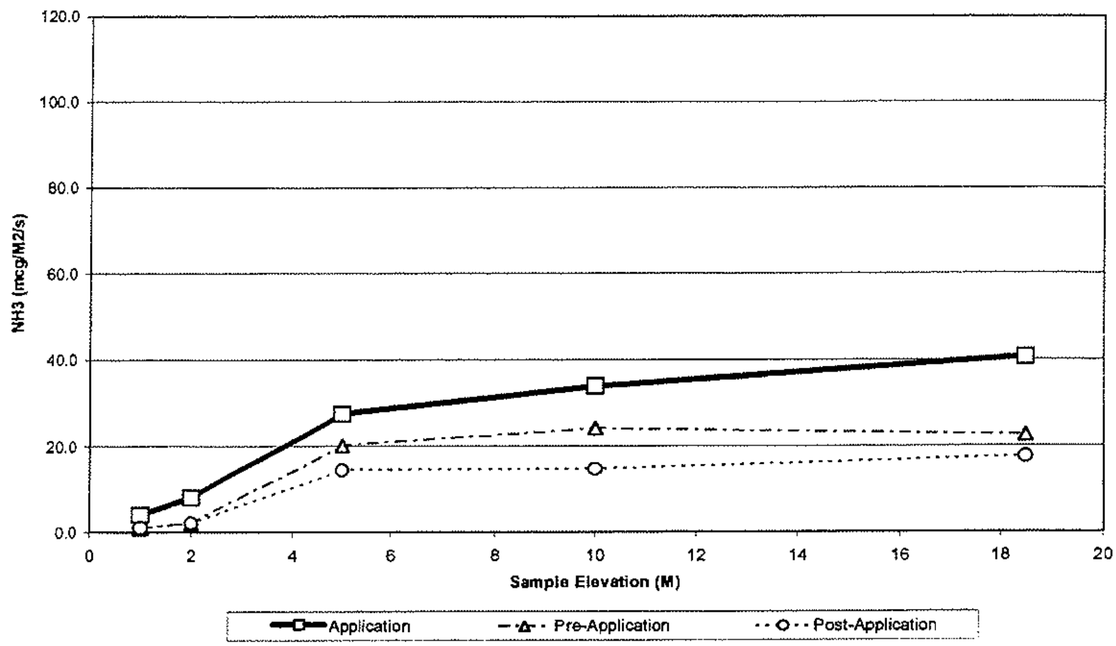
Subsequent data analysis indicated the wind speed at 1 meter is generally only 30% to 70% of the wind speed at 2 meters. The wind speed at 10 meters was assumed to be near the average of the measured values at 5 and 20 meters. Analysis of the data files confirms this assumption. A fifth anemometer has been purchased and will be re-installed at the 10 meter height for the next sampling season.

Preliminary Results

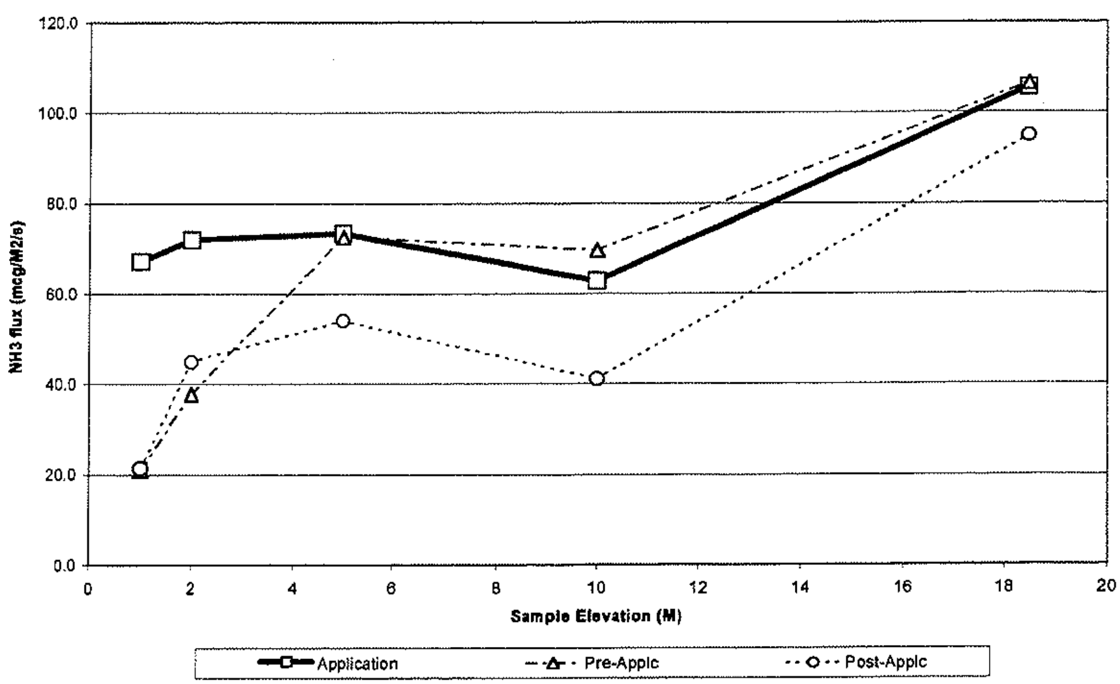
Currently, laboratory and data analysis is complete for sites A through J. Results of the remaining sites will be completed by February, 2001. Some, preliminary conclusions have emerged, the most significant of which is the fact that field sampling can detect volatile NH_3 from an application of N fertilizer. In each of the ten applications for which data is available, an increase in atmospheric NH_3 was measured compared to the levels sampled both before and after the application. The two graphs (Sites D and J) shown below are typical of the results analyzed to date. The line labeled "Application" is the average of 2 to 5 sampling periods during which the N application was actually occurring. The lines labeled "Pre-application" and "Post-application" were the averages of 2 to 10 samples taken prior to and after the application. The "Application" values were greater that those before and after in each of the ten sites analyzed so far. This is the basis for the conclusion that the methodology can detect volatile NH_3 resulting from a fertilizer application.

After the increased NH_3 levels during the fertilizer application, the most striking characteristic of the data as shown in these two examples is the consistent presence of a negative gradient. The significance of the gradient direction is still open to interpretation. It may be that the foliage and soil surfaces are acting as a sink for NH_3 even during the application period. The reactive nature of atmospheric NH_3 and the structure of the leaf with regard to absorption of gas from the atmosphere certainly supports that possibility. It may also be that the physical properties of the atmosphere and the aerodynamics of the boundary layer from the soil/crop surface to the ambient air are much more complex than can be properly monitored by a simple "stacking" of horizontal flux rates layers. The meteorological monitoring system was only capable of measuring horizontal wind speed. Vertical components of wind movement that certainly existed and could have altered the gradient as measured were not monitored.

Ammonium Nitrate on Citrus (Site D)



Site J: NH₃ on Cotton (soil injection)



The determination of an emission factor from the data was possible due to the elevated levels of volatile NH_3 regardless of the direction of the gradient. A curve fitting process was applied to the data and the levels of atmospheric NH_3 of the pre and post application periods were subtracted. The resulting line function was assumed to describe the NH_3 resulting from the fertilizer application and the quantity could be determined by integration. The calculated quantity of NH_3 emitted as a result of the fertilizer application was then divided by the total application rate to get the percentage of the application lost as volatile NH_3. That value is the emission factor required for the database to model the contribution of N fertilizer applications to the total in the atmosphere of California. The values for the ten sites analyzed to date range from 0.5% to 6% with the average at about 5%. The details of the calculation, specific emission factors for each site, and the modeling results will be presented by Dr. Potter in a separate paper.

Successes in Yellow Starthistle Control

Joseph M. DiTomaso, University of California, Weed Science Program, Robbins Hall, Davis, CA 95616 (530) 754-8715, FAX (530) 752-4604, ditomaso@vegmail.ucdavis.edu

The goal of any management plan should be not only controlling the noxious weed, but also improving the degraded community, enhancing the utility of that ecosystem, and preventing reinvasion or invasion by other noxious weed species. To accomplish this usually requires a long-term integrated management plan. A number of considerations can influence the choice of options; most important being the desired land-use objective. This can include forage production, preservation of native or endangered plant species, wildlife habitat development, or recreational land maintenance. Selection of the proper management tool(s) and program also may depend on other factors including weed species and associated vegetation, initial density of yellow starthistle infestation, effectiveness of the control techniques, years necessary to achieve control, environmental considerations, chemical use restrictions, topography, climatic conditions, and relative cost of the control techniques.

Before 1987 there were few options for the control of yellow starthistle, and long-term sustainable management plans had not yet been developed. However, considerable progress has been made in the past decade. Currently, there are a number of control options available for the management of yellow starthistle, including grazing, mowing, manual removal, clover or perennial grass reseeding, burning, chemical, and biological control.

When developing a yellow starthistle management program is to important to consider the advantages and disadvantages of each approach and to judge how each option may best fit into a long-term program. It is possible that several different strategies can prove successful in a given location. The consistent components of a successful program should include persistence, flexibility, and, most importantly, preventing new seed recruitment (DiTomaso et al. 2000). Some of the more recently developed control options are briefly discussed below. For a more detailed summary of the advantages, disadvantages, risks, timing and fit into a strategic plan for each control option visit the yellow starthistle website at the Weed Research and Information Center (wric.ucdavis.edu/yst).

Mowing

Mowing is a popular control technique along highways and in recreational areas and has less impact on the environment than tillage. Although mowing can be a cost-effective method for control of starthistle, it is not feasible in many locations due to rocks and steep terrain. Even when mowing is employed as a control technique, it is not always successful. Its success often depends on proper timing and the growth form of the plant. Mowing plants before the seedheads reach the spiny stage can suppress competing vegetation, thus enhancing light penetration and increasing the starthistle problem. Even repeated mowing conducted to early will not control starthistle and may extend the life cycle. Mowing after plants have produced viable seed will not substantially reduce the seedbank and the following year's infestation.

Despite the limitations of mowing, Thomsen et al. (1997) and Benefield et al. (1999) demonstrated the successful use of mowing for yellow starthistle control. Thomsen et al. (1997) consistently demonstrated over 90% control of yellow starthistle using two timely repeated mowings per year over a three year period. Benefield et al. (1999) also showed that mowing conducted at the early flowering stage, before viable seed production, was most effective in controlling yellow starthistle. However, they also demonstrated that the success of mowing as a control strategy not only depended on mowing timing, but also on the plant's growth form and branching pattern. Plants with an erect, high-branching growth form were effectively controlled by a single mowing at the early flowering stage, while sprawling, low-branching plants were not controlled even with repeated mowings at the proper timing.

Prescribed burning

Fire has long been an important factor in the development and continuance of most grassland systems. In addition to controlling some important noxious annual grasses, such as barbed goatgrass (*Aegilops triuncialis*), medusahead (*Taeniatherum caput-medusae*) and ripgut brome (*Bromus diandrus*), prescribed burning can all be used successfully to control yellow starthistle (DiTomaso et al. 1999a).

As with mowing, the success of this method depends on proper timing. Unfortunately, the proper time for burning is in early to mid-summer (late June to early July), which may not be feasible in some areas. At this time starthistle is in the very early flowering stage (similar to ideal mowing timing). At this time starthistle has yet to produce viable seed, whereas seeds of most desirable species have dispersed and grasses have dried to provide adequate fuel. Fire has little if any impact on seeds within the soil.

After a single year of burning, the resident seedbank of yellow starthistle will be sufficiently high enough to allow re-infestation the following year. However, burning will reduce the thatch layer, expose the soil, and recycle nutrients trapped in the dried vegetation. In the first growing season after the burn, plant diversity will often increase, particularly native species, both perennial grasses and forbs. After three consecutive years of burning, DiTomaso et al. (1999a) showed that starthistle seedbanks were reduced by over 99%, with vegetative control greater than 90% in spring and summer measurements.

Despite its effectiveness, there are some risks associated with prescribed burning as a method of controlling yellow starthistle. Air quality issues can be a significant problem when burns are conducted adjacent to urban areas. This potential problem can be avoided by conducting burns only in more isolated regions not adjacent to urban areas. A major risk of prescribed burning is the potential of fire escapes. This is particularly true when burns are conducted during the summer months.

Re-vegetation

In a re-vegetation program designed to suppress noxious weeds, a major limitation is choosing a species or combination of species that is more vigorous than the invasive weed. Only a limited number of species have proven to be aggressive enough to displace invasive species, and the proper species choice varies depending on the location and objective. Perennial bunchgrasses are among the most common species used for re-vegetating western grasslands, but broadleaf species such as legumes can also be used in re-vegetation programs to suppress rangeland weeds.

Because of California's Mediterranean climate, re-vegetation programs for control of yellow starthistle are more difficult that those in other western states where summer rainfall is critical to the establishment and survival of native perennial grasses. In the most desirable cases, competitive, endemic, native species should be re-established. This may not always be possible depending on the objective of the land use and the location of the site. In many cases non-native perennial grasses or legumes with high forage quality and quantity are used in re-vegetation programs.

For example, in a study underway near Yreka (Siskiyou County, California) Enloe et al. (2000) combined herbicides, biological control, and competitive perennial grass reseeding, perennial wheatgrass ('Luna' pubescent; *Thinopyrum intermedium*). To establish the perennial grass they employed a late winter glyphosate treatment for annual grass control in the first year and one to three consecutive years' treatment with clopyralid for starthistle control. In the first year, spring drill seeding with perennial wheatgrass followed the herbicide treatments. The goal of this re-vegetation project was to develop sustainable high quality range conditions and improved wildlife habitat capable of providing long-term starthistle control without the need for continued herbicide treatments.

From their work, they showed that a first year only treatment with clopyralid and glyphosate was sufficient to allow wheatgrass establishment. In this case, the wheatgrass provided some level of starthistle control in subsequent years, but was not as effective as two or three years of clopyralid treatment with wheatgrass (Enloe et al. 2000). Plots treated with clopyralid and not seeded with pubescent wheatgrass were dominated by annual species, particularly grasses. They also showed that yellow starthistle infestations could deplete soil moisture to a greater degree than rangeland dominated by annual grasses or perennial wheatgrass. Wheatgrass was able to utilize soil moisture at shallow and intermediate soil depths, whereas starthistle depleted soil moisture at the deeper soil levels. Heavy infestations of yellow starthistle led to inadequate deep soil moisture recharge. The investigators concluded that on severely degraded rangeland an integrated combination of clopyralid treatment and wheatgrass seeding can be very effective in suppressing yellow starthistle seed production and provides a more effective long-term solution than applying clopyralid alone.

Because of the ecological diversity within California, no single species or combination of species will be effective under all circumstances. Although pubescent wheatgrass has proved successful in Siskiyou County, it may not be appropriate in most other areas of the state that lack summer rainfall. Unfortunately, few studies have been conducted on the restoration of yellow starthistle infested grasslands, particularly with native species.

Biological control

State and federal agencies have been active in pursuing biological control of yellow starthistle in California. Since the first biological control insect in California (seed-head weevil; *Bangasternus orientalis*) was reported in California in 1986 (Maddox et al. 1986), there have been five additional insects released and established in the state. Today, three of these have become widespread: seed-head weevil, seed-head fly (*Urophora sirunaseva*), and the hairy weevil (*Eustenopus villosus*). A fourth insect, the false peacock fly (*Chaetorellia succinea*) was accidentally released in 1996, and is now widespread and more effective against yellow starthistle than the intentionally released peacock fly (*Chaetorellia australis*) (Balciunas and Villegas 1999). One other insect has been released, the flower weevil (*Larinus curtus*), but has yet to become well established. All six insects attack the flower heads of yellow starthistle and produce larvae that develop within the seedhead and feed on seeds.

Of the four insects that are well established only two, the false peacock fly and the hairy weevil, have any significant impact on seed production (Pitcairn et al. 2000). The combination of these two insects has been reported to reduce seed production by 43 to 76%. Balciunas and Villegas (1999) reported a 78% reduction in seed production when seed heads contained false peacock fly larvae. Although this level of suppression is not sufficient to provide long-term starthistle management, the use of biological control agents can be an important component of an integrated management approach. A more successful biological control program will likely require the introduction of plant pathogens or other insect organisms capable of feeding on roots, stems, or foliage.

Herbicides

For yellow starthistle control, herbicides are an effective tool on large infestations, in highly productive soils, and around the perimeter of infestations to contain their spread. The most effective herbicides for season-long control of yellow starthistle are those that provide postemergence control of seedlings and rosettes, as well as soil residual activity for at least a couple of months until spring rainfall is completed.

Prior to 1998, few herbicides were available in California for season-long control of yellow starthistle in California pasture, rangeland or wildland areas. With the registration of clopyralid (Transline®) in California in 1998, ranchers and land managers have a highly selective herbicide available for starthistle management. It is a growth regulator with similar activity to 2,4-D, dicamba, triclopyr, and picloram. Unlike 2,4-D, dicamba, and triclopyr, clopyralid has excellent soil (preemergence) and foliar (postemergence) activity. Injury symptoms are typical of other growth regulators and include epinastic bending and twisting of the stems and petioles, stem swelling and elongation, and leaf cupping and curling. This is followed by chlorosis (yellowing), growth inhibition, wilting and eventually death.

Clopyralid is very effective for the control of yellow starthistle at extremely low rates and a broad timing window. In addition, it does not appear to negatively impact insect biological control agent populations and has a very low toxicology profile with no grazing restrictions.

Selectivity. Clopyralid is a very selective herbicide and does not injury grasses or most broadleaf species. However, depending on the timing of application, it does damage or kill most species in the legume family (Fabaceae), as well as the sunflower family (Asteraceae), and this may not be a desired outcome in a control program with the goal of increasing native plant diversity or enhancing a threatened native plant population susceptible to the herbicide.

Rate and timing. Clopyralid provides excellent control of yellow starthistle seedlings and rosettes between its registered use rates of 0.1 to 0.28 kg ae/ha (1.5 and 4 oz ae/acre) (DiTomaso et al. 1999b). Season-long control can be obtained with one application made from December through April, but maximum grass forage occurs with mid- to late winter treatments. The most effective timing for application is from January to February, when yellow starthistle is in the early rosette stage. Applications earlier than December may not provide full season control and treatments after May usually require higher rates.

Clopyralid is also effective on plants in the bolting and bud stage, but higher rates (0.28 kg ae/ha [4 oz ae/a]) are required. Applications made after the bud stage will not prevent the development of viable seed (Carrithers et al. 1997).

Effects of forage. Late season treatments with clopyralid (April to June) can have a negative impact on forage quantity. Reduced forage at later treatment times is likely due to the competitive effects of yellow starthistle on grass development during the early spring months. Desirable forage biomass is maximized with an early season treatment (December to March). At this timing, yellow starthistle is in the early rosette stage. Early season treatments also give better control of yellow starthistle.

Fit into strategic management plan. In most circumstances clopyralid can be an important component in a yellow starthistle management program. For example, clopyralid is often a very effective first year option in a multi-year program. This is particularly true in heavily infested areas. The herbicide can substantially reduce the starthistle population, thus depleting much of the seedbank. Because clopyralid is typically used in late winter to very early spring when the competitive interactions for soil moisture are minimal, the control of yellow starthistle will result in high grass forage production during that growing season (DiTomaso et al. 1999b). If yellow starthistle seedling numbers in the second winter are also very high, a second year of treatment may be needed. However, in subsequent years it may be more advantageous to delay the use of clopyralid or other preemergence herbicide until the extent of the problem can be evaluated. In these situations, a prescribed burn, mowing or physical removal can be sufficient. In some instances one or two years of control can dramatically reduce the starthistle infestation to very low or even nearly insignificant level. When this occurs, an additional application of clopyralid or another postemergence herbicide would be unnecessary.

Integrated approaches

Most often a single method is not effective in the sustainable control of a range weed. A successful long-term management program should be designed to include combinations of mechanical, cultural, biological, and chemical control techniques. There are many possible combinations that can achieve the desired objectives, but these choices will have to be tailored to the site, economics, and management goals.

Using an integrated approach, Pitcairn et al. (2000) hypothesize that combining clopyralid applications with insect biocontrol agents might provide for more effective long-term control of yellow starthistle. Clopyralid applications would reduce plant density and the seed bank. The attack of biocontrol insects on escaped plants in subsequent years should slow the rate of re-infestation by impacting the few seedheads available. Results thus far indicate that the combination of biocontrol agents suppressed seed production by 76% in 1997, and 43% in both 1998 and 1999 (Pitcairn et al. 2000). In addition, the reduction in starthistle resulting from the herbicide treatment did not affect the ability of the insects to attack the seedheads of escaped plants. It is hoped that seed destruction by the established biological control agents can retard resurgence to 4-6 years and thereby reduce the need for continuous herbicide treatments. This would lower the economic costs required for effective long-term management of yellow starthistle.

Re-vegetation projects for yellow starthistle control nearly always rely on integrated strategies. In most cases, it is difficult to establish desired plants without the management of competing vegetation, including starthistle and annual grasses. The goal of these re-vegetation projects is to develop sustainable high quality range conditions and improved wildlife habitat capable of providing long-term starthistle control without the need for continued herbicide treatments.

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MANAGING LYGUS IN THE LANDSCAPE

Peter B. Goodell

Regional IPM advisor, University of California, Cooperative Extension
Kearney Agricultural Center, Parlier, CA 93648
559-646-6000, ipmpbg@kac.edu

Lygus bug (*Lygus hesperus*) is a major pest on many crops including alfalfa seed, dry and fresh beans, cotton, strawberries, apples, pears and cool season vegetables. In addition, this mirid has a wide host range including many common weeds and crops. Thus, it seems improbable that lygus can be managed in isolation from its surroundings.

Lygus is well adapted to the western landscape. It thrives on native plants, on cultivated crops and introduced weeds. In the Central Valley, lygus populations build throughout the year, moving from plants that become unsuitable to those that can provide habitat for the next generation. Thus the movement of lygus into a farmer's field usually is not a result of his or her current management practices in that field, but rather it is a threat external to the management of the recipient crop.

There is no "*silver bullet*" solution to lygus. No single insecticide, cultural technique, or biological approach will provide an economic and environmental satisfactory solution.

However, there is good news. Across the country, current research efforts are providing new knowledge and developing new approaches to managing lygus, including host plant resistance, biological control, insecticide management strategies and cultural management alternatives. However, no single approach will solve the problem in an individual field, they must all be brought to bear on the problem. To succeed, the context of the large region surrounding his or her fields must be considered. Professor Vern Stern, the eminent entomologist from UC Riverside, recognized this fact in 1967 when he wrote:

> "The grower, faced with rising production costs at all levels must decide if he will rely completely on insecticides to fight *Lygus* and accept the financial burden or if he will look for another method of control….."
>
> "In attacking the *Lygus* problem, chemicals are used when absolutely necessary; but first a major change must be made in farm practices to keep *Lygus* out of cotton"

Dr. Stern and his students made invaluable contributions to our understanding of lygus in a regional context (Stern, 1969). They realized that managing lygus on a large scale required understanding of the crops that acted as sources and which ones became sinks for lygus. To prevent movement into susceptible crops required one of two general approaches; managing the habitat from which lygus originated or providing alternative, preferred habitats into which they can move. Several specific approaches included:

- habitat diversification through the interplanting of alfalfa strips in a cotton field

- habitat preservation in alfalfa hay by retaining uncut strips or staggering the harvest of large alfalfa fields
- prevention of lygus movement from safflower by timing insecticides based on insect phenology.

Interest in regional approaches is increasing in the management of plants bugs in general and lygus in particular. For example, as boll weevil is eradicated in the South and the Heliothine complex is controlled with transgenic cotton, plant bugs are becoming the key pest in their cotton systems. Area-wide management, so successful in taming boll weevil, is seriously being considered as a viable management approach for lygus. Key to this approach is the destruction of host plants that provide important habitat for lygus population development.

Nordlund (in press) suggests that the tarnished plant bug (*Lygus lineolaris*) is a likely candidate for an area-wide program to suppress lygus populations in the southern United States. Area-wide management moves the decision-making authority for the management of lygus from the individual farmer to a group authority, usually governmental or quasi-governmental (Knipling, 1978). Area-wide management is a coordinated and offensive strategy designed to reduce the pest population to easily managed numbers. Within the San Joaquin Valley, the Pink Bollworm Eradication Project and Whitefly Management Zones are examples akin to this concept.

California, and especially the Central Valley, has a wide diversity of cultivated and wild plants. These provide lygus with multiple habitats, some being preferred over others. In non-host crops such as garlic and onions, annual weeds provide suitable hosts, allowing the field to act as a source for lygus. Thus, implementing a regulatory area-wide management for lygus may not be feasible.

However, informal and community-based programs do show promise. For example, within the Tulare Lake bottom area of Kings County, farms will work together to time insecticide treatments on safflower (Sevacharian et al, 1977), coordinating both timing and insecticide choice. This approach provides some uniformity in seeking to minimize the need for duplicate treatments in a field.

Examples from the San Joaquin Valley

In northwestern Fresno County, almond growers were unwittingly driving lygus into cotton fields through poor timing of their mowing of the orchard floor. Consultants and extension advisors facilitated meetings between cotton and almond growers to develop a strategy that limited the population development of lygus while not being onerous. By mowing alternate orchard middles more frequently in those orchards that bordered cotton, lygus hosts were limited in their growth and lygus population buildup was minimized.

The use of interplanting crops to draw lygus away from the primary crop has been proposed (Stern et al, 1969). While this approach was used on large farms in the 1960's, it was abandoned shortly thereafter, primarily due to the incompatibility between cotton and alfalfa production. Other examples of trap cropping, utilize the primary crop as the trap. For example, Pima cotton (*Gossypium barbadense*) is considered more attractive to lygus than Acala cotton varieties (*G. hirsutum*). Large strips of Pima were interplanted within Acala fields to draw and concentrate lygus. The same idea is employed when strips within a cotton field were maintained in a more vigorous state of growth. These strips were considered more attractive to lygus and would concentrate the population. In both approaches, insecticides are focused on the trap area while the larger area of the field is left undisturbed. While only limited demonstration trials have been conducted to evaluate the performance of these approaches, practical experience indicates the results are of limited use.

California blackeye beans (*Vigna sinensis*) have been demonstrated (Goodell and Eckert, 1998) to be more attractive to lygus than cotton (Figure 1). The advantage of blackeye beans is their compatibility with cotton production. Beans can be sown with the same planters and at the same time as cotton. It is managed similarly and is not overly stressed when its irrigation schedule is dictated by cotton. The beans, planted on the edge of a cotton field, act as a buffer slowing the movement of lygus generally into the cotton field. Such a buffer strip could provide a killing zone in which lygus would be drawn and treated with insecticides. This approach would concentrate the lygus, reduce the overall amount of insecticides applied and preserve natural enemies on the majority of the cotton field. This concept was demonstrated on fields in the West Side of Fresno County with some success. The key problem was lygus movement into the field from many directions. If the buffer strip was encountered, lygus settled. However, lygus will not search for the buffer strips and there are practical limitations to the amount of acreage that can be committed to non-productive areas. There is a breakeven point between loss of yield (and profit) due to lygus damage and management and loss of yield due to reduction in cotton acreage to accommodate buffer or trap crops.

In many areas of the Valley, alfalfa forage plays a key role in providing stable, preferred habitat for lygus. Modified harvesting patterns has been suggested for over 30 years as a strategy for maintaining habitat and reducing the movement of lygus from alfalfa to more susceptible crops, especially cotton. This technique was articulated by Van den Bosch and Stern (1969) and Stern et al (1967) but has not been accepted due to pragmatic management issues. Demonstration trials in 1998 and 1999 (Goodell et al, 2000) have rekindled an interest in maintaining alfalfa as alternative habitat. There are two viable approaches; first leaving smaller, uncut strips in the field (Summers 1976) and second modifying the approach of Stern to ensure that vigorously growing alfalfa is available to absorb lygus displaced from harvested areas.

Following up on observations of Summers (1976) that smaller uncut alfalfa strips will retain lygus, on-farm demonstrations were initiated in 1998. These three demonstrations fields were bordering cotton fields. Two, three and eight strips were left uncut in three fields representing 5%, 7%, and 18% of the total area. All three alfalfa fields retained lygus equally well. In contrasting the neighboring cotton to alfalfa strips, there was a 30-fold population difference in lygus density (Figure 2). In another demonstration, hand moved sprinkler lines were not removed prior to hay cutting, providing a four-foot wide strip of uncut alfalfa. This approach provided labor savings for the grower, while providing habitat throughout the field for lygus.

While there are still questions concerning the minimal amount of uncut alfalfa that is required to hold sufficient lygus, general guidelines suggest leaving end strips and several strips through the field. It is not well understood how far lygus will travel to a strip or how much of the population remains in the field. Further studies utilizing mark and recapture methods (Hagler, 1992) are planned.

The forage hay industry has expressed concern about the impact of quality when 28-day and 56-day (uncut strip from previous harvest) hay are mixed. Summers (1976) find no difference in quality but changes in variety since 1976 and current market pressures require that this concern be further examined. Experiments are underway to evaluate mixtures of old and new hay using both qualitative and quantitative measures.

The concept of splitting hay fields and staggering harvests is a valid but an unacceptable approach for farmers. However, in many locations alfalfa is produced on sufficient acreage that existing harvest schedules may provide adequate habitat. For example, in the San Joaquin Valley, hay is cut on a 28-day cycle. In any given area, it could be estimated that 25% of the fields are harvested and curing, 25% are getting the first irrigation since cutting, 25% are vigorously growing and 25% are being prepared for harvest. Thus, about 75% of the acreage in an area might be receptive to attracting and holding lygus. In 1998 and 1999, large-scale, on-farm trials demonstrated that alfalfa could provide adequate habitat and be managed to avoid lygus movement into cotton (Goodell et al, 2000). Cotton in close proximity to alfalfa resulted in lower lygus populations in those fields than in situations in which there was no alfalfa nearby (Figure 3).

Regional management issues come into focus when questions about the relationships between crops need to be addressed. What proportion of an area is required for alfalfa to be effective sink for lygus rather than a source? What are the spatial relations between alfalfa and cotton? How close to each other do they have to be? How close do alfalfa fields have to be from each other? These questions require spatial analytical techniques such as those offered by geographical information systems (GIS) and ecological landscape integration tools (Berry et al, 1998). Efforts are currently underway to investigate the usefulness of these landscape analysis approaches.

Piecing it together

The development of regional management strategies will not be easy. Successful programs have generally been imposed and involved some governmental or quasi-governmental organization to conduct the program. While lygus is a key pest in some crops in most years, it does not represent the threat that exotic pest introductions often do. Thus, the driving need to organize and work together is not compelling.

Since lygus does not threaten everyone in every year, what is the motivation to work together? Several factors actually encourage the development of community-based programs:

1. farm economics are driving the search for ways to reduce cost; i.e. avoiding insecticide costs
2. many of the cultural control techniques can be implemented and become almost transparent in the production practices
3. multiple tactics will lead to a general decrease in population density while no tactic will solve the entire problem
4. the entire area may not have to be committed; suppression and management of the population is the goal, not eradication

Many of the approaches we have heard today fit into this community-based, regional management approach. Maintaining alfalfa habitat could provide pyrethroid-free refugia while providing release sites for parasitoid releases. Safflower could be another potential release site for natural enemies of lygus, thereby slowing the area-wide buildup of the population. Introduction of lygus resistant crops could not only reduce insecticide pressure on lygus populations, but could reduce the population development in an area. Introduction of specific genes into cover crop plants could provide population reduction while avoid issues associated with GMOs (genetic modified organisms) and human food supplies.

A successful management program will result in the overall reduction in lygus population. This in turn should result in reduced movement into susceptible crops, fewer broad-spectrum insecticides required for lygus management, less secondary disruptions and improved stability in field and fruit crops. Such a program will have two pillars supporting it. The first is having adequate knowledge of lygus biology at the ecological landscape level and second is the willingness of the community to implement such a program.

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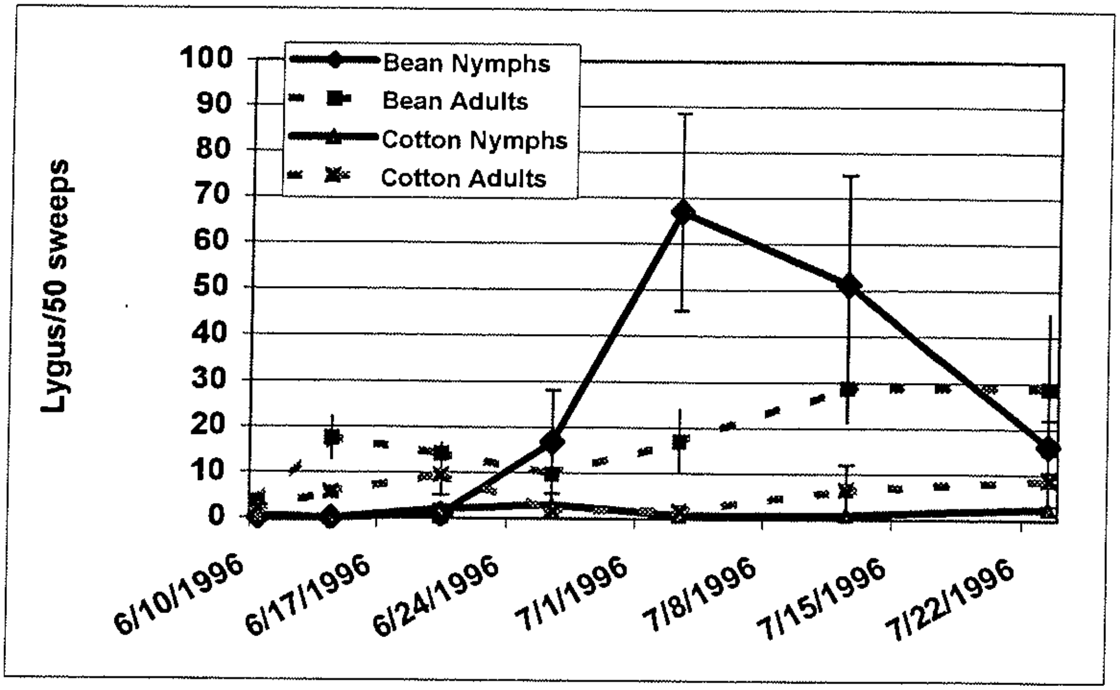

Figure 1. Lygus densities in adjacent, replicated small plots from blackeye beans and cotton. Kearney Research and Extension Center, 1996.

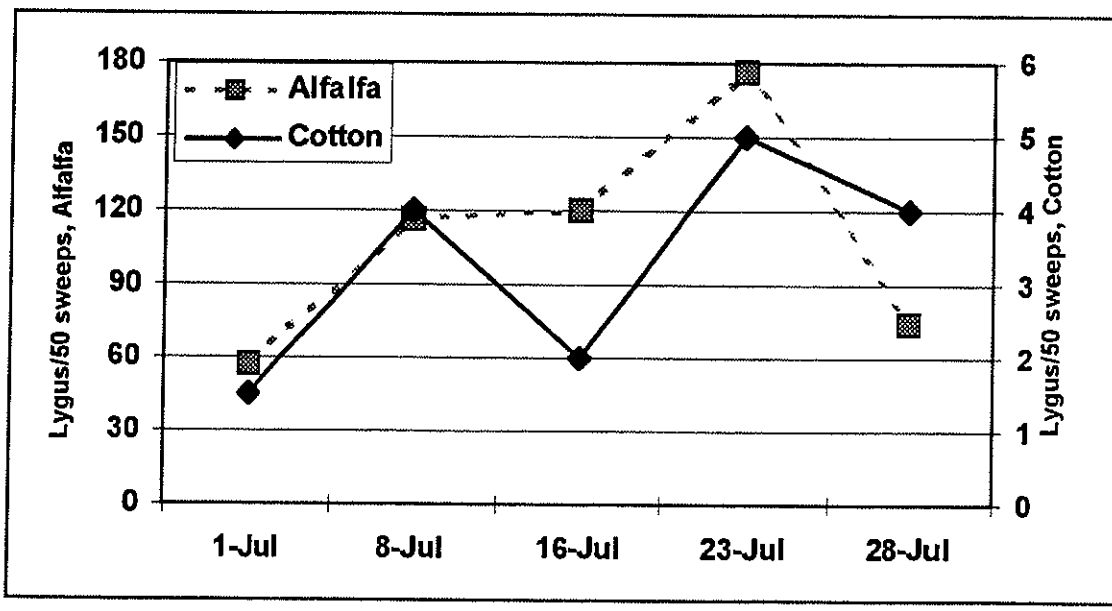

Figure 2. Lygus densities from adjacent alfalfa and cotton fields, Tulare Co. 1999. Note the difference in scale between cotton and alfalfa axes.

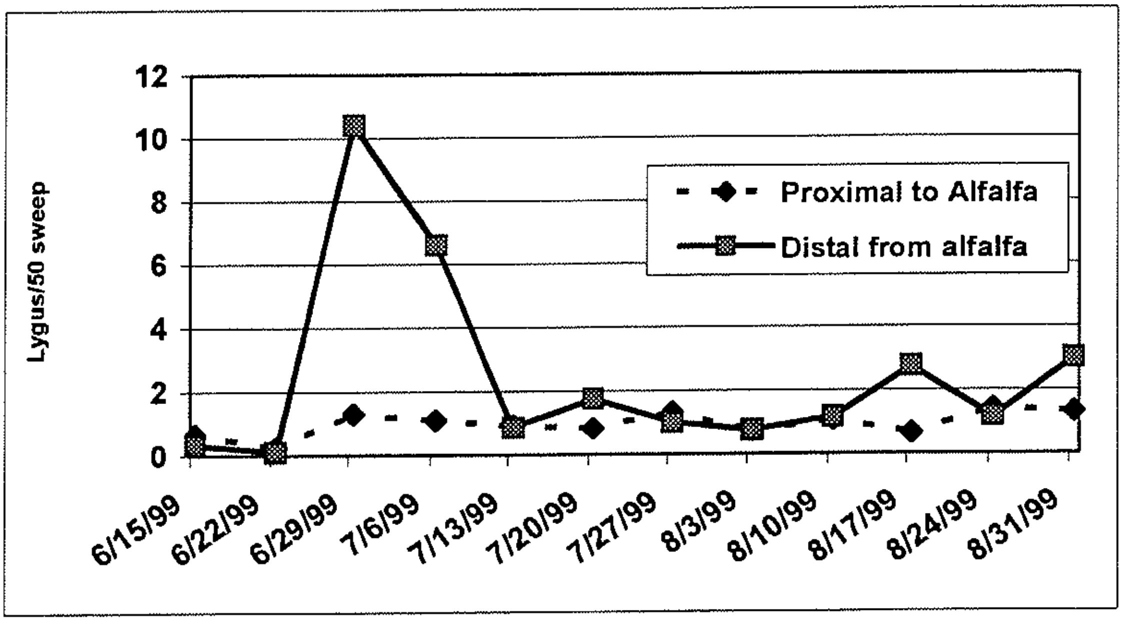

Figure 3. Lygus densities from cotton near alfalfa or distant from alfalfa, Fresno County 1998.

Resistance Monitoring and Applications for Arthropod Management

Dr. Beth Grafton-Cardwell, Dept. of Entomology, UC Riverside, stationed at the Kearney Agricultural Center, 9240 S. Riverbend Ave., Parlier, CA 93648. (559) 646-6591, fax: 559-646-6593, bethgc@uckac.edu

Pesticide resistance is an ever increasing problem in a variety of pests in California crops. For over 40 years, agriculture has depended upon a fairly small number of insecticide classes for control of most pests; chlorinated hydrocarbons, organophosphates, carbamates, and pyrethroids. During that time, pests have developed a number of methods to resist pesticides. Pests can avoid walking on or feeding on the pesticide residues, they can increase the number of enzymes in their bodies so that some enzymes bind with the pesticide and some continue normal function of the insect, they can decrease penetration of the pesticide through their cuticle, or alter the shape of the site the pesticide binds with so that it can no longer attach and disrupt the insects normal function. Pesticide resistance is an enormous challenge to the agricultural chemical industry requiring the industry to develop insecticides that attack insects in new ways.

Researchers have developed a number of ways to test for resistance in insects and mites. One purpose of these tests is to determine how common the resistance is, that is, how many populations have resistance. Another purpose might be to determine how intense the resistance is, that is, is it high enough to cause field failure of the insecticide. Another purpose is to determine if resistance is increasing through time. Bioassay methods can range from techniques that attempt to mimic field conditions by spraying plant material to those that are fairly artificial, taking place in a plastic petri dish. The method used is not as important as whether it provides answers to the questions on pesticide resistance.

A pesticide resistance bioassay usually assesses mortality after a certain time period over a range of concentrations in order to establish an LC_{50} or LC_{90}. This is the concentration of pesticide that results in 50 or 90% mortality of the pest. Using LC_{50}s, two populations can be compared for their relative resistance to a pesticide. The difference between LC_{50}s is the 'fold' difference in susceptibility to the pesticide. However, this method requires a large number of insects (5-7 concentrations of pesticide x 4 replications x 20 individuals per replication = a minimum of 400 individuals). Some pests that reproduce quickly and easily as colonies in the laboratory, like aphids and mites, adapt well to this type of bioassay.

If the insect pest is hard to rear in the laboratory, or if the researcher wants to test pests directly from the field, it is often difficult to obtain enough individuals to test many concentrations of pesticide. In this situation, a researcher may instead use a single discriminating concentration to detect resistant populations. After detailed analysis of one or more resistant and susceptible colonies, the researcher selects a concentration of pesticide that reliably kills >98% of the susceptible population but allows the resistant individuals to survive. The researcher uses that concentration to test 20-80 individuals from the field. The discriminating concentration doesn't define resistance as well as the LD50, but it does allow the researcher to test many populations quickly and so defines the geographical and temporal distribution of resistance much better. These measures of resistance are critical for developing a resistance management program.

During 1995-2000, my laboratory used discriminating concentrations of pesticides to analyze the resistance of lygus bug (*Lygus hesperus*), cotton aphid (*Aphis gossypii*), and spider mites (*Tetranychus turkestani*, *T. urticae* and *T. pacificus*) to insecticides and miticides in San

Joaquin Valley cotton. Because lygus bugs were difficult to find in sufficient numbers for bioassay in cotton, we chose cotton fields next to alfalfa and collected the lygus from the alfalfa. We used the discriminating concentration, because we wanted to test many populations throughout the San Joaquin Valley straight out of the field throughout the season. We knew that sometimes we would not find very many pest individuals in field and sometimes we would have many populations to test in one day.

Insecticide resistance bioassays for aphids were prepared by treating plastic petri dishes with discriminating concentrations of formulated pesticides mixed in ethanol. We expected to observe greater than 80% mean mortality of individuals placed in these dishes if the population was susceptible to the pesticide. We could not test all insecticides registered, and so we chose insecticides from major chemical classes. For aphids, the insecticides included the organophosphate Lorsban (510 ppm chlorpyrifos), the organochlorine Thiodan or Phaser (270 ppm endosulfan), the pyrethroid Capture (5 ppm bifenthrin), and the chloronicotinyl Provado (40 ppm imidacloprid) with mortality assessed after 3 hours. For lygus bugs, plastic ziploc bags were treated with 5 μl technical grade insecticide in acetone and mixed with the pyrethroid Capture (200 micrograms), the organophosphate Metasystox-R (100 micrograms), the carbamate Lannate (40 micrograms), or the chloronicotinyl Provado (50 micrograms). The bags were prepared by Dr. Bill Brindley (Utah State University) and kept frozen till used. Lygus mortality was assessed after 8 hours. Lygus bugs were collected from both cotton and neighboring alfalfa in order to obtain enough numbers for bioassays. For spider mites, plastic petri dishes were treated with discriminating concentrations of Kelthane (56.2 ppm dicofol), Comite (1000 ppm propargite) or Zephyr (3 ppm abamectin) in ethanol. Mortality was assessed after 24 hours. Pesticide use data was obtained from the California Department of Pesticide Regulation for 1990-1999 and summarized for Merced, Madera, Fresno, Kings, Tulare, and Kern counties. Estimates of pest densities were obtained from the Cotton Insect Losses summary for the National Cotton Council.

Pesticide resistance trends generally follow pesticide use patterns and so it is important to look at pesticide use for lygus and aphid control between 1990-1999 in the San Joaquin Valley (Fig. 1). Thiodan/Phaser use reached a peak in 1993, organophosphate and pyrethroid use peaked in 1995, carbamate use peaked in 1998 (primarily Temik), and Provado use was initiated in 1995. In 1995, when organophosphate and pyrethroid use was at it's highest, pesticides were not very effective in controlling cotton aphid or spider mites. This is because pyrethroids are very toxic to the natural enemies needed for control of these pests.

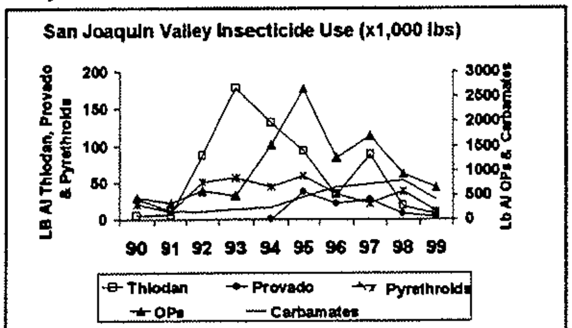

Figure 1.

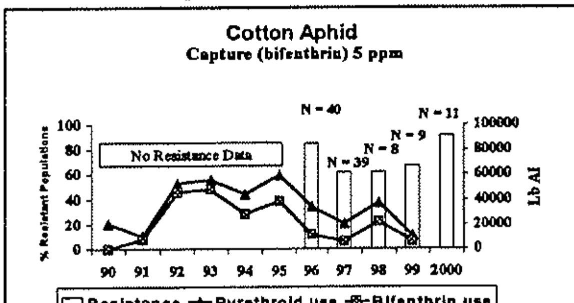

Figure 2. Capture and pyrethroid use (lb AI) during 1990-99 and the percentage of bifenthrin-resistant cotton aphid populations of total (N) tested during 1996-2000.

Resistance to Pyrethroids: Cotton aphid developed resistance to Capture rapidly, and by 1993, it was no longer effective for controlling aphids. The percentage of cotton aphid populations with resistance to Capture was high in 1996 (85% of populations tested) when resistance monitoring was initiated (Fig. 2). Capture resistance declined slightly in subsequent years as pyrethroid use in cotton declined, however, reduction in pyrethroid use did not bring the San Joaquin Valley cotton aphid population back to a pyrethroid-susceptible state and in 2000 it increased again. In 1996 and 1997, lygus bugs were found to be fairly susceptible to Capture at the beginning of each season before insecticides were applied (Fig. 3). Resistance was observed to increase after Capture was applied to alfalfa and cotton in June-July. These data suggested that resistance could be managed by limiting Capture to a single application per year. However in the 1998-2000 resistance surveys, resistance to Capture in lygus bugs, averaged over the entire season, increased to ≥80% of populations tested. Although pyrethroid use generally declined in cotton after 1995, use in alfalfa has dramatically increased (Fig. 4). Recent registration of pyrethroids for alfalfa weevil control and other pests of alfalfa greatly escalated pyrethroid use in this crop. If the heavy pyrethroid use in alfalfa continues, we are likely to see Capture resistance in lygus continue to intensify.

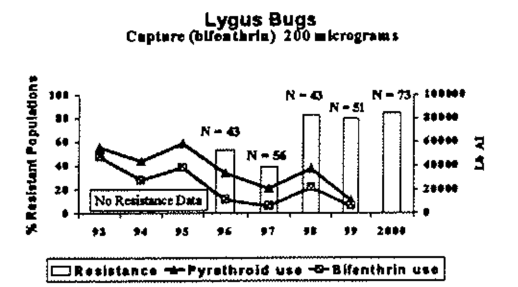

Figure 3. Capture and pyrethroid use (lb AI) during 1995-99 and the percentage of bifenthrin-resistant lygus populations of total (N) tested during 1996-2000.

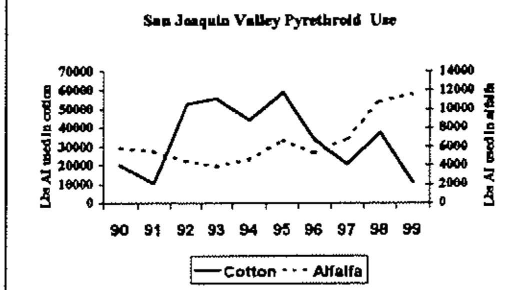

Figure 4.

Resistances to organophosphates, carbamates and chlorinated hydrocarbons.

Resistances to the older classes of insecticides, Lorsban, MSR, Lannate, and Thiodan tend to fluctuate more than resistance to the pyrethroids. An example is the response of cotton aphid to Lorsban (Fig. 5). Resistance to Lorsban was fairly high in 1996 (40% of cotton aphid populations tested), but as use declined after 1995, so did the percentage of resistant populations. This suggests that organophosphate resistance in cotton aphids is unstable and manageable through minimizing organophosphate applications and careful rotation of insecticide classes. A similar pattern was seen for Thiodan resistance in cotton aphid and Metasystox-R and Lannate resistance in lygus bugs.

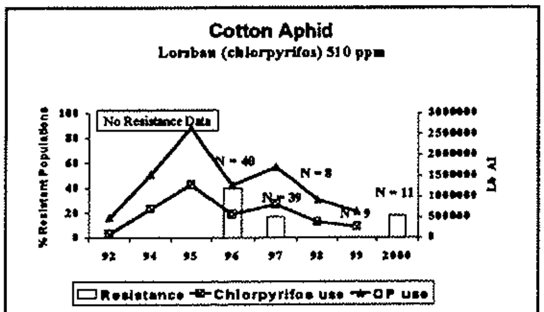

Figure 5. Organophosphate and Lorsban use (lb AI) during 1993-99 and the percentage of chlorpyrifos-resistant cotton aphid populations of total (N) tested during 1996-2000.

New Insecticide Chemistries

Provado was first registered for use in 1995, and to date, no resistance to this insecticide has been detected in cotton aphids. Part of the reduction in organophosphate and pyrethroid use in the late 1990s was due to the introduction of this new insecticide class (chloronicotinyl). A low percentage of lygus populations with resistance to Provado (16%) were first detected in 2000. There is a great need for development of selective insecticides for aphid and lygus control that would allow natural enemies to survive so that the number of sprays could be reduced. In addition, new classes of insecticides are needed to manage the building resistance to the currently registered pesticides.

Spider mites

Spider mites have long been a classic example of insecticide resistance that is manageable through careful rotation and minimal use of pesticides. For years, cotton growers used Kelthane primarily in the early season because it required good coverage and Comite in the mid season because it could be phytotoxic to cotton seedlings. Zephyr was introduced in the early 90s and has replaced much of the Kelthane and Comite use (Fig. 6). However resistance to all of these insecticides continues to show an annual low in the early spring (June) and a mid to late season increase after the miticides are applied (Fig. 7). Three factors contribute to the subsiding of resistance each year. First, strawberry mite is the most common mite in the early season and it continue to be susceptible to all three miticides. Second, the resistances are recessive and so if susceptible mites intermix with the population resistance tends to decline. There is a lot of movement of mites between crops as they dry down at the end of the year. Third, growers tend to treat for mites only once or twice per year and so the selection pressure is fairly low.

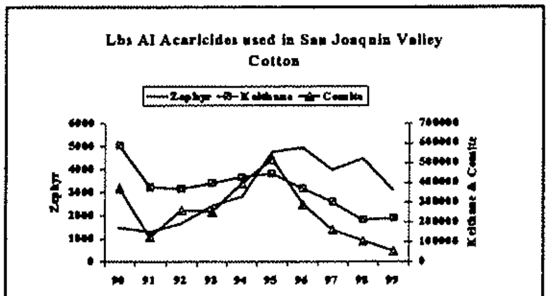

Figure 6. Acaricide usage (lb AI) during 1990-99 in San Joaquin Valley cotton.

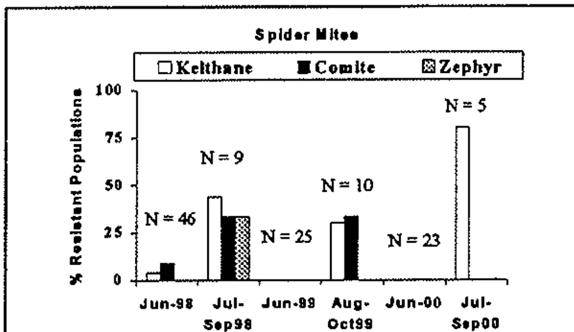

Figure 7. The percentage of Kelthane-, Comite-, and Zephyr-resistant spider mite populations of total (N) tested during 1998-00.

Pesticide bioassays that used discriminating concentrations of pesticides were useful for detecting trends in resistance to major groups of insecticides. The data indicate that pyrethroid resistance in lygus bugs and cotton aphids is quite high, and very stable in spite of a reduction of the use of pyrethroids in cotton. These data suggest that pyrethroid usefulness for these cotton pests may be approaching an end. In contrast, resistances to organophosphates, carbamates, and organochlorines occur, yet the level or frequency of resistance fluctuates in response to pesticide use. There is greater potential for maintaining susceptibility to these pesticides if their use is limited. Use of insecticides for either lygus or cotton aphids selects for resistance in both insects and cotton insect pests are influenced by insecticide use in neighboring crops. Escalating pyrethroid use in alfalfa is a likely cause of increased resistance in lygus infesting cotton. Spider mite resistance to miticides, in contrast, continues to be very manageable in spite of a many years of exposure.

ADDRESSING SUSTAINABLE AGRICULTURE AT A LANDSCAPE SCALE

Adina M. Merenlender, Cooperative Extension Specialist, Integrated Hardwood Range Management Program
and
Emily Heaton, Graduate Student Researcher, Department of Environmental Science, Policy, and Management, UC Berkeley, 151 Hilgard Hall, Berkeley CA 94720-3110
707/744-1424 Ph.
707/744-1040 Fax
E-mail: adina@nature.berkeley.edu, eheaton@nature.berkeley.edu

Introduction

Environmental health, economic profitability, and social and economic equity are considered necessary components of sustainable agriculture. Sustainability rests on the principle that we must meet today's agricultural and economic needs without degrading the natural resources so essential for our future. Clearly, sustainable agriculture requires proper stewardship of the land such as soil and water conservation, to ensure that farming can remain a way of life for future generations. However, the concept of sustainable agriculture goes beyond the boundaries of the farm to include entire ecosystems, the myriad of species these systems support, and the goods and services they provide. Preserving the vitality of agriculture and the surrounding ecosystem is sustainable agriculture on a landscape scale.

Vineyards are expanding rapidly in California's North Coast due to a booming wine market. Much of this expansion is occurring in oak woodlands, one of the most diverse forest types in the state. Vineyard owners are under scrutiny from the environmental community, government agencies, and the local press, who are concerned about protecting natural resources. In response to the need for more environmental oversight for vineyard development, county governments have developed various regulatory approaches to prevent hillside erosion and protect natural habitat.

Our research has focused on developing a geographic information system (GIS) to examine the pattern of vineyard expansion in Sonoma County and develop models of future vineyard expansion based on physical landscape parameters. The applications of this GIS include quantifying the extent of vineyard development (Merenlender 2000), identifying areas where habitat fragmentation may result from continued agricultural expansion (Heaton and Merenlender 2000), and local policy analysis (Brooks and Merenlender 2000). This research allows local producers, policy-makers, and interest groups to evaluate current trends in conversions, and to assess the impact of alternative public policies. Our methodology is designed to be used at the county or regional scale, not to assess individual parcels.

Mapping Vineyards

Estimates of vineyard acreage in California can be off by 20-50%, depending on the county. To address this problem in Sonoma County we[1] developed a GIS to analyze the amount and pattern of vineyard development in Sonoma County's major appellation areas. The first finding from this effort was that 11,663 acres of new vineyards were planted from 1990 through 1997, for a total of at least 48,000 acres in 1997, 20% more than were reported in the County Crop Report in 1997.

Using this GIS we were also able to conclude that vineyards planted in the last 10 years are at higher elevation and steeper slopes than earlier plantings, resulting in the conversion of approximately 9,505 acres of natural habitat.

Modeling Vineyard Suitability

To explore future vineyard development scenarios and the potential environmental consequences we developed a methodology to model vineyard expansion at a landscape scale. These models are based on the assertion that past development trends can provide a basis for modeling possible future land-use scenarios. We used a statistical modeling technique, logistic regression analysis, and the GIS to map areas of possible future vineyard expansion in Sonoma County based on vineyard development during 1990-1997. This approach involved identifying landscape characteristics that were associated with vineyard development during this time and mapping the areas with similar characteristics that were undeveloped as of 1997. Forecasting land-use and land-cover change provides us with the opportunity to assess potential environmental costs that may result if vineyard expansion persists.

Identifying Oak Woodlands at Risk of Fragmentation

As part of the UC Integrated Hardwood Range Management Program, which was established to maintain and restore California's oak woodlands, we are particularly interested in the loss and fragmentation of this habitat type. In order to identify where vineyard expansion may lead to habitat fragmentation in the future, we identified changes in habitat connectivity that resulted from one expansion scenario. The results reveal areas that are more susceptible to future vineyard expansion and where these conversions may cause habitat loss and fragmentation.

Policy Analysis

We used a GIS that includes vineyard maps, topography, and soils information for the major appellation areas to map the areas in Sonoma County that fall into the three levels defined by Sonoma County's new Vineyard Erosion and Sediment Control Ordinance. The purpose here was to map and quantify the areas that would be more and less affected by new regulation in order to better evaluate the policy and assist decision-makers.

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[1] The original digital data for vineyards in Sonoma County was developed by Circuit Rider Productions Inc. for the Sonoma County Grape Growers Association.

We concluded from this exercise that no more than 36% of future vineyard development, and more likely closer to 20%, will fall under the more stringent regulations requiring 50ft set backs and an erosion control plan. We provided analysis of this type to the committee that developed this ordinance and presented the results to the Board of Supervisors and the public prior to the adoption of the ordinance. We hope continued use of this approach will assist the public and policy makers in quantifying the implications of these types of policies for agricultural development and environmental protection.

In Summary

We would also like to expand our investigations in this area by using remote sensing to monitor vineyard development more regularly through time and across a larger geographic extent. Active collaborations have been initiated to investigate how changes in vineyard development costs and wine grape values may affect future patterns of development. There are many areas of research to expand into. However, our first attempt to demonstrate this method of land-use change analysis has stimulated a good deal of discussion at the local level and provided conservation planners with some direction for protecting oak woodlands, thereby demonstrating that this information can be used to support science based planning and policy decision-making.

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FROM YIELD MAPS TO MANAGEMENT ZONES

J.F. Perez, Graduate Student, Department of Agronomy & Range Science,
S. Pettygrove, Extension Soils Specialist, Department of Land, Air & Water Resources,
R.E. Plant, Professor, Departments of Agronomy & Range Science and
Biological and Agricultural Engineering
University of California, Davis
One Shields Avenue, Davis CA 95616
E-mail: jfperez@ucdavis.edu, gspettygrove@ucdavis.edu, replant@ucdavis.edu

Agricultural managers traditionally have viewed crop fields as uniform systems. The technology currently available allows us to make a differential use of the resources in order to obtain 1) crop yield increment, 2) increase in homogeneity and, 3) improvement in temporal stability. These three goals will be achievable only if we have a good understanding of the processes and the factors that regulate crop responses to within-field soil variability. Although a long-term approach is needed, only a few multi-crop studies have been conducted.

Data from two four-crop-rotation fields in Sacramento Valley, California were analyzed. The two fields are designated Field 5 and Field 58 The soils in the two fields are predominantly alluvial clay loams and silty clays. Both fields are about 31 ha (77 acres) in area. Field 5 had a wheat-tomato-bean-sunflower rotation from 1996 to 1999, and Field 58 had a wheat-tomato-sunflower-corn rotation during the same period. Soil samples were taken on a 61-m grid resulting in 86 samples in Field 5 and 78 samples in Field 58. Baseline soil traits measured ranged from relatively stable ones like texture, pH and soil organic matter, to more dynamic ones like NPK content (Plant et al., 1999). Yield was monitored every year and after georeferencing, interpolation and correction of the data, correlation was measured between the years using 20 × 20m cells. Six two-year comparisons were performed in each field, accounting for the congruence of inter-annual variation in defining yield patterns within the fields. In general, there was a lack of yield stability within the four-year period, making the potential use of this information questionable (Lamb et al., 1996). The best correlation was found in Field 58 between sunflower and corn with an $R^2 = 0.32$.

Since every year has its own spatial yield pattern, and every crop has different yield standards, data were standardized based on a similar analysis of Blackmore (2000). By adding the standardized yields, a coefficient called *sumscore* was calculated. This represents the average or total standardized yield over the four-year period. Figure 1 shows the sumscore divided into three classes using the natural breaks classification. As can be seen, in Field 5 (Fig. 1-A) there is a high spatial autocorrelation between those areas with similar yield performance. There is an increasing gradient in yield from the northern to the southern ends of the field. This pattern is very likely to be the result of a texture gradient in the field where the southern part is coarser and better drained than the northern part (Plant et al., 1999).

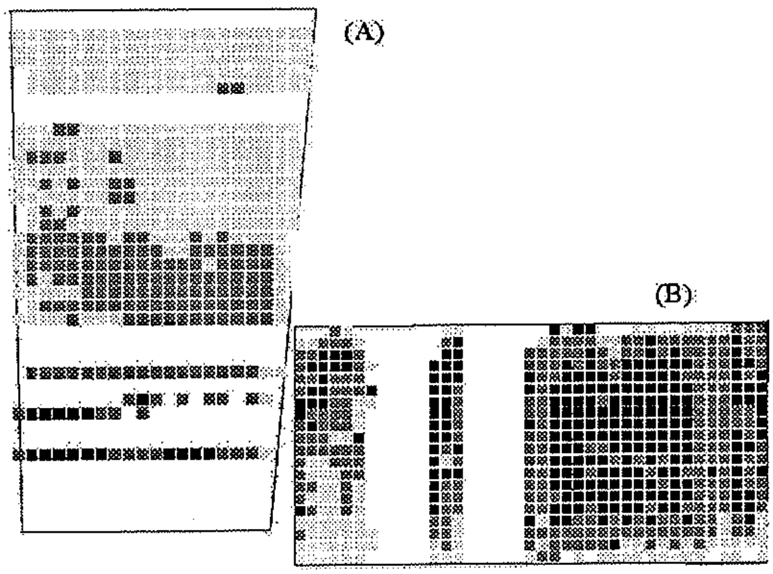

Fig. 1. Sumscore of Field 5 (A, left) and Field 58 (B, right). The line shows the border of the field and different color represent each index where data was available for the four-year period.

In Field 58 there is also a high spatial autocorrelation with the middle parts having higher sumscores (Fig. 1-B). The spatial and temporal patterns are much more homogeneous in this case except where they are altered by a weed infestation during the first year in the lower left part of the field (Plant et al., 1999).

Preliminary regression analyses were carried out between the sumscore and the five most stable soil variables (the three textural classes, soil organic matter and pH). In Field 5, a maximum of 54% of the variance of the sumscore was explained by percentage of silt and percentage of organic matter. These two characteristics are more or less stable at field level and imply that the spatial gradient in yield observed in Field 5 would persist unless some action were taken to improve drainage in the northern portion of the field. In Field 58 there were 60 soil samples that matched were yield data for all four years was available. The higher homogeneity was reflected in a much lower coefficient of determination. The maximum adjusted R^2 in this case was reached when using the silt content of the soil (0.15).

Another way of looking for spatial and temporal yield patterns is through cluster analysis (Stafford, 1998). We performed this analysis using the K-means clustering method. In this method the number of clusters is selected and then the analysis identifies clusters so that the variance within groups is minimized and the variance among groups is maximized, without considering spatial information. Figure 2 shows the spatial arrangement of three clusters in both fields, demonstrating the high level of spatial autocorrelation of these clusters. In Field 58 the cluster analysis indicates that there are two natural clusters, one of which consists of consistently high yielding areas and one of which is characterized by lower yields except in the second (tomato) year. As with Field 5, the clusters display a high level of spatial contiguity.

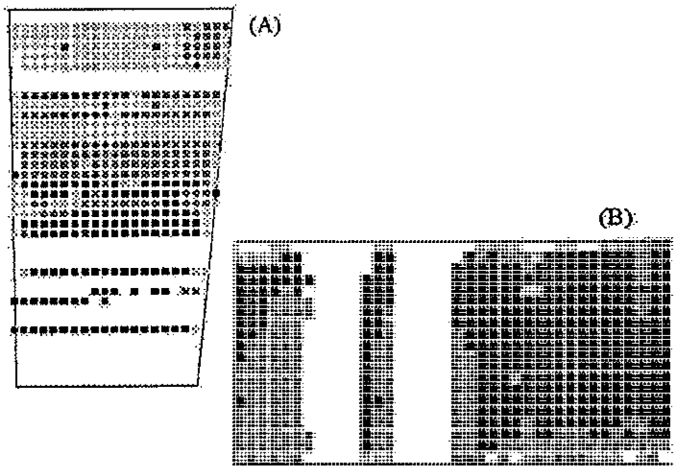

Fig. 2. Result of the cluster analysis in Field 5 (A-left, 3 clusters) and Field 58 (B-right, two clusters). The line shows the border of the field and different shading represent each cluster where data was available for the four-year period.

Using the yield maps and data provided by the grower, we created profit maps for each crop. Figure 3 shows the result for Field 5 where the dark areas represent a negative income for the growing season. As can be observed, in the sunflower year, the whole field presented positive results, whereas in the bean year, the entire field showed a loss. The wheat year map shows clearly the increasing yield trend towards the south (bottom) end of the field, where the coarser texture responded better to the rainy conditions of that year (150% of normal precipitation). During the fully irrigated tomato-cropping season, the best yielding area was the one that has an intermediate texture condition, suggesting that the northern part received too much water whereas the southern end received less than needed. In field 58 there was a more homogeneous yield distribution but when analyzing the economic result, it is clear that the difference between gaining and loosing money is more variable both intra- and inter-annually.

In summary, even though there is a lack of year to year relation in yield among pixels, the clustering analysis appear to be a good way of identifying spatial and temporal patterns within a field. At least in these fields, the clustering method, which does not incorporate positional information, nevertheless identified geographically contiguous clusters. This implies that the method may be a useful management tool for applications.

The two fields monitored in this study represent in extremes of a spectrum of variability that may be encountered in these production systems. Field 5 is characterized by a high level of soil texture variability that is probably related to soil drainage. This variation dominates the yield pattern in the field and gives this pattern a high degree of stability. Field 58 is at the other end of the spectrum in that it is more homogeneous in its soil properties. This makes prediction of variability more difficult and probably more specific to crop and to environmental factors. Nevertheless, the field does display structured patterns of yield. The challenge in this field and others like it is to identify the sources of variability and determine how to respond to them.

In an attempt to define such management zones, the EPIC model is being calibrated to first recreate the yield responses observed in both fields and, in the future, be able to test whether the cluster classification is a good way of dividing the fields. To do this, soil characteristics will be averaged within each cluster and used to simulate, for example, different irrigation scenarios. By measuring the difference in yield response and after an economic analysis of costs involved, we will be able to determine whether if it is worthwhile to split the field into two or three zones and manage each zone differently.

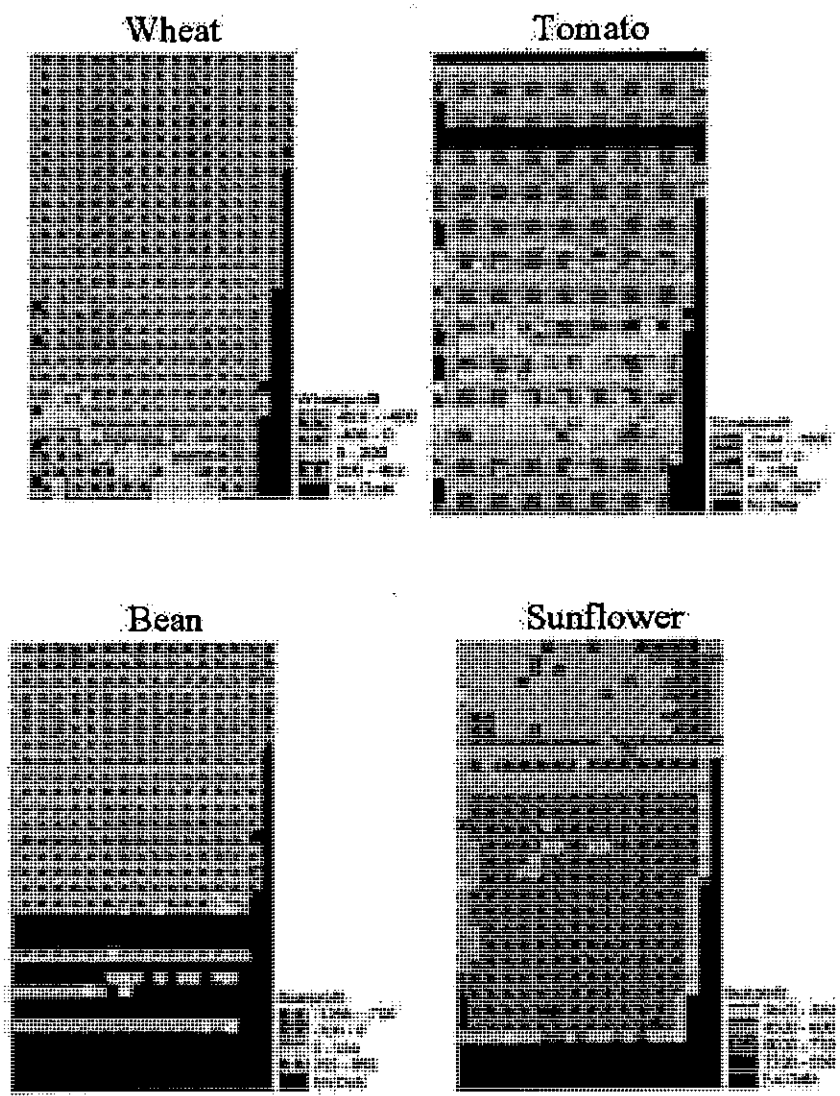

Figure 3. Profit maps for field 5, values are in $ per ha.

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Soil Salinity Mapping in the Imperial Valley of California

Steven L. Burch, Project Leader, Imperial Irrigation District
P.O. Box 937, Imperial CA 92251
760/339-9084 Ph.
760/355-1268 Fax
E-mail: sburch@iid.com

The Salinity Assessment Vehicle (SAV) is a project that the Imperial Irrigation District and the U.S. Bureau of Reclamation (USBR) have partnered to better understand soil salinity in the Imperial Valley. The Imperial Valley Research Center (IVRC) has volunteered to analyze the necessary soil samples.

There are four basic steps involved in completing a field salinity survey. First, the SAV is driven across the field to collect the electronic sensor data. The sensor (EM38 DD) takes salinity readings to a depth of approximately 2 meters while the SAV is traveling at a ground speed of about 5 mph. An on-board lap top computer monitors the sensors, and functions as the datalogger. The electronic portion of the survey involves taking EM38 readings along lanes (transects) spaced 75 to 125 ft. apart, across the field. Each EM38 reading has an associated GPS position, which is differentially corrected for increased accuracy.

Once the EM38 survey is completed, the second step is to analyze the electronic data and develop a soil sampling plan using software available from the U.S. Salinity Lab (USSL). Ground truthing soil samples are then collected at each of 12 specific data points in the field. Soil samples are taken in 1 ft. increments to a depth of 4 ft. and delivered to IVRC where they are analyzed for salinity.

The third step is to produce a final field salinity map. The laboratory data is correlated with the electronic data and merged together using the USSL software. Two-dimensional maps of the spatial distribution of salts in the field are generated for each 1 foot increment of soil through the 4 ft. depth, as well as, bulk average salinity in the 4 ft. profile. Additionally, one dimensional salinity trends are plotted for individual transects, which show the salinity levels for each depth, or the profile average, along the length of the specific transect.

A meeting is then scheduled with the cooperating grower to discuss the report, which includes two sets of two dimensional salinity maps of the field, and transect trends depicting average profile salinity along every other transect across the field. Other reports include; projected potential yield/yield loss for specific crops, laboratory results and the sample plan map, showing the relative location of each of the ground truthing sample sites. The grower can then utilize the information in his management schemes to improve his farming practices. This may include; modifying irrigation management plans, including irrigation schedules and leaching irrigations, or scheduling tile line cleaning.

Some of the information that can be interpreted from the survey data includes: 1) how the soil salts are distributed throughout the field, at various depths, down to the maximum sampling depth, 2) how the soil salts are distributed throughout the profile along the individual transects/lanes traveled, 3) relative subsurface tile drain locations and apparent effectiveness of the tile line operation in fields with subsurface tile systems, and 4) soil texture and moisture content changes within the field boundaries.

Since mid-April, 2000, over 40 field salinity surveys have been performed.

The SAV is based on a Melroe SpraCoupe, model 233, which was stripped of all external spray components, including the tank and booms. Several modifications were made to the basic chassis, and the various components, including GPS, adjustable mounting for EM38 sensor, printer, computer and hydraulic soil sampler (Concorde Environmental - Model 9800), were installed

Public awareness efforts have included 2 articles in the local newspaper (Imperial Valley Press), an on-camera interview with television station KYMA (Yuma), and a press release by the IID, which was sent to over 100 recipients (including various agricultural publications and newspapers). Additionally, the SAV was been displayed as part of the Alfalfa Field Day held at the Desert Research Experiment Center at Meloland (Holtville) and at the Lower Colorado River Salinity Assessment Network conference held at the USBR office in Yuma, AZ.

COMMERCIALLY AVAILABLE SERVICES AND PRODUCTS FOR PRECISION FARMING

Karol Aure, VP Field Services, Precision Farming Enterprises, Inc.
2850 Spafford, Davis, CA 95616
530/758-1946 office 661/330-3238 mobile 530/758-6008 fax
www.precisionfarming.org
kaure@precisionfarming.org

Market awareness and knowledge of Precision Farming technologies have grown steadily over the last 5 years. Many California growers have had an opportunity to apply Precision Farming techniques to their unique crop and management systems, profiting from both the agronomic and efficiency capabilities of tailored GPS products and services.

1. Agricultural markets have benefited from the extension of general GPS education through applications such as hunting and municipal use. By demystifying and improving GPS reliability, the door has been opened to an explosion of new applications for this central enabling technology of spatial information
2. Additional technologies, such as sensor packages, ruggedized field computers, and software have become more dependable, with more features.
3. Points of distribution serving California growers have grown.

These trends translate to a broad offering of commercially available products available through vendors and service providers. Precision Farming products can be divided into categories with a number of vendors serving each category:

1. GPS and DGPS (positioning and guidance)
2. Yield Sensors for Grains, Cotton, Conveyor harvested crops
3. Soil Sensors and Probes
4. Variable Rate Controllers
5. GIS Software
6. Remote Sensing, Satellite and Aerial

Precision Farming services can also be loosely described by a number of categories:

1. Field mapping – Features by polygon, arc, or point (area, line, point data)
2. Point data mapping – Soil or yield data sets (point data with unique data set statistics)
3. Software and Information Management – Software consulting/training services and database management

A number of providers, with different skills and customer objectives, currently serve the California market. California growers are faced with many choices to access products and services. These sources are likely to become more specialized with time. Along with expected technology advances, commercial sources for both products and services will become streamlined and deliver to growers faster and with added value.

Management Strategies to Promote Soil C Sequestration

J.P. Mitchell

Department of Vegetable Crops and Weed Science, University of California, Davis,
Kearney Agricultural Center, 9240 S. Riverbend Avenue, Parlier, CA 93648
Telephone (559) 646-6565, Fax (559) 646-6593, mitchell@uckac.edu

Introduction

Soil carbon (C) typically constitutes about half of soil organic matter (SOM) and is closely linked to many desirable soil physical, chemical and biological properties that may be associated with enhanced soil productivity and quality (Reicosky, 1996; Ismail et al., 1994). Carbon has been called a "keystone" element in agroecosystems because of its role in such critical soil functions as water infiltration and storage, nutrient cycling, aggregation and overall tilth maintenance (Reicosky, 2000). Although the universal desirability and feasibility of efforts aimed at increasing SOM has been questioned (Sojka and Upchurch, 1999) because high levels SOM may in certain cases lead to such "negatives" as increased by-pass flow and reduced pesticide efficiency, and because of the presumed difficulty of actually being able to increase it in certain agroecosystems, there is general and growing interest among producers in improving soil quality via C sequestration (Romig et al., 1995; Mitchell et al., Submitted). This article summarizes recent evaluations of various management strategies aimed at promoting soil C storage that have been undertaken in California.

Cover crops, compost and manure

Western Fresno County in the Central San Joaquin Valley (SJV) is one of the world's most productive agricultural regions. Preserving soil quality in this region provided much of the motivation for the West Side On-Farm Demonstration Project, a participatory research and extension program consisting of fourteen large-scale San Joaquin Valley row crop farmers, University of California researchers, USDA National Resource Conservation Service consultants and private sector consultants, that was conducted from 1995 through 1998 to evaluate management practices designed to maintain soil quality and sustain productivity in this region. The objectives of this project were to monitor and evaluate on-farm demonstrations of soil management practices including cover cropping and the use of organic soil amendments / compost and manure, to develop, test and evaluate a soil quality index for the region, and to facilitate information exchange among farmers, consultants and researchers on alternative soil management practices.

One of the three specific questions that guided the project's implementation and monitoring activities was to determine the extent to which SOM might be increased by routine compost, manure or cover crop inputs. This study thus provided a comprehensive soil quality property data set and it enabled the development and testing of a soil quality index for the region.

Side-by-side comparisons of conventionally-managed versus organic amendment production systems were established at 12 farms in the fall of 1995 in the western SJV region between Huron, CA in the south and Mendota, CA in the north. The sites consisted of adjacent fields that were randomly designated *conventional* and *alternative* and generally ranged from 80 to 150 acres at each location. Cover crop and compost or manure amendments were integrated into each alternative field site whenever feasible and that the conventional field was maintained without these deliberate organic amendment inputs. In 1997, sampling at one farm was expanded to include adjacent long-term organic and conventional fields as well as a field that was in the second year of transitioning to organic production practices.

Six composite soil samples were taken from the alternative and conventional fields of each farm in the spring and fall of each year of the project. Each composite sample consisted of 8 to 12 subsamples taken from the surface 15 cm of soil, processed and analyzed for SOM, total C, microbial biomass C and other related properties.

Applications of compost or manure were made to amended fields 25 times during the course of the project while late summer or winter cover crops were grown as green manures 9 times and combinations of cover crops and compost or manure applications were used twice. No current regional organic amendment use patterns were available, however, it is very unlikely that they are used on more than 5% of farmland annually. Interviews with project participants revealed that these soil amendments were being considered primarily as a means for adding carbon to the soil so as to improve soil quality, rather than for fertility purposes or as a means for reducing fertilizer inputs.

Statistical end-point summaries of data for selected soil quality properties at the end of the project in 1998 for 7 of 12 farms at which a deliberate, concerted commitment to the side-by-side comparisons was maintained throughout the course of the project indicated that properties that tended to change most frequently included total soil carbon, microbial biomass C and N, organic matter and TKN. SOM and soil carbon were significantly higher in the alternative / amended fields at 5 of the 7 sites in 1998. Increases in carbon from 1995 to 1998 at these 5 sites were 0.08 to 0.24 percent, averaging 0.15 percent. Similar short-term changes in SOM in organic and low input cropping systems in California's southern Sacramento Valley have also been reported in the 12-year Sustainable Agriculture Farming Systems (SAFS) Project that has been conducted at UC Davis. Current soil organic matter levels in agricultural soils of farms of the West Side SJV region typically average 0.83% (Mitchell et al., 1999). Microbial biomass carbon and nitrogen also were significantly higher in the alternative fields at 4 of 6 sites (excluding the manure / compost comparison at farm 3) in 1998. Biomass C and N were on average, 32 and 37% higher in the alternative fields relative to the conventionally-managed fields, respectively.

These data provide an indication of what *short-term* impacts of alternative management practices may be in this region. Longer-term impacts of these types of practices were more clearly seen in the cropping system comparison at the participating farm in which conventionally-managed, long-term (10 years) organically-managed, short–term compost and manure amended and a field being transitioned to organic practices were compared. When conventional and organic soil management impacts were compared at this site, significant differences were determined for 13 of 15 properties, including total C and SOM.

The relative magnitudes of differences between conventionally-managed, short-term amended (compost and manure) and long-term organically-managed soils that are presented for this farm reveal a number of significant outcomes. First, these results confirm findings of the SAFS Project which evaluated conventional, cover crop-based low input and compost / cover crop-based organic, and support the long-standing observation that changes in what is perceived to be soil quality, take considerable time and may not likely surface after the relatively short time during which the other farm comparisons of this project were monitored. Second, these data provide evidence that fundamental changes in soil quality indicator properties, including C, can result from deliberate management attention in an irrigated, semi-arid environment such as the San Joaquin Valley, and that these differences persist despite current heavy tillage practices (Mitchell et al., 2000). The practical, environmental and functional significance of these management-induced differences is the focus of intense ongoing research

Conservation tillage

During the last two decades, awareness has increased concerning the negative impact tillage may have on SOM storage (Reicosky, 1995). While moderate tillage may provide more favorable soil conditions for crop growth and development and weed control over the short term, (Carter, 1998), intensive tillage of agricultural soils has historically led to substantial losses of soil C that range from 30 to 50 percent (Schlesinger, 1985). Conventional tillage practices disrupt soil aggregates exposing more organic matter to microbial degradation and oxidation (Reicosky, 1996), and are one of the primary causes of tilth deterioration over the long-term (Karlen, 1990). Channels within the soil, created by natural processes such as decaying roots and worms may also be destroyed by tillage (Carter, 1998). Recent surveys from long-term crop rotation studies such as the Morrow Plots at the University of Illinois, the Sanborn Field Plots in Columbia, Missouri and the Columbia Plateau Plots near Pendleton, Oregon, have documented that intensive tillage typically leads to decreased soil C via gaseous CO_2 emissions (reviewed by Reicosky *et al.*, 1995). There is mounting evidence as well as concern that this C source has been a significant component of the historic increase in atmospheric CO_2 (Wilson, 1978; Post *et al.*, 1990), and the potentially associated greenhouse effect (Lal *et al.*, 1998) that is attracting intense attention worldwide.

Recent studies by Reicosky and Lindstrom (1993) involving a variety of tillage methods indicate major gaseous losses of C immediately following tillage, but point to the potential for reducing soil C loss and enhancing soil C management through the use of conservation tillage (CT) crop production practices. Though these practices have been developed over the past several decades primarily for erosion control in other parts of the US, recent concerns regarding the need to sustain soil quality (Abdul-Baki, 1998) and profitability (Mitchell and Goodell, 1999) in areas such as California where CT is virtually nonexistent, as well as potential global climate change have reemphasized the importance of CT and how it might be implemented on a broader scale to help reduce soil C losses (Carter, 1998) and thereby sustain soil quality and agricultural productivity.

Most current SJV annual crop production systems are very tillage intensive. Typically 9 – 11 tillage operations are made in most fields following harvest in preparation for a succeeding crop at about 18 – 24% of a farmer's seasonal budget (West Side On-Farm Demonstration Project Participant Survey, 1999). Tillage in these production systems is typically done in a "broadcast" manner throughout a field, without deliberate regard to preserving dedicated crop growth or traffic zones. Studies by Carter (1991, 1987, 1985, 1998) over the last several decades however, have confirmed the potential to eliminate deep tillage, decrease the number of soil preparation operations by as much as 60%, reduce unit production costs, lower soil impedance and maintain productivity in a number of SJV cropping contexts using reduced, precision or zone tillage practices that limit traffic to permanent paths throughout a field thereby reducing soil compaction and preserving an optimum soil volume for root exploration and growth (Carter, 1991; Carter *et al.*, 1991; Rechel *et al.*, 1990).

During the last 5 years, a number of short-term conservation tillage research studies and demonstration evaluations have been initiated in California. The University of California's Division of Agriculture and Natural Resources Conservation Tillage Workgroup has taken an active leadership role in many of these evaluations which have increased from one site in 1996 to over twenty sites in 2000. To date, these efforts have focused on determining the extent to which equipment and other crop management practices might need to be modified in order to accomplish economically-viable production levels for single-season crops. However, longer-term evaluation efforts that are investigating the extent to which soil C sequestration may or may not change under these alternative tillage system have also been recently initiated.

(Parts of this Proceedings summary are being published in the article *Reduced-disturbance agroecosystems in California* in the Proceedings of the Congress on Ecosystem Health that was held in Sacramento, CA in August 1999. Work reported here that is related to the West Side On-Farm Demonstration Project has also been more fully summarized in an article by Andrews et al. that has been submitted for possible publication to *Agronomy Journal*).

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Role of Agro-Industries in Realizing Potential of Soil C Sinks

By
Bruno Alesii
Monsanto Company

Most of the focus over the last few years to find technologies to reduce greenhouse gases in the atmosphere has been in the areas of energy use, renewable energy sources, manufacturing efficiencies, and motor vehicle efficiency. Recently however, farmers are learning that the way they farm can have a significant impact on climate change. By using a simple but powerful farming technology facilitated by *Roundup* and *Roundup Ready* crops, farmers can significantly reduce atmospheric carbon dioxide.

The technology is called conservation tillage. It's a farming practice that utilizes little if any tillage, leaving the soil relatively undisturbed. It's not a new concept and some farmers have used it for years as a way of reducing erosion, protecting the water quality of streams and lakes and providing habitat and food for birds and other wildlife. Now however, farmers are learning that conservation tillage can significantly mitigate global climate change.

The concept is simple: through the photosynthesis process, crops pull carbon dioxide from the atmosphere and store it in their stalks and leaves. When their residue is left on the fields to decompose, the carbon they pulled from the atmosphere is deposited in the soil. Unfortunately, traditional intensive-tillage farming practices release virtually all of the carbon back into the atmosphere. Tillage stirs up the soil and exposes the stored carbon to oxygen, which turns it into carbon dioxide and releases it back into the atmosphere.

However, if the soil is farmed with conservation tillage techniques, a significant portion of the carbon sequestered by the crop is returned to the soil profile building up the soil organic matter.

According to the Soil and Water Conservation Society, no-tillage farming methods (a form of conservation tillage)can sequester from a fifth to a half ton of carbon per acre per year and that process could continue for the next 30-50 years. That yearly amount would offset the carbon released by the burning of 20 to 50 gallons of gasoline per acre.

In the United States alone, widespread adoption of conservation tillage and other management practices, such as buffers and crop intensification, could potentially fulfill 20-30 percent of the U.S. carbon dioxide reductions targeted at the Kyoto meetings. Additionally, since heavy tillage with large tractors is not necessary, no-tillage farming saves 3.5 gallons of fuel per acre, resulting in less carbon dioxide emitted.

Monsanto's agricultural products are well suited to support and encourage conservation tillage. *Roundup* herbicide is an environmentally-friendly tool that farmers can use to control weeds without resorting to the plow or cultivator. *Roundup* has been instrumental in facilitating conservation tillage around the world.

The more recent addition of *Roundup Ready* crops has further encouraged and facilitated the adoption of conservation tillage. These crops are resistant to *Roundup* herbicide which means that even after the crops are up and growing, *Roundup* herbicide can still be used to control weeds without tillage.

Monsanto believes that it can help mitigate climate change through its products, especially by encouraging the adoption of conservation tillage. As a company, Monsanto is also committed to support and help the agricultural community as a whole adopt practices which sequester carbon and develop technologies that are climate friendly.

Monsanto's Position:

◊ There is sufficient scientific evidence on the issue of climate change to justify prudent action.

◊ We will measure and publicly report our own greenhouse gas emissions and manage our activities to continually improve material and energy use efficiency.

◊ We will seek to develop and introduce products, technologies and services that contribute to stabilizing greenhouse gases

◊ We will work to insure that agricultural practices such as conservation tillage that increase carbon sequestration in soils are recognized as a positive factor in mitigating climate change and that these practices are included in market driven mechanism such as CO2 emission trading programs.

◊ We support worldwide policies for reducing the possibility of global climate change that emphasize flexibility, market driven mechanisms and meaningful participation by all.

Soil Carbon Sinks/Con-Till

◊ Soil carbon sinks can play a significant role in mitigating global climate change by sequestering carbon dioxide out of the atmosphere and storing it in the soil. Soil carbon sinks are natural systems such as farmland or forests.

◊ Farmers who practice conservation tillage are sequestering carbon. In con-till or no-till farming, crops are planted into the previous year's stubble without plowing. The carbon, trapped in the fiber of the crop residue, is returned to the soil in the form of organic matter, enriching the soil in its biological, chemical and physical properties.

◊ The elimination of tillage also prevents the soil organic matter (carbon) from being oxidized and released into the atmosphere where it can become a greenhouse gas that contributes to global warming.

◊ Monsanto products complement the use of no-till farming techniques.

◊ No-till farming methods can sequester from 0.2-0.5 ton of carbon acre per acre per year -- equivalent to the carbon released from burning 20-50 gallons of gasoline. In addition switching from conventional to no-till farming can reduce fuel use by at least 3.5 gals/a

◊ Soil C sinks can offset 20-30% of the emission reduction target of the US

◊ In addition to sequestering carbon, con-till holds these additional benefits:

- Topsoil preservation: 25 billion tons of topsoil are lost each year to runoff. No-Till farming decreases soil erosion rates by 90 percent by holding soil particles on the field.
- Groundwater quality: nutrient, pesticide and water runoff is decreased by at least 70 percent over conventional tillage.
- Reduced air pollution: Crop residues reduce wind erosion and the amount of dust in the air. Lower horsepower requirements and fewer trips also reduce fossil fuel emissions.
- Long term farm productivity: The less you till, the more carbon you keep in the soil to build organic matter and promote future productivity. Intensive tillage speeds the breakdown of organic matter and soil structure.
- Increased wildlife habitat: Crop residues provide shelter and food for wildlife, such as game birds and small animals.
- In addition, conservation tillage saves farmers money and time: No-Till requires as little as one trip for planting compared to two or more tillage operations plus planting for conventional tillage This saves an average 450 hours on a 1000 acre farm. Fuel savings average 3.5 gallons an acre compared to conventional tillage systems. Fewer trips requires less wear on equipment and maintenance costs estimated to save $5 per acre.

Need for Unity in Agriculture Industry on Climate Change

◊ We don't pretend to speak for the ag community on the issue of climate change. However, we would like to see the leadership of the Ag community take a more pro-active position on the climate change issue. By doing so we will shape our own destiny on this issue rather than have others do it for us. We believe that agriculture can play a major role in mitigating climate change. We have the technology and the capacity to begin to impact the climate change issue today without having to wait for new technology development. All that is needed is the development of ag policies that would be favorable to agriculture to begin to take action i.e. incentives, research dollars, tax credits. We believe that for the next 20-40 years agriculture can be the bridge to a safer climate. Agriculture needs to be at the table on the climate change issue so that we can help to shape the outcome into one that is good for U.S. agriculture and the environment. This should include:

- A process to build consensus on a position across the ag community on climate change

- The establishment of an ag community working group to shape a U.S. agriculture position on climate change. This working group would be comprised of representatives from all key commodity groups, AFB, Industry representatives (fertilizer, equipment, chemical, food processors, distributors) as well as representatives from key governmental agencies i.e. USDA, DOE etc. The working group would be facilitated by a third party organization to insure that every group had an equal voice on the outcome. Outcome from this effort would include:

1. Development of U.S. agriculture position on climate change agreeable to all participants

2. Agreement on what kind of policies would encourage climate-friendly practices in agriculture

3. Future actions that agriculture can undertake together to have an impact on climate change

What Government Can Do to Promote Ag Involvement

The government can also play an important role through actions which encourage stewardship and development of new technologies such as incentives for best practices, raising awareness and funding innovative research and by supporting market driven mechanisms such as carbon dioxide emission trading programs.

◊ We also believe that government can do a lot more than it has done to engage agriculture in a more meaningful way:

  - More frequent and open dialogue with the ag community not only on the climate change issue but also on other environmental issues.

  - Tax credits to advance the adoption of new technologies such as biofuels

- Development of farm policies that provide Incentives to growers who adopt best management practices (BMP's) that improve the environment

- Funding of research to overcome/address the issue of greenhouse gases methane in our livestock industry and NOX in our rice industry

- Funding to support research and development of new biofuels

- Funding to support research in the area of measurement, monitoring and verification of soil C as it relates to carbon credit trading.

- Early action legislation to reward, not penalize, early adopters for their environmental stewardship

- Assisting in the creation of a working model for carbon credit trading

COMPARISONS AMONGST HALOPHYTES AND SALT TOLERANT FORAGES IN A DRAINAGE WATER RE-USE SYSTEM: RELATIVE EVAPOTRANSPIRATION, ION ACCUMULATION, AND FORAGE QUALITY

Benes S.E.[1], Grattan S.R., Cervinka V., Eroh C.[1], Sharmasarkar S[1].
[1]California State University, Fresno, Dept. Plant Science M/S AS72, 2415 E. San Ramon Ave. Fresno, CA 93740-8033. email: sbenes@csufresno.edu
[2]University of California, Davis and [3]CA Dept. of Water Resources.

Drainage water (DW) re-use is amongst several management options available to address the salinity and drainage problems on the westside San Joaquin Valley. The use of subsurface drainage to lower water tables and control root zone salinity and boron is limited by environmental regulations related to the disposal of the collected drain water. A sequential drainage water re-use system, now called "Integrated, On-Farm Drainage Management (IFDM)", was initiated at Red Rock Ranch (RRR) in 1997 to test the feasibility of irrigating salt tolerant forages and halophytes with saline drainage water so that drainage volumes could be reduced prior to their discharge into a solar evaporator. As designed, high quality canal water is used to irrigate **Area A** that is in transition from low value row crops to higher value vegetable crops. Primary drainage collected from A is applied to **Area B** containing salt tolerant row crops. The secondary drainage from B is applied to **Area C** where salt tolerant forages are grown and finally, the tertiary drainage is applied to **Area D** where only halophytes are grown due to the highly saline soil conditions (ECe ranging from 30 and 50 dS/m and boron from 25 to 50 ppm).

A major objective of the research is to obtain relative evapotranspiration (ET) rates for several of the salt tolerant forages and halophytes included in the IFDM system. Secondarily, ion accumulation, particularly selenium (Se), and ash content is of interest due to the forage potential of some of these species. Lastly, more extensive monitoring of soil salinity (EC) and boron (B) has been initiated to track the movement of salt and boron through the system.

ET is measured using sand-containing drainage lysimeters. The halophytes under evaluation are *Salicornia bigelovii, Distichlis spicata* ("saltgrass"), and *Atriplex nummularia* irrigated with highly saline drainage water (25 – 30 dS/m and 39 ppm boron) transported from Mendota, CA. The salt tolerant forages are *Cyndon dactylon* (bermudagrass), Agropyron elongatum ("Jose Tall Wheatgrass") and *Leymus triticoides* (Creeping Wild Rye) and are irrigated with less saline drainage water from RRR (12 – 15 dS/m and 22 ppm boron). The ET rates presented are considered valid for relative comparisons amongst halophyte and salt tolerant forage species. It is likely that all ET rates are substantially increased due to bare soil patches surrounding our lysimeters where revegetation has been slow following the disturbance of lysimeter installation.

Initial forage quality and selenium data (April 00) will be presented for the forages that are now successfully established in Area C (Jose Tall Wheatgrass, Creeping Wild Rye, Alkali Sacaton, Perla grass and Puccinellia). In the first two seasons (98 and 99) they were fresh-water irrigated for the purposes of stand establishment. As of April 00, they are now irrigated only with saline drainage water from Area B. Soil salinity and boron data for areas A, B, C, and D will also be presented.

DEVELOPING A MONITORING PROGRAM FOR *HELICOVERPA ZEA* IN SWEET CORN

Janet Caprile, Farm Advisor
University of California Cooperative Extension
75 Santa Barbara Rd., 2nd Floor
Pleasant Hill, CA 94523

(925) 646-6540
jlcaprile@ucdavis.edu

Dr. Larry Godfrey, Entomology Specialist
University of California
Entomology Department
One Shields Ave.
Davis, CA 95616
(530) 752-0473
ldgodfrey@ucdavis.edu

Helicoverpa zea is a pest of sweet corn (corn earworm), tomatoes (tomato fruit worm), and cotton (cotton bollworm). Monitoring systems that have been developed for tomatoes and cotton are not sensitive enough to detect damaging levels in sweet corn. This research was initiated to develop a more sensitive monitoring program appropriate for sweet corn. Six trap designs and four pheromone lures were evaluated for their ability to detect Corn Earworm (CEW) in 1999 and 2000. Preliminary work to establish trap thresholds to correspond to damage potential was begun in 2000. Both the lure and the threshold evaluation need to continue for at least another year. The project was funded by the University of California, Center for Pest Management Research and Education (CPMRE).

TRAP EVALUATION: Five trap designs were compared in 1999: the Scentry heliothis trap, a plastic bucket or funnel trap, the Trece 1C wing trap, the Trece IIB delta style trap, the Trece IV water style trap. A sixth trap was evaluated in 2000: a clear-topped McPhail trap with the lure suspended in the funnel opening.

Methods: All traps were baited with Trece red rubber septa pheromone lures. Sets of traps were placed in random order within the first few rows along the upwind edge of 4 commercial sweet corn fields. Traps were placed 150 feet apart on adjustable poles and hung so that the lure was in the upper canopy as the corn grew. They were checked weekly or semi weekly and rotated within the field on a weekly basis. Lures were changed monthly as recommended by the manufacturer. Trapping was continuous from May to October and each set of traps was moved to a new site as fields were harvested. Nineteen fields were trapped in 1999 and 20 fields were trapped in 2000. The average weekly trap counts are presented in Figure 1.

Results: The heliothis trap (commonly used in research trials) and the bucket trap caught significantly more moths than the other three traps. Both of these traps showed similar flight initiation, peak and duration patterns. The heliothis trap is impractical for routine field monitoring due to size, cost, visibility, and collection reservoir. The bucket trap is a much more practical field tool as it is inexpensive, reusable, inconspicuous, and easy to count and identify moths. The wing, water, delta, and McPhail style traps caught too few moths to accurately identify flight patterns. The low trap catch in the wing trap was surprising as this has been the standard monitoring trap used for this pest in California.

LURE EVALUATIONS: The Trece septa is the corn earworm (CEW) lure most frequently used in California. Previous research[1] has indicated that there may be a significant difference among pheromone lures in their attractiveness to CEW and *Heliothis phloxiphaga*, the False Corn Earworm (FCEW), a frequent contaminate in CEW traps.

Methods: Bucket traps baited with four different pheromone lures were compared during the 2000 season: the Trece red rubber septa, the Hercon orange laminate, the Scentry black PVC, and the Scenturion red rubber septa. The Scenturion was a new lure designed to be less attractive to the FCEW. A set of four Bucket traps were placed in each of four commercial sweet corn fields. Each trap in the set was baited with a different lure and traps were placed 150 feet apart in random order within the first few rows along the upwind edge of the field. Traps were checked and rotated weekly and adjusted to be in the upper canopy as the corn grew. Lures were obtained at the beginning of the season, stored in the freezer until use, and aired out for 1-2 days before baiting the traps. They were changed monthly (Trece, Scentry, Scenturion) or semi-monthly (Hercon) as recommended by the manufacturer. Trapping was continuous from May to October and each set of traps was moved to a new site as fields were harvested. Twenty fields were trapped during the course of the season.

Results: Trap counts are included in Figure 2. The Trece septa caught significantly more CEW than all other lures and the Hercon laminate lures caught significantly more CEW than the Scentry PVC or Scenturion septa lures. Both the Trece and Hercon lures tracked flight patterns similarly; however, the Trece lure caught more CEW during each flight than the Hercon lure. FCEW pressure was not sufficient this season to evaluate any difference in lure attraction to this contaminate moth. As lure effectiveness may vary by lot, this trial needs to be repeated for another season to confirm results.

PRELIMINARY THRESHOLDS

Methods: Three test plots of unsprayed corn were established on the UC Davis campus and in Brentwood. Two varieties of sweet corn were planted in each field every 3-4 weeks from May through June in order that susceptible ears would be present all season. One variety was Attribute, a genetically modified super sweet corn variety containing the BT gene. The other variety was either Snow White (first planting) or Prime Plus (all subsequent plantings). Prime Plus was the precursor to Attribute before genetic modification. Bucket traps baited with Trece lures were placed in each field. Traps were checked weekly and lures changed monthly. Fifty to 100 ears were harvested from each planting at maturity and evaluated for CEW damage.

Results: Trap counts and damage at harvest are included in Figures 3A,B,and C. There was a high rate of CEW mortality in the standard varieties presumably due to cross-pollination with the BT corn. The harvest damage rating includes the total damage from worms found alive or dead or those which had completed the larval stage and left the ear. Due to the high mortality, it was not possible to calculate egg laying dates for the entire population and compare them with flight patterns to establish accurate thresholds. However, it was observed that significant damage (30-75%) occurred in the standard sweet corn with modest trap counts during silking (8-44 moths/week). Damage in the BT corn ranged from 1-13% with the same moderate trap counts. In addition, damage was much less severe in the BT variety as most worms died before reaching the

3rd instar and damage was often difficult to see without magnification. No damage occurred in either variety when traps did not catch CEW during the silking period.

1. Drapek, R. J., L.B. Coop, B.A. Croft, and G.C. Fisher. 1990. *Heliothis zea* pheromone trapping: studies of trap and lure combinations and field placement in sweet corn. Southwestern Entomologist 15: 63-69.

Figure 1: 1999 corn earworm trap catches

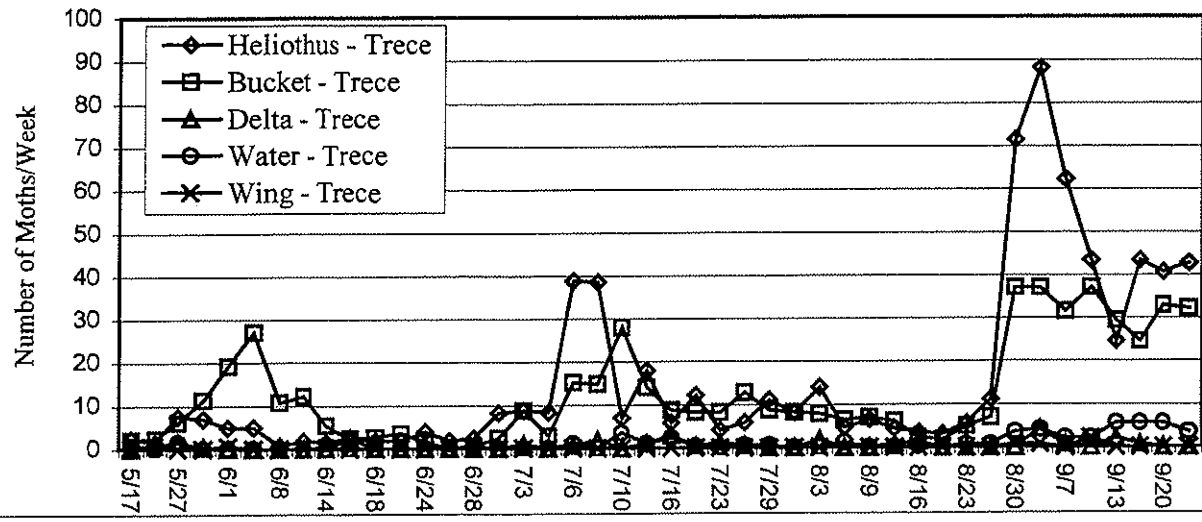


Figure 2: 2000 corn earworm trap catches

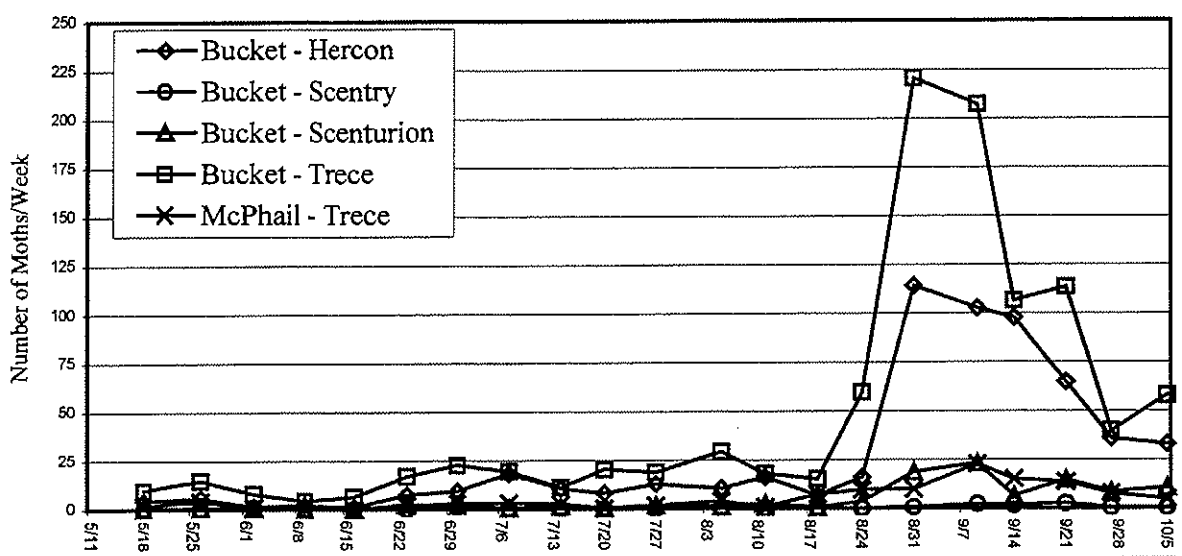
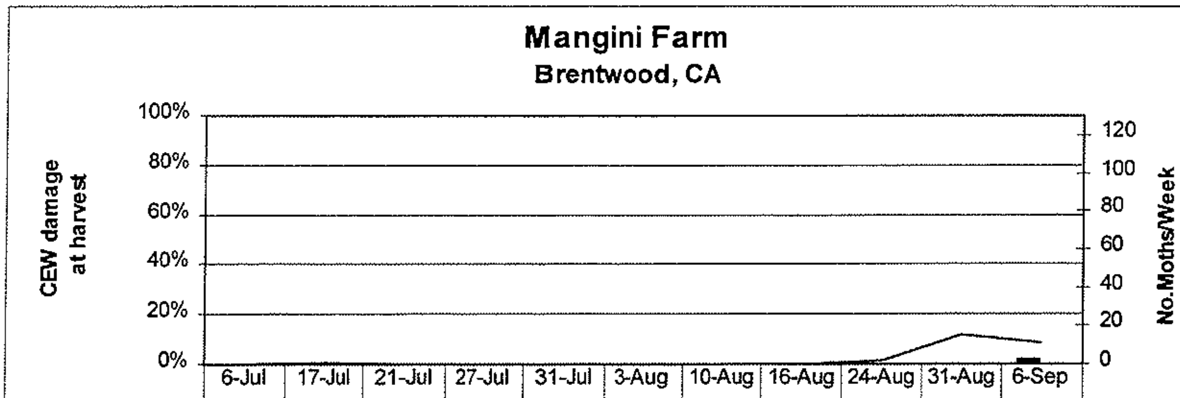
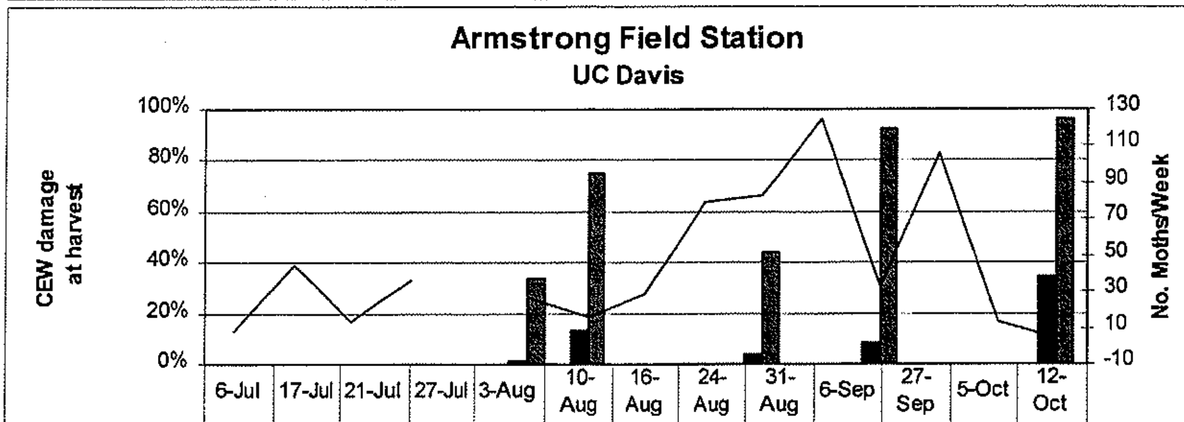


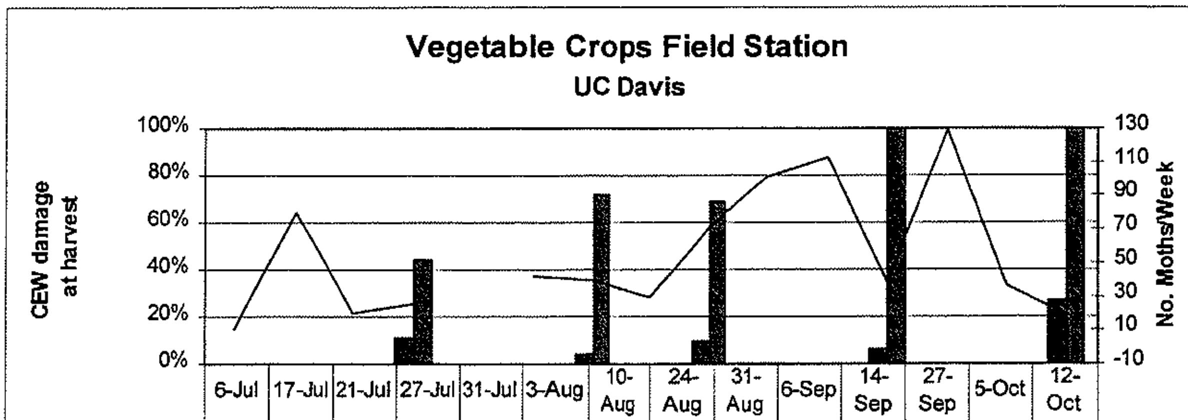
Figure 3 A,B,C: Trap counts and damage at harvest in unsprayed plots



	6-Jul	17-Jul	21-Jul	27-Jul	31-Jul	3-Aug	10-Aug	16-Aug	24-Aug	31-Aug	6-Sep
BT corn					0.000				0.000		0.020
Standard corn					0.000				0.000		
Trap Counts	0	1	0	0	0	0	0	0	2	15	11



	6-Jul	17-Jul	21-Jul	27-Jul	3-Aug	10-Aug	16-Aug	24-Aug	31-Aug	6-Sep	27-Sep	5-Oct	12-Oct
BT corn					0.014	0.132			0.038				0.346
Standard corn					0.338	0.755			0.442				0.962
Trap Counts	8	44	13	36	27	16	28	79	83	125	106	13	4



	6-Jul	17-Jul	21-Jul	27-Jul	31-Jul	3-Aug	10-Aug	24-Aug	31-Aug	6-Sep	14-Sep	27-Sep	5-Oct	12-Oct
BT corn				0.113			0.040	0.098			0.059			0.269
Standard corn				0.444			0.720	0.686			1.000			1.000
Trap Counts	10	80	20	26		42	39	71	101	113	38	129	36	19

Production function methodology describes the salinity effects on avocado yields and water use.

J.D. Oster*, D. Stottlemyer and Mary Lu Arpaia
*Emeritus Specialist and Adjunct Professor, UC Center for Water Resources
University of California, Riverside, Ca, 92521. 909.224.6785, oster@mail.ucr.edu

Abstract:

Over a 3-year period, the cumulative yield of 'Hass' avocado on seedling rootstocks increased with increasing applied water. The applied water had an average salinity of 0.75 dS/m. Three levels of irrigation, 90, 110 and 130 % of potential crop evapotranspiration, resulted in average annual yields of 65, 85 and 150 kg/tree, respectively. The soil water salinities at the 1.2 m depth were not significantly different for the three irrigation treatments and ranged from 3.7 to 4.6 dS/m. The corresponding leaching fraction averaged 0.15. In order to achieve the observed soil salinities and leaching fractions, crop water use had to increase with increasing applied water. This is consistent with predictions based on production function methodology where the threshold salinity of avocado study is about 0.2 dS/m and the yield decline with salinities greater than the threshold is about 15 %/(dS/m).

EFFECT OF COMPOSTED-BIOSOLIDS ON FRUIT QUALITY AND TRACE ELEMENT ACCUMULATION IN FIELD-GROWN APRICOTS

Pasakdee S.[1,2], Bañuelos G.S.[1], and Benes S. E.[2], Gu S.[3]

[1]USDA-ARS-Water Management Research Laboratory, 2021 South Peach Avenue, Fresno, CA 93727 Tel. (559) 453-3100, Fax. (559) 453-3122, e-mail: *sp102@csufresno.edu*
[2]California State University, Fresno, Dept. Plant Science, email: *sbenes@csufresno.edu*
[3]California State University, Fresno, Dept.Viticulture & Enology, e-mail:sanliang@csufresno.edu

The environmental and food safety concerns related to Biosolids applications to agricultural farmlands are under extensive investigation. Due to the food safety concerns, current policy is to utilize Biosolids on turf, fiber crops, or on food crops for which the edible part unit would have minimal direct contact with the Biosolids. Tree fruits, nuts, and vines would fulfill this criterion.

Research data on the use of Biosolids on stone fruits were barely available. The Central Valley of California is the main stone fruit production area in the country. Studies on Biosolids application in orchards are needed to determine their potential as an alternative nutrient source and due to their high carbon content, as a soil amendment to improve soil quality. However, concern has been raised regarding the potential for negative impacts on fruit quality due to nitrogen loading from long-term applications of Biosolids.

We studied apricot trees (Patterson variety on Marianna rootstock) that received annual applications of composted BioSolids since the orchard was initiated in 1994. The BioSolids fully replaced synthetic fertilizer applications to the trees. The control treatment (1) received no Biosolids and treatments 2, 3, and 4 received 57, 170, and 340 kg N/ha (0.9 lbs./acre), respectively. Soil samples were taken yearly before and after the fall Biosolids application. Leaf sampling was conducted in May and October. Fruit and pit tissue were harvested during summer. All soil, leaf, fruit, and pit samples were analyzed for major ions (Ca, Mg, K, S, P) and minor ions (B, Na, Mn, Zn, Cu, Fe, Al, Co, Cr, Ni, Pb) using inductive couple plasma technique (ICP) at USDA laboratory. Total N was also measured for soil and leaf samples. The soil and leaf ion data are not presented here.

Data are presented for fruits harvested in summer 1999 and 2000 with three harvest dates per season. Fruits were separated by overall color. These included: green, green-yellow, yellow, orange and dark-orange. Each group was counted and tested for quality parameters that included soluble solid content (SSC), brix, acidity, firmness and organic acid (ascorbic, citric, and malic) contents.

Marked differences in the mentioned fruit quality parameters were not detected. The BioSolids did delay fruit maturity: the control trees reached maturity earlier than did trees receiving low, medium, or high Biosolids application. These fruit quality and maturity data will be presented.

BIOSOLIDS LAND APPLICATION: CONTROVERSY IN THE SAN JOAQUIN VALLEY

Blake Sanden (UCCE Kern County), David Crohn and Andrew Chang (UC Riverside)

Ocean dumping of biosolids (sewage sludge) was banned by international treaty in 1988 due to the accumulation of heavy metals at treatment plant outfalls on the ocean bottom. CA passed the Waste Reduction Act of 1992 (AB 939) calling for reduction of landfill inputs by 25% of 1990 levels as of 1995 and 50% by the year 2000. US EPA released the final version of regulations (CFR 40 Part 503) for the land application of sewage sludge for feed and fiber crops on general farmland outside of permitted sewer farms in 1993. These three factors provided economic and regulatory incentive to begin shipping Los Angeles basin "Class B" biosolids into Kern County by the end of 1993. Initial acreage had to be permitted on a site-by-site basis in a manner similar to the permitting of sewage treatment plants. All permitting, reporting and oversight was in the hands of the CA State Regional Water Quality Control Board (SRWQCB) for that area. By 1994, about 30,000 acres were permitted from Modesto to Mojave.

The general ag community and public took little notice at this time. In fact, Los Angeles County biosolids, local cotton gintrash and greenwaste had been co-composted in Kern County and sold as "San Joaquin Compost" as a general amendment since 1989. This product met the regulatory standard for Class A/Exceptional Quality and, therefore, could be applied without restriction.

In an attempt to streamline the permitting process for Class B land application, the SRWQCB issued a "General Order" in 1995. Permitted acreage jumped to 50,000 acres with 40,000 acres in Kern County by the end of 1995 with about 1,000,000 fresh tons of biosolids imported annually. Complaints from Mojave and northern Kern County about odors, flies and misapplication compel the Board of Supervisors to begin development of a biosolids ordinance to provide for local control. Significant debate within the scientific community over pathogens, heavy metals and nitrogen mineralization, fuel the concerns voiced by growers and the public over the safety of this practice. Tulare, Madera, Merced and Stanislaus Counties pass ordinances that effectively ban the application of Class B biosolids. Kern County finally adopts a "sunset ordinance" that bans all Class B application by 1/1/03. Class A/Exceptional Quality is exempt.

All of this is decided without the benefit of any replicated field trial for the San Joaquin Valley. After 5 years of attempting to find cooperators for such trials, funding and 2 Kern County sites were finally secured in Fall 1998. These trials are to assess the agronomic benefit of the biosolids for crop production and soil reclamation, estimate effective N mineralization and nitrate residuals and track the fate of selected heavy metals. Assessing the fate of pathogens is beyond the scope of this study.

Effective field mineralization of organic N was determined by soil sampling to 9 feet in 3 fields over two years. Comparing residual nitrate after harvest in the biosolids plots to the control treatments receiving mineral N fertilizer N mineralization ranged from a high of 71% (a lightly sprinkled field yielding only 1.4 ton/ac wheat, Fig. 1) to a low of 9.2% (furrow irrigated wheat yielding 3.2 ton/ac grain and > 20" applied irrigation). Significantly greater N was lost to denitrification in the latter field with adequate water and significantly greater residual of organic N remained in the biosolids treatment after harvest. There was no significant difference in NH_4-N levels.

A one-time biosolids application showed significant measurable increases of Cd, Cu, Mn and Zn above background soil levels in the top foot in heavy alkaline soil with a decrease of 15 to 50% in all treatments after harvest.

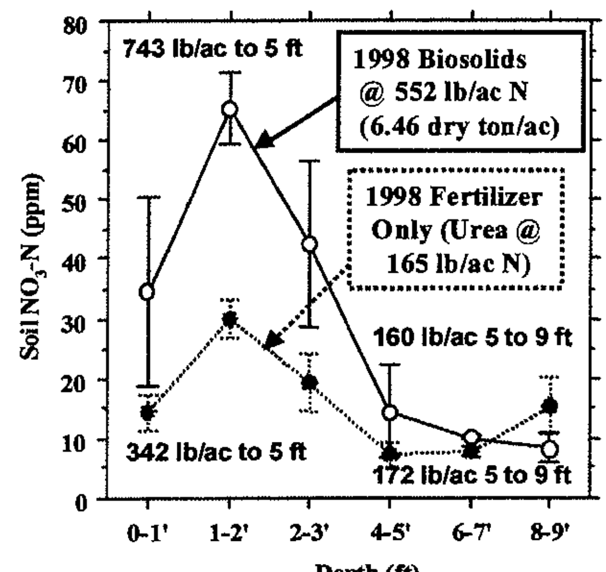


Fig. 1. Residual soil nitrate for injected biosolids slurry and N fertilizer control treatments after harvest of 1.4 t/ac wheat crop. Sprinkler irrigation. Effective mineralization 71%.

MEASURING THE FLOW RATE OF DAIRY MANURE POND WATER

Larry J. Schwankl
LAWR, UC Davis
One Shields Avenue
Davis, CA 95616
Tele: 530-752-4634 FAX: 530-752-5262
e-mail: ljschwankl@ucdavis.edu

Alison J. Eagle
UC Kearney Agricultural Center
9240 S. Riverbend
Parlier, CA 93648
Tele: 559-646-6589 FAX: 559-646-6593
e-mail: ajeagle@uckac.edu

Carol A. Frate
UC Cooperative Extension Tulare County
2500 Burrel
Visalia, CA 93291-4584
Tele: 559-733-6483 FAX:559-733-6720
e-mail: cafrate@ucdavis.edu

Ben Nydam
Dellavalle Laboratories
442 N. Douty, Suite H
Hanford, CA 93230
Tele: 559-647-5331 FAX: 559-584-0523
e-mail: bnydam@dellavallelab.com

It has been difficult to measure water from dairy manure ponds because of manure solids and debris in the water. Propeller meters, frequently used for measuring agricultural water, can become entangled with debris, quit working, and clog the pipeline. Recently, two other types of flow meters – electromagnetic and doppler– were tested at a Tulare County dairy. These meters do not obstruct the pipeline and are not affected by solids or trash in the manure water.

Two types of electromagnetic flow meters were tested. Tube magmeters are short sections of pipe that install in the pipeline via flanges. A second type of electromagnetic meter inserts into the pipeline via a two-inch hole drilled and tapped into the pipe. Both types of electromagnetic flow meters require a 110V power source, although the insertion type can be run off a battery, and a tube magmeter has been installed at a location using a 12V battery, a DC to AC inverter, and a solar panel. The tube magmeter is permanently installed while the insertion electromagnetic meter can be permanently installed or moved from site to site.

The doppler flow meter has a sensor which easily mounts to the outside of a plastic or metal pipe (it will not work on concrete pipe). Depending on the model, it can either be battery powered or run off a 110V power source. The doppler flow meter is particularly well suited if you want a portable meter to measure flow rates at multiple manure water sites.

Three tube magmeters, an insertion electromagnetic meter, and a doppler meter were compared to a previously tested and calibrated propeller meter. All meters did a very good job of measuring manure water flow rates. Any of the tube magmeters would work well as permanent installations on a manure water pipeline. They provide both an easily-read instantaneous flow rate (e.g. gallons/minute) and a totalized flow measurement (e.g. gallons). The insertion electromagnetic flow meter would also work well but requires some fairly complicated on-site calibration. The doppler meter would be a good choice if moving the flow meter easily and quickly from site to site. All of the tested meters cost approximately $3,000 to $4,000, with the magmeters varying in price depending on the pipeline size.

For all flow meters, the pipeline needs to be flowing full and there should be straight sections of pipe upstream and downstream of the meter. There should be 8 to 10 pipe diameters (for an 8" pipe, this would be 64" to 80") of straight pipe upstream of the meter, and 4 to 6 pipe diameters (for an 8" pipe, this would be 32" to 48") of straight pipe downstream of the meter. Flow meter installations immediately downstream of a pump or of a partially closed valve should be avoided if possible. If the flow meter must be installed in such a location, greater lengths of straight pipe upstream of the meter will be required to ensure accurate measurement.