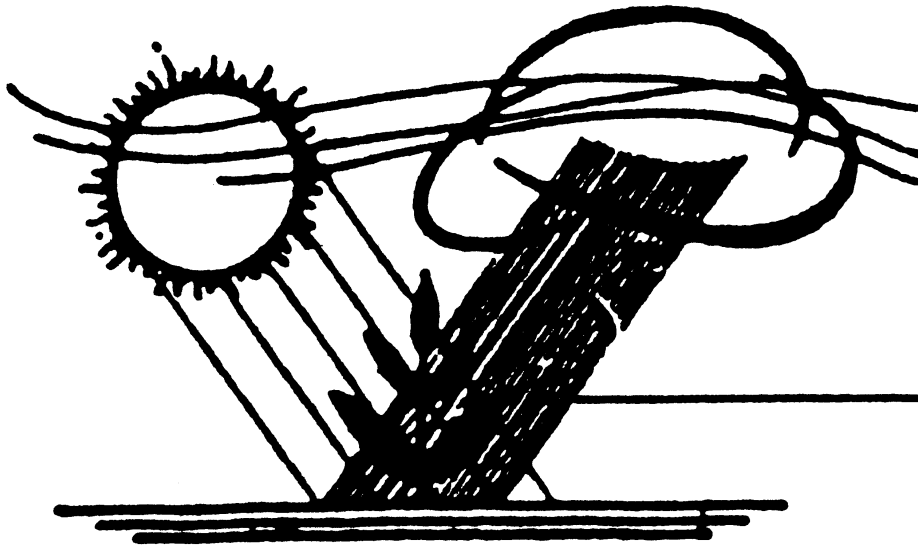


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**ENERGY AND AGRICULTURE:
NOW AND THE FUTURE**



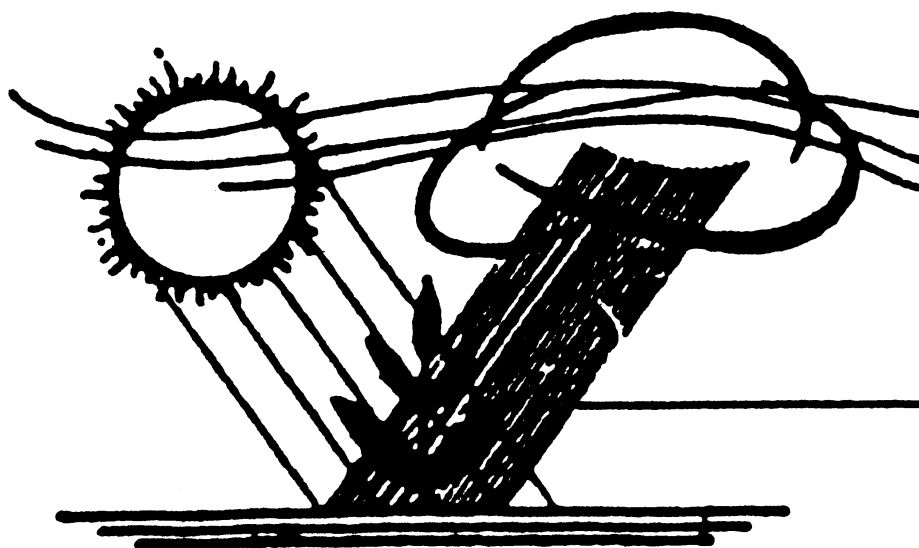
**CALIFORNIA CHAPTER OF AMERICAN SOCIETY OF AGRONOMY
AND
CALIFORNIA PLANT HEALTH ASSOCIATION**

FEBRUARY 5 & 6, 2002

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	Robert D. Whiting		James R. Rhoades
	Eduardo Apodoca		Carl Spiva
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	Richard M. Thorup		Vince Petrucci
			Ken Tanji

**2002 Honorees
California Chapter of the
American Society of Agronomy**

Emanuel Epstein

Vince Petrucci

Ken Tanji

Emanuel Epstein



Professor Epstein was born in Germany. Emanuel began his undergraduate studies at the University of California, Berkeley, in 1938. In his words he wanted to become an agricultural plant scientist, but in those days the Davis campus did not offer the necessary preparation in chemistry, physics, mathematics, or even biology. You first went to Berkeley for that and more, and only after that foundation had been laid did you go to Davis for more specialized agricultural subjects. He received his Master's degree from the Davis campus in 1941. He then returned to Berkeley to study for a Ph.D. but his studies were interrupted by service in the U.S. Army. In 1946 the war was over, Emanuel joined the Division of Plant Nutrition at UC Berkeley to resume his work on a Ph.D. in plant physiology, which he completed in 1950. His Ph.D. research earned him a reputation in an emerging field of determining plant mineral nutrition through the use of radioisotopes. His research dealt with the absorption and translocation of micronutrients by tomato plants. Upon attaining his Ph.D. degree he worked for the U. S. Department of Agriculture, Beltsville, MD as a Plant Physiologist until 1958. He returned from the east and joined the faculty at the University of California Davis. He continued to refine his work on the kinetics of ion transport from soil to roots and into the plant. He became especially interested in the role of calcium in its influence on the selectivity for potassium and sodium. His work led to a mechanistic understanding of how plants cope with salt tolerance, especially the role of calcium regulating the intrusion of sodium into leaves. Emanuel advanced his research by examining the genetic dimension to plant nutrient uptake.

Emanuel Epstein's contribution to the area of plant nutrition has been immense. He has published over 140 peer-reviewed articles in the scientific literature. He has mentored many graduate students and taught many undergraduates the science of plant nutrition. Many of his students are found across the globe continuing in the tradition of research he so proudly pursues. His achievements are nationally and internationally recognized. He is a member of the National Academy of Science, a prestigious distinction bestowed on a select group of scientists. He is a Fellow of the American Association for the Advancement of Science and is a member of numerous national and international societies. Emanuel's contribution to California agriculture forms the basis of our understanding of plant nutrition and salt tolerance in the most productive agricultural region of the world.

In Emanuel's words "It has been, and still is, a fascinating journey. Being a professor and research scientist is, to me, the most important, the most challenging, the most rewarding job a person can have. An extravagant claim? I think not. In all society there are just two growing points: the new, young people who are our students and the new knowledge gained through research. And it is these two sole sources of renewal and growth that a professor in a research university deals with: you readers—our young, new people—and the new knowledge that we generate through research. Nothing is more crucial to the advancement of society, and no occupation more satisfying than that dealing with these two wellsprings of society's future."

Dr. Vincent E. Petrucci

Vincent E. Petrucci, a native of California, completed his studies at UC Davis, where he earned his B.S. degree in pomology and a M.S. degree in horticulture. California State University, Fresno honored Dr. Petrucci with an honorary degree of Doctor of Science on May 28, 1994. In 1949, he began a 45-year tenure at Fresno State as professor of viticulture. His major activity has been to develop the viticulture and enology programs at Fresno State, including the curriculum and facilities. In 1985, the Viticulture and Enology Research Center (VERC), became an official entity with Professor Vincent E. Petrucci as Director. Since his retirement, he serves as Director Emeritus of VERC.

Dr. Petrucci has been invited to over thirty-four different grape-growing countries around the world which have sought his consulting advice. These countries include the Soviet Union and the People's Republic of China. Dr. Petrucci has participated in the O.I.V (International Office of the Vine and Wine), whose headquarters are in Paris, France. He has served as Vice President of the International Group of Experts on Raisins and Table Grapes for this organization. Dr. Petrucci's involvement in this area has resulted in international recognition to the viticulture program and the School of Agricultural Sciences and Technology at California State University, Fresno.

His many awards include the California State University, Fresno Outstanding Professor Award, the Nicolas Salgo Outstanding Teacher Award, the 1981 Wines and Vines Man of the Year Award, the 1990 California Restaurant Association Lifetime Achievement Award, and the Distinguished Achievement Award of UC Davis.

Dr. Petrucci's favorite vocation is his relationship to his family. He is married, has five children, and sixteen grandchildren.

Kenneth K. Tanji

Ken Tanji was born in Honolulu and raised on a farm in Keokea, Maui. He obtained a B.A. in Chemistry from the University of Hawaii, B.S. and M.S. in Soil Science from the University of California, Davis, and a D.Sc. in Agriculture from Kyoto University, Japan. Ken's career of more than four decades has been with the University of California starting as a laboratory technician in 1958 in the former Department of Irrigation, lecturer in 1972 in the former Department of Water Science and Engineering, and professor in 1977 in the Department of Land, Air and Water Resources (LAWR), including twelve years in administration.

Ken is an internationally recognized soil and water chemist in water quality aspects of irrigation and drainage. Ken was a pioneer in the early 1960s for computer modeling of ion association, solubility of gypsum and calcite, multi-component cation exchange and salt transport. He was the senior author of the 1967 papers in *Hilgardia* presenting details of computing chemical reactions in salt-affected soils as well as quality of percolating waters through 100 meters of substrata at several sites in the San Joaquin Valley from near Dos Palos to Lost Hills. Ken's 1972 paper on reclamation of salt-affected soils in western Kern County was selected as a Benchmark Paper in Soil Chemistry as well as Benchmark Paper in Chemistry of Irrigated Soils by the International Society of Soil Science.

Ken was promoted to Lecturer in 1972 to teach a new graduate course in Hydrochemical Models and a new undergraduate course on Chemistry of the Hydrosphere. These were unique courses at UC Davis and attracted students from many disciplines across three colleges at UC Davis. The graduate level course was taught continuously to 1997 and the undergraduate course to 2001. Also during this period, Ken and his associates demonstrated in 1974 that rice herbicides can be degraded by holding flood waters for several weeks after herbicide applications in paddy rice that later became a regulation in the 1980s. With graduate student Sumant Gupta, Ken co-authored a paper on three dimensional finite element modeling of water and salt flows in Sutter Basin, one of the first finite element models applied to a multi-aquifer system in the field. Ken led a team consisting of graduate student Gupta and postdoc Mohsen Mehran in the mid 1970s formulating and validating nitrogen transformation and transport models in cornfields to quantify nitrate leaching losses.

Ken was promoted to full professor in 1977. By 1980 he was appointed vice chair and then chair of LAWR in 1981 which at that time consisted of 54 professors, lecturers and cooperative extension specialists. His principal accomplishments as chair included campus administration's approval of a forward-looking ten-year academic plan reserving 12 faculty positions for expected retirements. Ken also led a team of five chairs across three colleges in 1983 to propose a center of excellence in water resources and hydrology at UC Davis. This proposal resulted in new faculty positions in hydrogeology and aqueous geochemistry in LAWR, expansion of departmental computer facilities in Civil Engineering and later a new graduate program in hydrologic science.

In mid 1984, Ken was appointed as director designate of the Kearney Foundation of Soil Science with a five-year mission on water penetration problems in irrigated lands. He insisted on a good balance between fundamental research and practical field studies with laboratory researchers utilizing the same soil types as field researchers. He also was the first director to encourage extension specialists and farm advisors to participate as Co-PIs in the projects. Vice President James Kendrick in 1985 appointed Ken as Assistant Director in the Agricultural Experiment Station overseeing soil and water research. Prior to the public becoming aware of the selenium poisoning of waterbirds at Kesterson Reservoir in September 1985, Ken secured line budget funding for the UC Salinity Drainage Program from the state. This UC program provided technical services to the joint state-federal San Joaquin Valley Drainage Program and filled gaps in research knowledge. The annual research conferences of the UC Salinity Drainage Program were heavily attended. Ken served as the director of the UC Salinity Drainage Program from 1985 to 1992 which is still active under the direction of John Letey. Taking advantage of USDA-Extension Service program on water quality

in the 1980s, Ken helped secure funding for cooperative extension on rice pesticides in the Sacramento Valley, irrigation, salinity and drainage in the San Joaquin Valley, and coastal zone water quality in San Luis Obispo County.

In 1992, Ken returned back to LAWR as a full time faculty member. While in 12 years of administration, Ken continued to teach and conduct research. He served as principal investigator on agricultural evaporation ponds from 1985 through 1995 with Blaine Hanson and later Mark Grismer. Ken's graduate students Gregory Smith, Mitchell Herbel and Colin Ong studied salinity, trace element chemistry including selenium, boron, arsenic and molybdenum, and evaporite mineral formation. Ken oftentimes served as an interface between pond operators and regulatory agencies. He also served as principal investigator on reuse of saline drainage waters in agroforestry from 1987 through 1994 in collaboration with Vashek Cervinka of CDFA and Steve Grattan of UC Extension. A 1993 paper on drainwater reuse on eucalyptus trees with graduate student Fawzi Karajeh won the best paper award in the Journal of Irrigation and Drainage Engineering. In another collaborative project with Douglas Davis of Tulare Lake Drainage District and Norman Terry of UC Berkeley, Ken, Suduan Gao and Douglas Peters of UC Davis investigated the efficacy of constructed flow-through wetlands for the removal of selenium from drainage waters prior to impoundment on evaporation basins. The work on mass balance of selenium in wetlands is a major accomplishment based on intensive water and selenium monitoring from 1996 to 2001.

Ken has participated in a number of professional societies in elective and appointed capacities. He was the chair of the Division of Soil Chemistry in 1979 for the Soil Science Society of America (SSSA), Associate Editor for the SSSA Journal from 1984 to 1987, and chair of the Budget and Finance Committee in 1993-94 for the trisocieties: Agronomy, Soil Science and Crop Science. Ken served as chair of the Water Quality Technical Committee of Irrigation and Drainage Division of American Society of Civil Engineers (ASCE) in 1986-88 and chaired four task committees, including the one that produced ASCE Manual 71, an internationally acclaimed monograph on Agricultural Salinity Assessment and Management. He was the co-organizer of Engineering Foundation Conferences on Desert Technology held in Kona, Hawaii, in 1993 and Mount Fujii, Japan, in 1995. Ken served on the Board of Directors of the 131-member Universities Council of Water Resources in 1993-95. He also has served on three committees of the National Research Council, appointed by the National Academy of Science or the National Academy of Engineers, addressing soil and water quality (1990-93), planning and remediation for selenium in western USA (1990-95), and assessment of our nation's water quality (1999-2001). He currently serves on the Research Advisory Board of the National Water Research Institute.

Ken's publication record includes five books, 29 book chapters, and 209 journal and conference/symposium papers. He is a Fellow of the American Institute of Chemist (1976), Soil Science Society of America (1982) and Agronomy Society of America (1982). He received the Outstanding Service Award in 1990 from ASCE's Irrigation and Drainage Division and the Royce J. Tipton Award in 1993 from ASCE. UC Davis honored him with the Award of Distinction in 1990 and Distinguished Public Service Award in 1995. The California Irrigation Institute also honored Ken as Person of the Year in 1997. Ken is probably the only lab tech with a masters degree in the University of California system to become Professor, Step VIII, the highest rank at that time. He obtained his doctorate degree one year before his retirement in July 1998. During retirement, Ken continues to offer Chemistry of the Hydrosphere, participates in research projects and preparation of journal manuscripts, presents papers before conferences and symposia, participates in several committees of professional societies, and provides technical services to governmental agencies here and abroad.

Professor Emeritus Tanji is being nominated as an Honoree of the California Chapter of ASA. Besides compiling an exemplary record in academia, he has contributed heavily towards sustaining California Agriculture especially in water quality aspects of irrigation and drainage.

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**CALIFORNIA CHAPTER
AMERICAN SOCIETY OF AGRONOMY
2002 PLANT AND SOIL CONFERENCE CEUS**

Certified Crop Advisor -- Continuing Education Units/Hours

Session Name	When	Nutrition Mgt.	Soil & Water Mgt.	Pest Mgt.	Crop Mgt.
Irrigation & Energy Issues	Tue pm		2.0		
Pest Management Innovations	Tue pm			2.5	
Water Quality, Ag & TMDLs	Wed am		2.0		
Advances in Nutrient Mgt.	Wed am	2.0			
New Regulatory Framework for Groundwater Protection	Wed pm			1.5	
New Technologies for Crop & Soil Mgt.	Wed pm				1.5
Totals		2.0	4.0	4.0	1.5

Pest Control Advisor -- Continuing Education Units/Hours*

Session Name	When	Laws & Regulations	Other
Irrigation & Energy Issues	Tue pm		
Pest Management Innovations	Tue pm		
Water Quality, Ag & TMDLs	Wed am		
Advances in Nutrient Mgt.	Wed am		
New Regulatory Framework for Groundwater Protection	Wed pm		
New Technologies for Crop & Soil Mgt.	Wed pm		
Totals		2.0	4.0

***PCA units applied for; final units will be posted at the conference.**

Prepared By: Walt Bunter & Ron Brase Updated: Jan 14, 2002

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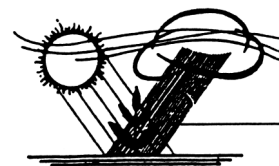
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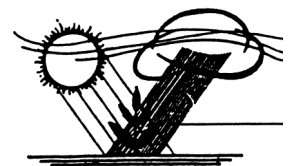
APPENDIX

Constitution and By-Laws of the California Chapter of the American Society of Agronomy

**2002 CALIFORNIA
PLANT & SOIL CONFERENCE
SESSION PAPERS**



**IRRIGATION
AND
ENERGY ISSUES**



Does Improving Pumping Plant Efficiency Really Save Energy?

Blaine R. Hanson

Irrigation and Drainage Specialist

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During a meeting many years ago, the question, “Does improving pumping plant efficiency save energy?” resulted in an interesting response. Most of the growers attending the meeting indicated that it did not, while most of the utility employees at the meeting indicated that it did. Prior to this meeting, the utility company had spent much money subsidizing pumping plant improvements of irrigation pumping plants. Results of that effort improved the pumping plants’ efficiency substantially.

Last winter/spring’s energy crisis has resulted in a state-funded program for pump testing and improving pumping plant efficiency. The objective of the program is to reduce energy use in California. Yet, based on the grower response at the above-mentioned meeting, a potential exists for little energy to be saved as a result of the program unless the reasons for the different responses are understood.

What is Energy?

Users of electricity pay energy costs based on kilowatt-hours (kWh) consumed in addition to fixed charges. kWh consists of two components, kilowatts (kW) and hours. kW is the energy demand of the electric motor and is synonymous with horsepower. One kW equals 1.34 horsepower. The hours is the operating time of the motor. If electrical energy use is to be reduced, kWh must decrease as a result of any measure promoted as energy saving. This means that kW or horsepower and/or operating time must be reduced. Regardless of the claims about a proposed energy-saving measure, if kW or operating time is not reduced, no energy savings will occur.

Energy costs can be reduced by either reducing kWh or reducing the unit cost of energy. The latter can be accomplished by converting from a conventional energy rate to a time-of-use program or converting to a different energy source such as diesel, propane, and natural gas.

Improving Efficiency

Options for improving pumping plant efficiency include:

- ◆ Adjusting impellers.
- ◆ Repairing worn pumps.
- ◆ Replacing mismatched pumps.
- ◆ Converting to energy efficient electric motors.

Impeller Adjustment

The clearance between the bottom of the vanes of a semiopen impeller and the bowl housing is critical for efficient pump performance. Sand wear can increase the clearance and cause poor pumping plant efficiency. The efficiency can be partially restored by adjusting the impellers. This involves slightly lowering the pump shaft and thus the impellers by turning the nut at the top of the shaft. This adjustment will not work for enclosed impellers.

The data in Table 1 illustrate the effect of an impeller adjustment. The adjustment increased both pump capacity and overall efficiency considerably. Total head was increased slightly because the total head consisted of pumping lift only. However, for all four pumps, the impeller adjustment increased the input horsepower. This means that if the operating time before and after the adjustment is the same, energy use will increase because of the increased kW or horsepower demand. Reducing energy use will only occur if the operating time is decreased. The operating time can be reduced, yet the same amount of water pumped because of the increased pump capacity. This increased capacity will result in a smaller kWh per acre-foot of pump water.

Table 1. Effect of impeller adjustment on pumping plant performance.

		Capacity (gpm)	Total Head (feet)	Overall Efficiency (%)	Input Horsepower
Pump 1	Before	605	148	54	42
	After	910	152	71	49
Pump 2	Before	708	181	59	55
	After	789	206	63	65
Pump 3	Before	432	302	54	61
	After	539	323	65	67
Pump 4	Before	616	488	57	133
	After	796	489	68	144

Repairing Worn Pumps

Sand is the culprit most responsible for pump wear. Sand wear increases clearances between wearing rings, vanes, and bowl housing and erodes impellers. Restoring the performance of a worn pump requires removing it from the well and repairing or replacing worn parts.

The data in Table 2 illustrate the possible effect of repairing a worn pump. After the repair, capacity, total head, and overall efficiency increased considerably compared to pump performance before the repair. However, IPH increased from 83 to 89. This behavior appears to be typical of repaired pumps. A summary of 63 data sets of pump performance before and after pump repair showed average increases of 39%, 0.5%, 33%, and 8% in pump capacity, total head, overall efficiency, and input horsepower, respectively. The small increase in total head is because these pumps were used for furrow irrigation, and thus discharge pressures were negligible. For these pump test data, using the same operating time before and after the pump repair will increase energy used by 8% on the average. However, if the same volume of water is pumped before and after the repair, resulting in reduced

operating times after repair, the average energy use decreases by 23%. This illustrates the need to reduce operating times to realize any energy savings from repair

Table 2. Effect of pump repair on pumping plant performance.

	Before	After
Pumping Lift (feet)	95	118
Capacity (gpm)	1552	2008
Input Horsepower	83	89
Overall Efficiency (%)	45	67

Replacing Mismatched Pumps

A characteristic of deep well turbine and centrifugal (booster) pumps is that as pump capacity increases from 0 to maximum, pump efficiency increases to a maximum and then decreases. Thus, a pump that initially was efficient can become inefficient because of changes in operating conditions such as changing ground water levels or changes to pressurized irrigation systems. A pump that is operating properly but not near the point of maximum efficiency is said to be mismatched to the operating conditions. Second-hand pumps are candidates for being mismatched. Restoring pumping plant efficiency requires replacing the mismatched pump with one that provides the desired output of total head and capacity near its maximum efficiency. The effect of this change is to reduce the kW demand of the pump, and thus energy savings will occur even though operating time before and after the replacement remains unchanged.

Energy Efficient Electric Motors

Energy efficient electric motors have higher motor efficiencies compared to standard motors. These higher efficiencies mean that less input horsepower is needed for the same rated shaft horsepower. Buying an energy efficient motor for a new irrigation pumping plant is economical with payback periods of several years. Retrofitting an existing pumping plant with an energy efficient motor will be less economical with payback periods of many years. For example, an energy efficient 100 HP (motor efficiency = 96%) motor can cost \$1,000 more compared to the \$5,000 cost of a standard motor (motor efficiency = 92%). IPH of the energy efficient motor will be 104 compared to 109 of the standard motor. Operating the pump for 2,000 hours per year will save \$746 per year at an energy cost of \$0.1/kwhr. The simple payback period is 1.3 years. However, the payback period for retrofitting is eight years.

Conclusions

Simply improving pumping plant efficiency may or may not save energy, as the examples herein illustrate. Adjusting or repairing worn pumps can increase the horsepower demand and thus, increase energy use if the pump operating times are the same before and after repair. Replacing mismatched pumps can save energy due to a smaller horsepower demand. An evaluation of the pump test data is needed to determine potential causes of low efficiency.

Flow Meter Use in Agriculture

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INTRODUCTION

Flow measurement is a critical component of good irrigation water management. It is critical that irrigation water be quantified since it is impossible to properly manage irrigation water unless the amount of applied water is not known.

Measurement of water in open channels, such as ditches and canals, is difficult. Weirs and flumes are available and when installed under good flow conditions, they can be relatively accurate. Weirs and flumes are difficult to use in many agricultural situations though since: (1) ditches are sometimes created and then closed between irrigations, (2) it is problematic to anchor and seal a weir or flume into a temporary channel, and (3) the backwater created by a flume, and especially a weir, may affect the upstream infiltration conditions.

Measuring the flow rate in pipelines is much easier and is usually more accurate. Numerous types of flow meters are available for measuring pipeline flow rate and the choice of which one to use should be based on: (1) meter accuracy, (2) water quality conditions, (3) permanent vs. portable installation needs, and (4) cost.

In agricultural applications, the first step in selecting a flow meter should be an evaluation of the water quality. Is there debris, weeds, etc. in the water? If there is, this material must be removed from the water or the choice of flow meter type is limited. An example of this, flow measurement of dairy manure water, will be discussed in detail later.

CLEAN WATER FLOW MEASUREMENT

If the irrigation water contains minimal foreign matter the user must decide if the meter is to be permanently installed or should be portable, how accurate measurements should be, and how much he is willing to spend. Flow measurement of groundwater is a good example of clean water flow measurement.

Permanent Flow Meter Installations

Permanent flow meter installations in which the flow meter remains at a site, often for many seasons, and totalizes the flow passing through the pipeline are the most common and extremely useful. When accuracy and cost are factored in, propeller meters and paddle-wheel meters are the most commonly selected flow meters. A propeller meter has a propeller which occupies nearly the entire crosssectional area of the pipeline. The speed with which the propeller turns is a function of the pipeline flow velocity. Flow velocity, combined with the crosssectional area of pipeline, allows calculation of the flow rate in the pipeline.

Flow velocities will vary across the pipe unless flow conditions are ideal. Since the propeller of a propeller meter occupies nearly the entire area of the pipeline, it integrates the varying velocities. Paddle-wheel meters have a small rotor which monitors a smaller portion of the flow crosssection so their accuracies are more sensitive to less than ideal flow conditions.

Portable Flow Meters

Portable flow meters can be relatively easily moved from site to site. They do not provide the continuous monitoring which can be very valuable to irrigation water management. Portable flow meters are frequently used by consultants, researchers, and irrigation district personnel who need to monitor flow rate at numerous locations.

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Portable flow meters include Collins tube meters, Hall tube meters, doppler meters, and transit time meters, portable electromagnetic flow meters, and some paddle-wheel meters. All of these meters monitor flow velocity. The doppler and transit-time meters strap on to the side of the pipeline, but the other portable meters listed above require an access hole(s) in the pipeline. Doppler meters require some (75 ppm or more) particulates or air bubbles in the water to read accurately, so they cannot be used on very pure water. Transit time meters work well on clean water, but not on dirty water.

FLOW CONDITION IMPACT ON FLOW METER ACCURACY

Most flow meters are impacted adversely by less than ideal flow conditions. Ideal flow conditions consist of a uniform flow velocity profile across the pipeline. Also critical to measurement accuracy is that the pipeline be flowing full. To ensure that flow conditions are good, the rule-of-thumb for meter installation is that there be 8-10 pipe diameters of straight pipe upstream of the meter and 3-5 pipe diameters of straight pipe downstream of the meter. The meter should also not be installed downstream of a partially-open valve or other condition which might cause a jetting action of water flow.

Unfortunately, many agricultural flow meters are installed in less than ideal flow conditions. This is often due to a flow meter being retrofitted into an existing pipeline system. The impact of various flow conditions on meter accuracy was tested under hydraulic laboratory conditions. The hydraulics laboratory was equipped with a tank of known dimensions so the volume entering could be accurately measured. This provided the standard against which the accuracy of the meters could be compared.

The flow meters investigated were a propeller meter, a paddle-wheel meter, a Collins Tube meter, a Hall Tube meter, and a doppler meter. These flow meters were subjected to various flow conditions including placement at various distances downstream of a check valve, downstream of a 90-degree elbow, downstream of a downstream of a partially-closed butterfly valve, and downstream of a combination 90-degree elbow and a partially-closed butterfly valve. Measurements were gathered across a range of flow rates.

Flow meter accuracy was measured under a control condition in which meters were installed with 9 pipe diameters of straight pipe upstream of the meter. The velocity distribution across the pipe was measured using a pitot tube and found to be very uniform. Table 1 summarizes flow meter performance under the control conditions.

Table 1. Flowmeter errors under control conditions.

<u>Flowmeter</u>	<u>Average Error (%)</u>
Propeller	1.6
Paddle-wheel	1.2
Doppler	-9.3
Hall Tube	-0.9
Collins Tube	0.5

Except for the doppler meter, all the meters were within 2% accuracy under the control flow conditions and the Doppler meter was within 10% accuracy.

Check Valve

Many pumping plant stations are equipped with a check valve to prevent backflow to the water source. These check valves frequently consist of a spring-loaded flap valve which swings open under normal conditions but will swing shut under backflow conditions.

The flow meters were tested for accuracy with a check valve placed upstream of each of the meters (Table 2). Comparing Table 1 to Table 2, it is evident that the placement of a check valve upstream of any of the meters did not seriously impact meter accuracy.

Table 2. Flowmeter performance with a check valve upstream.

Pipe Diameters	Propeller		Paddle-wheel		Doppler		Collins		Hall	
	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %
2	470	-1.1	464	3.7	464	20.3	470	-12.6	478	0.8
5			485	-13.4	467	-5.4	467	-2.6	468	2.9
10			470	-4.3	470	-6.6	486	-4.5	479	1.5
2	734	3.8	762	-28.4	763	-6.0	738	5.8	766	1.2
5			757	-7.6	797	-11.1	771	-3.4	779	-2.9
10			738	-2.6	739	-10.3	761	-3.3	776	2.6
2	969	0.9	980	-25.6	980	-11.6	969	4.7	997	-2.9
5			976	-6.9	977	-14.6	981	-1.3	961	3.2
10			969	-3.1	969	-14.4	956	0.6	984	-3.2
2	1224	2	1244	-28.5	1244	-17.4	1155	8.2	1197	1
5			1183	-4.6	1183	-15.4	1165	3.4	1219	2.8
10			1155	1	1180	-15.3	1179	1.3	1185	3.6

90 Degree Elbow

A 90 degree elbow was placed into the flow meter test section and each of the meters were evaluated (Table 3). It is evident when comparing Table 3 to the control conditions (Table 1) that a 90-degree elbow did not seriously impact flow meter accuracy of any of the meters.

Table 3. . Flowmeter performance with a 90 degree elbow upstream

Pipe Diameters	Propeller		Paddle-wheel		Doppler		Collins		Hall	
	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %
2	462	3.5	462	-2.6	462	-6.3	473	3.8	467	-4.9
5	467	1.7	470	-4.2	470	-9.9	457	0.8	478	0.6
10	462	3.9	478	-3.8	478	-17.6	470	-1.3	470	-2.6
2	721	1.2	729	-2.6	729	-9.7	729	2.7	729	0.4
5	723	0.7	739	-5.4	739	-13.2	731	-3.4	745	-4.6
10	692	6.3	745	-0.6	745	-15.6	705	2.7	739	-5.1
2	898	0.6	922	1.0	922	-12.6	961	-1.7	1003	-7.3
5	908	0.7	924	-4.8	924	-14.5	916	-2.6	922	-1.8
10	916	0.2	922	-3.4	922	-15.2	961	-0.5	924	-2.2

Butterfly Valve

A butterfly valve, partially-closed, was installed in the flow meter test section upstream of each of the flow meters, and the impact on flow meter accuracy was determined (Table 4). It is common to see a butterfly valve, used for flow control, in pumping plant installations and that butterfly valve is often installed upstream of the flow meter.

Examining the results of Tables 4 and 2, it is evident that the jetting action caused by a partially-closed butterfly valve can adversely impact flow meter accuracy. This is especially true if the meter is installed close to the butterfly valve.

Table 4. Flowmeter performance with a butterfly valve upstream

Pipe Diameters	Propeller		Paddle-wheel		Doppler		Collins		Hall	
	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %
2	393	14.2								
5	395	8.6								
10	392	7.9								
2	677	15.1	541	29.4	557	22.7	558	4.2	554	0.5
5	682	8.1	549	-3.5	549	4.7	540	1.1	542	-1.3
10	684	7.4	539	2.8	544	-0.7	545	0.7	553	-1.6
2	1289	2.4	987	33.6	977	0.1	976	8	987	-11.2
5	1273	2.8	969	3.1	977	-1.5	976	-0.6	969	-3.1
10	1284	2.8	985	-4.7	1000	-13.6	1000	0.1	985	-3.8

90-degree Elbow and Butterfly Valve

The flow meters were each tested with both a 90-degree elbow and a butterfly valve installed upstream (Table 5). Examining Tables 5 and 2, it is evident that a 90-degree elbow and butterfly valve upstream of any of the flow meters adversely impacted their performance.

Table 5. Flowmeter performance with a 90 degree elbow and a butterfly valve upstream

Pipe Diameters	Propeller		Paddle-wheel		Doppler		Collins		Hall	
	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %	Flow rate gpm	Error %
2	368	28	434	84.3	433	98.4	393	17.5	412	-37.9
5	383	28.9	432	-20.2	433	25.9	366	12.3	396	14.6
10	419	21.9	366	14.8	367	3.8	432	-0.9	440	-18.4
2	875	11.6	929	30.1	929	24.3	832	13.6	877	-11.8
5	840	16.3	902	1.9	903	4.9	895	-1.7	937	-7.5
10	899	637	895	-4.0	895	-11.0	905	-0.1	931	-1.5
2	1156	0.2								
5	1189	-1.7								
10	1190	-0.4								

“DIRTY” WATER FLOW MEASUREMENT

Flow measurement of irrigation water containing weeds, twine, or other debris offers a particular challenge. If the flow meter occupies any of the flow crosssection, debris will entangle the meter and seriously impact the meter accuracy. Only two flow meter types are well suited to debris-laden water - doppler meters and electromagnetic meters. Doppler meters are more commonly used as portable meters but they can be installed as permanent meters. Electromagnetic meters, commonly referred to as mag meters, are most frequently permanently installed but there is a portable mag meter also available. Electromagnetic flow meters are very accurate but they are also expensive which is why they are seldom used in agricultural clean-water applications. Doppler meters are less expensive but are not as accurate.

Dairy Manure Pond Flow Measurement

Many of the dairies in California's Central Valley use a water flush system to clean the freestall housing systems. This manure flush water is collected in ponds and later mixed with freshwater and applied to cropland as irrigation water. The manure water is rich in nutrients and being able to accurately measure manure water flow rate is both an important water management and a nutrient management issue.

Measuring the flow rate of pond water has been difficult because the solids and debris in the water will collect on and clog many flow meters. The propeller meter, widely used for measuring flow rates in agriculture, is very susceptible to weeds and twine entangling the propeller. Flow meters that have no flow obstructions – electromagnetic flow meters and doppler flow meters – were evaluated at a dairy in the southern San Joaquin Valley to determine how well they would work for measuring dairy manure pond water.

Meter Descriptions

A doppler meter has a sensor that attaches to the outside of a PVC or metal pipe. The meter transmits an acoustic signal of known frequency and then measures the signal reflected back from particles in the water. The velocity of the water flowing in the pipe influences the frequency of the reflected signal.

The electromagnetic meters are either: (1) a short section of unobstructed pipe that is permanently installed in the pipeline via flanges (tube magmeters) or, (2) a rod inserted into the pipe through a hole and threaded fitting (insertable electromagnetic meter). The tube magmeters have electromagnets built into the short section of pipe while the insertable magmeter has the electromagnet located on the tip of the rod. The magnets induce an electromagnetic field in the water passing through or by the flow meter and the water movement changes the voltage of the electromagnetic field. The voltage change is measured by the magmeter and the flow velocity is determined (Faraday's Law). The flow rate can then be determined from the flow velocity and the pipe inside diameter.

Test Description

Three tube magmeters from different manufacturers were installed in series in an 8-inch PVC pipe through which dairy pond water was pumped on its way to the irrigation system. The magmeters were installed far enough apart that they did not interfere with each other. Also installed during the tests were an 8-inch, saddle-mounted, propeller meter that had been carefully calibrated in a hydraulics lab, and an "insertable" electromagnetic flow meter that was installed in the pipe through a saddle with a 2-inch opening which had been mounted to the pipe. The propeller meter, used as the standard, was left in the pipe only long enough to run the tests because previous use of it had shown that it would foul with weeds if it was left in the pipe for an extended period of time.

Test Results

All the magmeters did an excellent job of measuring the flow of the pond water (Table 6). They were very accurate across a wide range of flow rates and were trouble-free in operation. The displays on the magmeters were digital and conveniently read out in instantaneous flow rate (e.g. gallons per minute) and totalized flow (e.g. gallons).

Both the doppler flow meter and the insertable electromagnetic flow meter were also accurate. The doppler meter is easily moved from site to site with its installation taking only a matter of minutes. The insertable electromagnetic flow meter can also be moved, or it can be permanently mounted at one location. However, its installation and calibration is substantially more complicated than that of the doppler meter.

Table 6. Sample results of flow meter tests with dairy manure water. Flow rates are in gallons per minute.

Flow Meter	Test					
	1	2	3	4	5	6
Tube mag meter 1	355	874	1080	801	880	742
Tube mag meter 2	361	859	1071	796	878	752
Tube mag meter 3	351	880	1120	813	896	750
Insertable Electromagnetic Meter				810	857	656
Doppler Meter	415	819	1115			
Propeller Meter	365	884				

Using Air in Sub-Surface Drip Irrigation (SDI) to Increase Yields in Bell Peppers

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Abstract: Root zone modification has long been a subject of interest among growers and researchers. Well-aerated soil is known to provide a generally better environment for root development and plant growth. Unfortunately, single purpose air injection systems have typically proven too costly for successful commercial application. With advances in subsurface drip irrigation (SDI) technology, that could change. The concept of aerating the irrigation water has the potential for the air to move with water within the root zone more generally and affect crop growth. In a pilot study, production trials featured injection of air into drip lines, so that the water applied had a volume of approximately 12 percent air. For air injection into the drip lines, a manifold was constructed using a Mazzei[®] differential pressure injector. Irrigations were conducted every seven days using reference Evapotranspiration (Eto) information. The experimental plot was one-quarter acre. Soil cover over the drip line was five to six inches of sandy loam, and plant rows were 190 feet long. Treatments consisted of SDI with untreated water and SDI with 12 percent injected air. Treatment plots consisted of two rows per treatment, with four replications of each treatment. Harvest data for one growing season showed that bell pepper plants irrigated with the aerated water produced 33 percent more peppers, with 39 percent greater weight, than plants irrigated with non-aerated water. In addition to yield data, there was greater dry weight and larger root mass in those plants that had received aerated water. The major effect of the injected air was within the first 150 feet of the drip tape inlet. The small-plot results are sufficiently encouraging to justify further trials on a larger plot approaching commercial scale, where rows can extend as long as 680 feet.

Introduction: The spaces within a soil, known as soil pores, can be filled with liquid and/or gases. Physical, chemical, and biological soil characteristics that influence crop growth and yield depend on the relative proportions of these two phases within the root zone. For example, a soil that is well aerated will favor increased root respiration and aerobic microbial activity (Mengel and Kirkby, 1982). Conversely, in soils where the pores are filled with liquid, or waterlogged soils typical of poor drainage, anaerobic conditions prevail. These anaerobic conditions are produced when the oxygen (O₂) that is carried in the water is depleted.

Oxygen (O₂) is essential for root respiration. However, immediately after the roots have been surrounded by water they can no longer respire normally. The liquid impedes diffusion of metabolites such as carbon dioxide and ethylene. This causes the plant to be stunted because ethylene is a growth inhibitor (Arkin and Taylor, 1981). When air is injected into the water within the root zone, diffusion of ethylene and carbon dioxide away from the roots may be increased. This increased diffusion rate should result in improved growing conditions. Increased oxygen diffusion rates to the root have shown to increase nitrogen (N₂) fixation in legumes (Paul and Clark, 1989). Atmospheric O₂ concentrations greater than 20% have been found to increase N₂ fixation, but levels higher than 50% result in inhibition (Paul and Clark, 1989). The supply of available carbon and the supply of O₂ both have major effects on symbiotic fixation. The amount of adenosine triphosphate (ATP) generated using a given quantity of O₂

appears greater when carbohydrate is oxidized than when hydrogen (H₂) is oxidized (Arkin and Taylor, 1981). Plants use ATP as the major carrier of phosphate and growth energy. Furthermore, increased N₂ fixation can be attributed directly to an increase of atmospheric O₂ in the root zone. The first regions to suffer oxygen deficiency are the regions of highest metabolic activity, such as the zones of cell division and elongation at the end of the roots (Paul and Clark, 1989). Hence, adding air to the root zone could result in less stress overall on the plants.

Oxygen is also essential for most soil microorganisms. It has been estimated that in a fertile soil, microorganisms consume more O₂ than crop plants (Wolf, 1999). Hence, sufficient oxygen is important for soil processes such as Nitrification and Ammonification, which involves the *Nitrosomonas* and *Nitrobacter* species, respectively (Stevenson, 1982). Shortages of O₂ can lead to denitrification, whereby important amounts of nitrogen are lost for crop production as nitrate is reduced to volatile nitrogen compounds (Wolf, 1999). In addition, oxygen is also needed for large groups of soil fauna. These include a number of insects, nematodes, mites, spiders and earthworms, which improve the soil physical, biological and chemical properties.

Modifying root zone environments by injecting air has continued to intrigue investigators. However, the cost of a single purpose, air-only injection system, separate from the irrigation system, detracts from the commercial attractiveness of the idea. With the acceptance of subsurface drip irrigation (SDI) by commercial growers, the air injection system is at least potentially applicable to the SDI system. Unfortunately when air alone is supplied to the SDI system it emits as a vertical "stream" moving above the emitter outlet directly to the soil surface. As a consequence, the air affected soil volume is probably limited to a chimney column directly above the emitter outlet. Balancing the air/water relationships as well as changing soil temperature could affect growing conditions, yield, and time of harvesting particularly in locations with limited growing seasons. The concept of aerating the irrigation water increases the potential for the air to travel with water movement within the root zone more generally and affect crop growth.

Over the past several years, grower experience in Kern county, California, has shown a positive crop response to air added to the root zone via venturi injectors capable of aerating water with fine air bubbles. In related work, a grower reported that on a commercial test plot basis pepper yield increases were 12.8 percent and 8.1 percent for premium and processed bell peppers, respectively. The value of the increased yield is however partially offset by increased energy costs. The main objective of the current project was to determine the impact of air injected into water delivered through SDI on yield of bell peppers. Specific tasks were to evaluate the following: (1) crop response to non-aerated (control) and air injected drip tape irrigation system by measuring yield, size and root weight; (2) bell pepper crops grown on mulched and non-mulched plant beds; and, (3) correlation of crop yield and location down the row (i.e. distance from source of air injection).

Procedure: The experiment was conducted on research fields located at the Center for Irrigation Technology (CIT), California State University in Fresno, CA (Fresno county, San Joaquin central valley; elevation < 150 m, average annual rainfall < 300 mm). The soils are fine sandy loam with < 2% organic matter in the upper soil horizon. Field plots consisted of approximately 1/4 ac. of bell peppers with plastic film mulch and approximately 1/4 ac. without plastic film mulch. Within the half-acre experimental area there were 8 pairs of rows approximately 380 ft. long. Each pair of rows was in a bed configuration with beds and drip lines spaced 60-in. center to center. Alternate beds were irrigated with aerated and non-aerated water, respectively. The bell pepper plant rows were offset 12 in. from both sides of the drip tape. The 8ml drip tape, buried approximately six inches, was rated at 0.34 gpm per 100 ft. at 8 psi. Emitter spacing was 12-in. center to center.

Manifolds for each treatment were fitted with dual flowmeters, pressure gauges and pressure regulators. The aeration manifold was fitted with a Mazzei® (patented) injector gas inlet port, a throttling valve and setup to attach to a rotometer capable of measuring airflow rates up to 20 cubic feet per hour (CFH). The basic principle of the injector is as follows: as water under pressure enters the injector inlet, it is constricted in the injection chamber (throat) and its velocity increases. The increase in velocity through the injection chamber, according to the Bernoulli equation, can result in a decrease in pressure below atmospheric in the chamber. This drop in pressure enables air to be drawn through the suction port and be entrained into the water stream. As the water stream moves toward the injector outlet, its velocity is reduced and the dynamic energy is reconverted into pressure energy. The aerated water from the injector is supplied to the irrigation system. The fluid mixture delivered to the root zone of the plant is best characterized as an air/water slurry.

Pre-germinated bell pepper plants were planted on May 4, 2000 at a down-the-row spacing of 12 in. Plants were then monitored for growth vigor and overall growing conditions in order to carry out weeding and fertilizer applications. Monitoring parameters included number of dead or wilted plants, green color and canopy cover for assessing vegetative growth, and proportion of weeds in plots. Both mulched and non-mulched plots were subjected to the same irrigation schedule. An effort was made to maintain adequate levels of soil moisture for the specific needs of pre-germinated plants especially given the late planting date of May 2000 and the onset of relatively hot field conditions.

Early irrigations were made as needed to maintain a moist root zone. As the pre-germinated plants took root it was possible to schedule irrigation at 7-day intervals. Calculated run times were modified as needed to ensure the wetting front moved the 12 inches from the drip line to the plant in order to provide contact with the plant's root system. The Reference Evapotranspiration (E_{to}) was obtained from a California Irrigation Management Information System (CIMIS) station on the California State University, Fresno campus. The canopy factor was developed by field observations. The crop factor (K_c) was taken from the literature. A system efficiency of 80% was assumed. Air to water volume ratio in the fluid mixture supplied via the SDI had a mean value of 12% and a range of 11.0 to 13.5%.

The plots had a total of 8 rows, consisting of 4 receiving aerated water and 4 receiving non-aerated water. Rows 1, 2, 5 and 6 received aerated water and the others received non-aerated water. Rows 1 and 8 were considered as guard rows and were not involved in the test harvesting. Row 2 (aerated) and row 3 (non-aerated) were paired together and designated as "A" pair. Likewise, rows 4 & 5 were designated "B" pair and rows 6 & 7 were designated "C" pair. Using a table of random numbers, four 10-ft. sections of test rows were identified in each A, B, & C pair and harvested for data collection and analyses. These 12 sample plots were accepted only if there were similar numbers of plants in the aerated and non-aerated treatments. Harvest data was coded to identify location as a measure of distance

from the source of air injection. Peppers were harvested three times during the growing season at 88, 116 and 168 days after planting. At the end of the final harvest, one aerated and one non-aerated plant from each of the twelve sample plots were examined for root and shoot (stem and leaves) mass. The representative plants were dug up, washed clean, separated into above and below ground portions, oven dried, and weighed.

Results and Discussion: Early observations revealed that a high percentage of plants were dying in the plastic film mulch plots. On closer inspection, the stalks seemed to be atrophied at the point where they emerge from the plastic mulch. Probable causes for this atrophy include root fungi, viral infection, mechanical action of the plant stalk rubbing against the plastic film, and sunlight reflection. Excess soil water because of the mulch preventing evaporation may also be a reason for death of plants. In any case, it was obvious that the mulched plots required a different irrigation regimen than the non-mulched plots. With a common manifold, this was impossible. Given the poor stand in the mulched plots and the inherent manifold restriction, the mulched plots were abandoned. The non-mulched plots exhibited a good stand and vigorous growth and were therefore used for the rest of this study.

Only saleable peppers within the 10-ft. section of rows were used in the data analyses. Saleable peppers were defined as those with no sunburn, no insect holes, and at least 50 grams. It was possible to harvest saleable peppers from all locations at 88, 116 and 168 days after planting, with the exception of the second picking at location in Row C, at 38ft from the inlet, for the plots receiving water only. Average weights (\pm standard deviation) for the aerated and non-aerated peppers were 103.7 (\pm 12.02) and 99.4 (\pm 11.49) grams, respectively. Based on a *t-test* statistic performed at the 95% probability level, there was no significant difference between mean weights of bell peppers from the aerated and non-aerated treatments. Weights of saleable peppers ranged from 50.57 grams (measured in Row B at 18ft from inlet line, to 285.51 grams (measured in Row A at 81ft from inlet line), for plants receiving water only, and from 50.55 grams to 440.81 grams (in Row A at 81ft from inlet line) for plants receiving both air and water. The lowest number of saleable peppers was obtained during the second picking, conducted 116 days after planting. The highest number of bell peppers from a given sample plot was 67 and this was obtained during the third picking of the aerated peppers at location 81ft from inlet line in Row A. When the three pickings were combined, the aerated plants had a production increase in both the number (**Figure 1**) and total weight (**Figure 2**). Because of the similarity in the mean weight of individual bell peppers from the aerated and non-aerated treatments, this production increase was due primarily to differences in the number of peppers from the different treatments. There were 212 more peppers, equivalent to a 33% increase, harvested from the aerated plots compared to plots that received only water (**Figure 1**). The aerated plants had a production increase of approximately 25.4 kg, a 39% increase, over the non-aerated plants (**Figure 2**). A paired *t-test* indicated that there was a significant difference, at the $p < 0.01$ level, between the number of saleable peppers harvested from the aerated and non-aerated treatments at the various sampling locations. The mean total number (\pm standard deviation) of bell peppers harvested during the study from the aerated and non-aerated sample plots were 71.5 (\pm 19.0) and 54.25 (\pm 14.38), respectively.

Indexing the sections of rows harvested from supply manifold along the drip tape provided an opportunity to evaluate possible position effects. **Figures 3 and 4** show the distribution of the total quantity and total weight of bell peppers picked, respectively, as a function of distance from the supply manifold. Generally, there was increased production from the beginning of the row to a maximum value at the 81-foot location. Yield then decreased down the row to a minimum value at the 168 feet location. As indicated above, the difference in production was due mainly to number of peppers in each plot. An attempt was made to curve fit the total pepper count versus location data, in order to ascertain a model to

describe a relationship between these two parameters (**Figure 5**). For the aerated irrigation treatment (**Figure 5a**), the relationship was best described by

$$y = 57.8 + 0.78x - 0.005x^2 \quad \text{Eq.1}$$

where y is the total pepper count, and x is the distance (feet) from source. The non linear regression given by Eq.1 had an $r^2 = 0.54$ and was significant at the $p < 0.01$ level. For the water only treatment, there was no significant correlation between the total pepper count and distance (**Figure 5b**). The quadratic relationship between the total pepper count and distance from air injection source, given by Eq.1, instead of a linear relationship may be indicative of the fact that air and water are not the only factors influencing the bell pepper yields. Subsequent studies should therefore incorporate additional parameters such as pressure and velocity measurements along the drip tape. In addition, nutrient status of the soil in the harvested plots should also be monitored, especially since the fertilizers were added in the irrigation water. By incorporating these additional parameters, it may be possible to better describe any relationship between pepper yield and distance from the supply manifold.

The final part of this study involved examination of the dry weights of roots, stems and leaves of mature pepper plants. When the total root and shoot dry weights of the plant material from the twelve test plots were combined, it was found that: (1) the aerated plants had a root weight increase of 17.53 grams, equivalent to a 54% increase, over the water only plants (**Figure 6a**); and, (2) the aerated plants had a stem and leaf weight increase of 68.98 grams, equivalent to a 5% increase, over the water only plants (**Figure 6b**). More importantly, there was a significant difference ($p < 0.001$) between the root dry weight: total plant dry weight ratio (R:P) for the aerated and non aerated treatments. The ratio, R:P, was calculated for each of the twelve locations using $[\text{root dry weight}] \div [\text{root dry weight} + \text{stem and leaves dry weight}]$. For the aerated plants, R:P ranged from 0.025 to 0.04 with a mean of 0.031 and standard deviation of 0.005. For the non-aerated plants, R:P ranged from 0.014 to 0.032 with a mean of 0.021 and standard deviation of 0.006. Assuming that water and nutrient availability were adequate for both the aerated and non-aerated plants, the increase in proportion of root mass in the aerated plants could be attributed to the air injection. Greater root mass is most likely associated with greater surface area of root material within the soil, thereby permitting the roots increased accessibility to water and nutrient supply. Ultimately, the plants can utilize the increased water and nutrients to produce more peppers.

Conclusion: The study showed that delivering aerated water to the plant root zone through subsurface drip lines resulted in a 33% increase in number, and a 39% increase in the weight of bell peppers produced. There were also significant increases in the dry weights of root and shoots from plants receiving aerated water as compared to plants receiving water only. These statistically significant results on a small plot (0.10 ac.) support reported results obtained on tests conducted on a commercial farm, and are sufficiently encouraging to justify follow-up fieldwork on larger plots. Special interest in the potential application of this air injection technology is the characterization of how the beneficial effect may vary with the length of drip lines. Hence, subsequent studies should attempt to monitor pressure and velocity changes along the drip system and correlate these with crop yield.

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Figure 1: Total quantity of bell peppers picked during the study (All Plots)

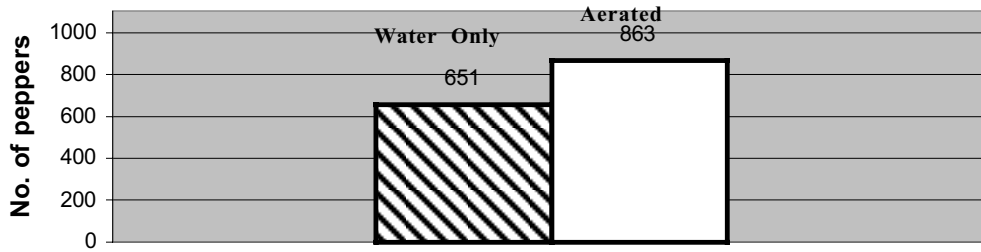


Figure 2: Total weight (grams) of bell peppers picked during the study (All Plots)

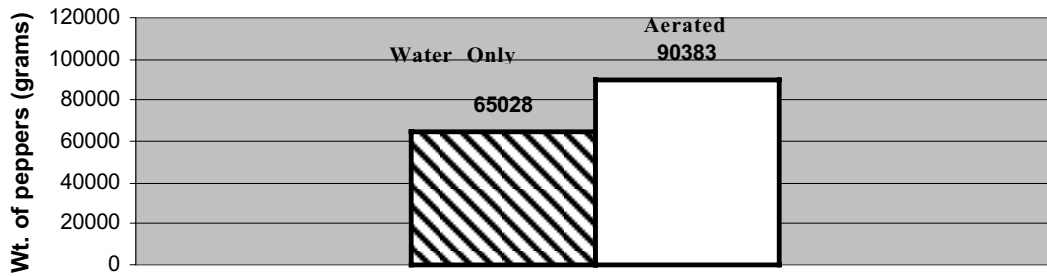


Figure 3: Quantity of peppers picked as a function of distance from supply manifold.

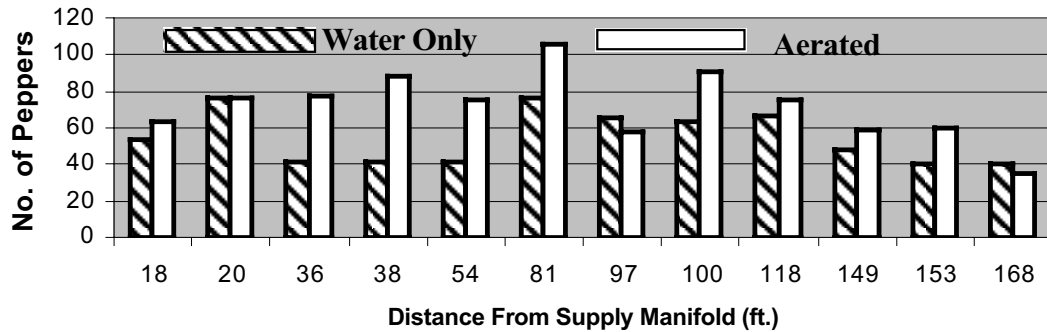


Figure 4: Total weight (grams) of pepper picked as a function of distance from supply manifold.

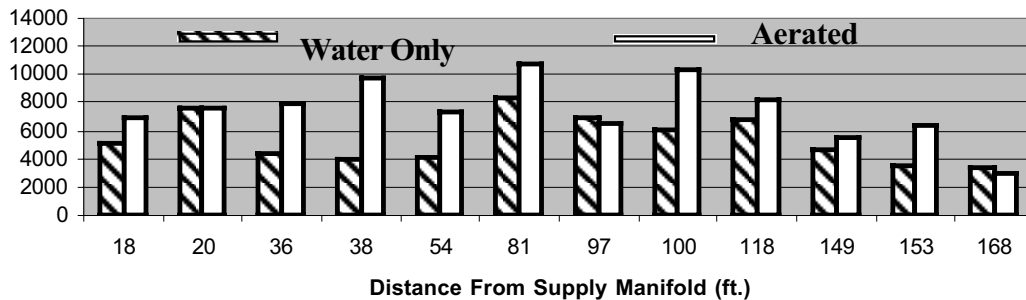


Figure 5: Peppers harvested by location for (a) aerated and (b) non-aerated irrigation water plots.

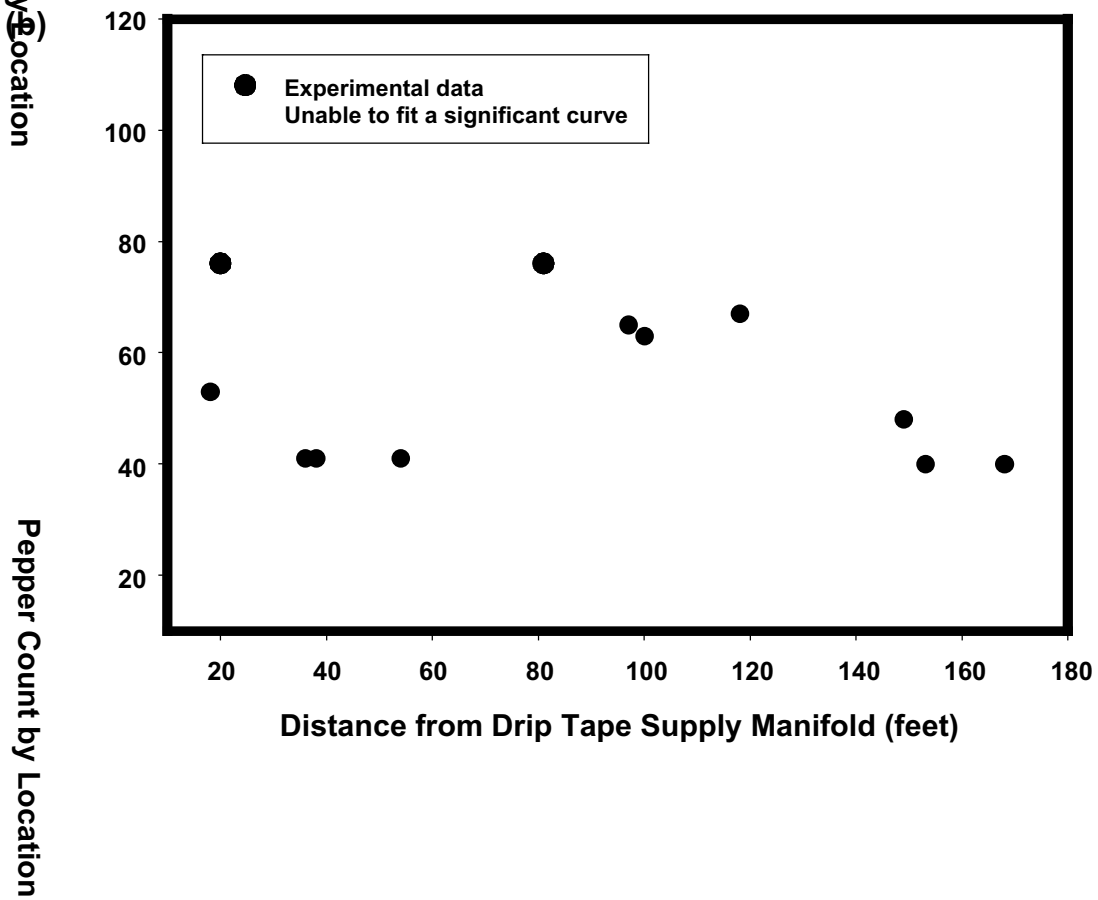
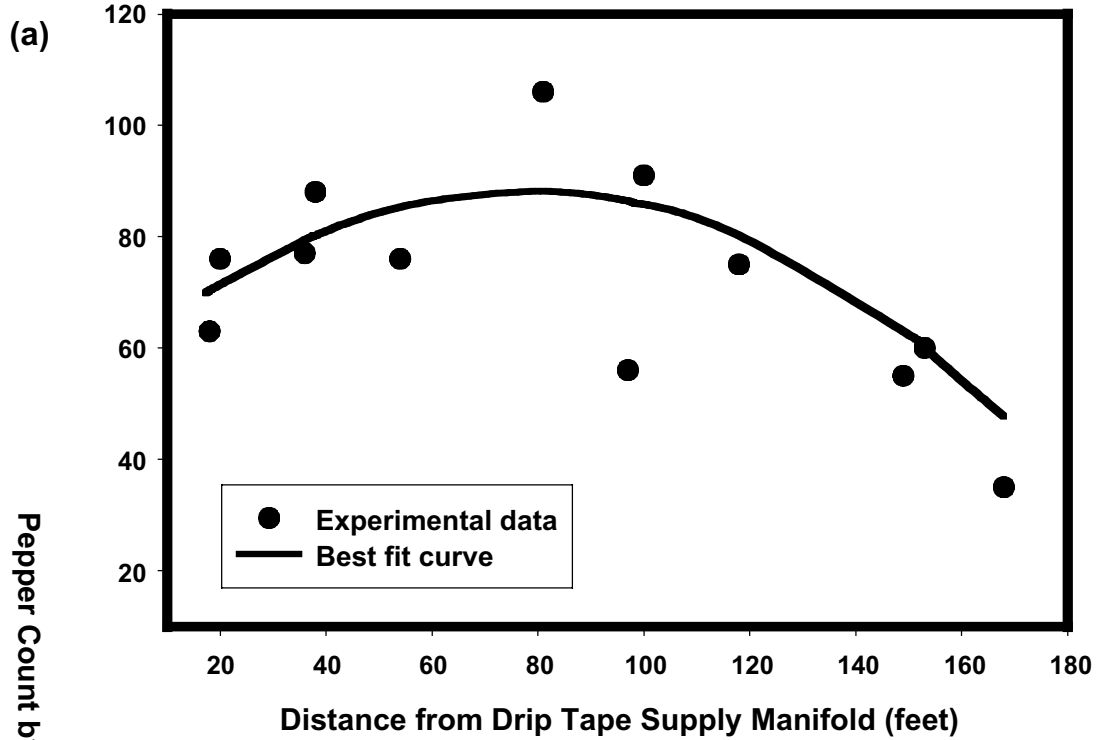


Figure 6a: Total dry weight (grams) of roots of mature bell pepper plants.

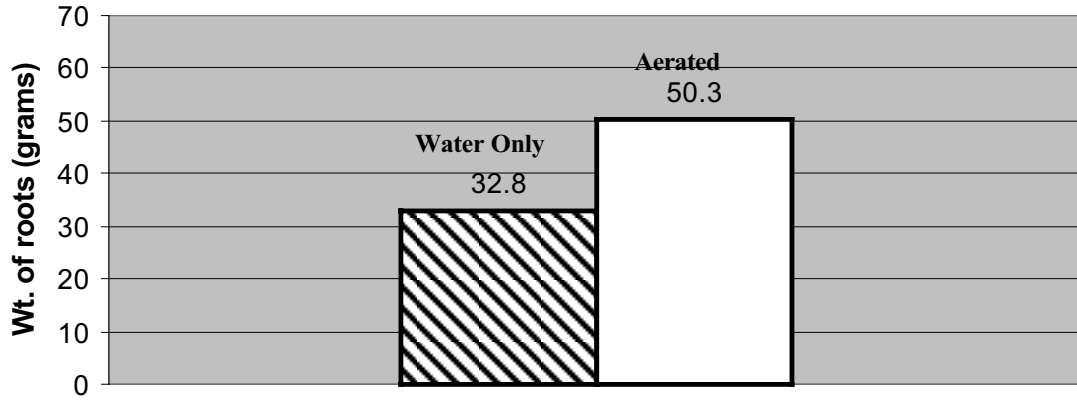
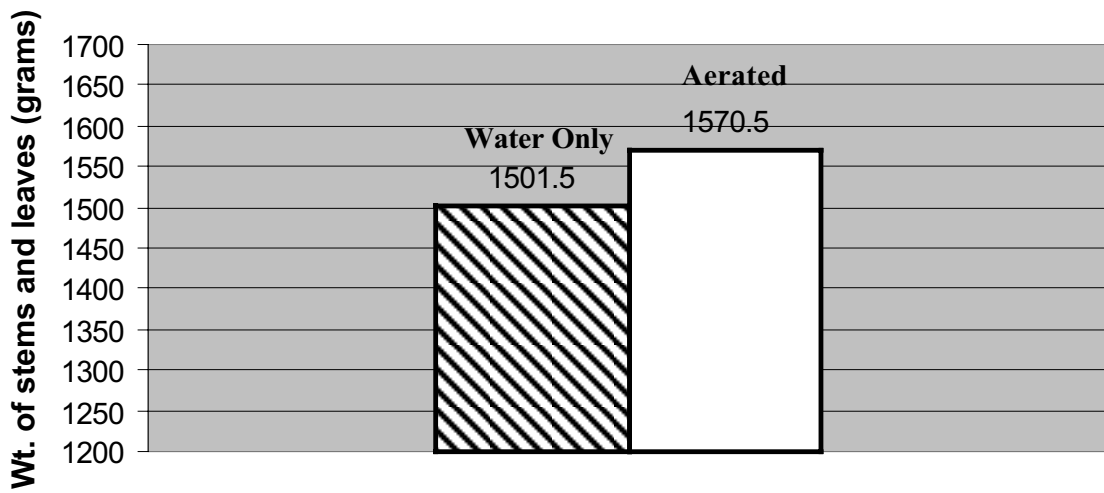


Figure 6b: Total dry weight (grams) of stems and leaves of mature bell pepper plants.



Imposing Water Deficits to Improve Wine Quality and Reduce Costs

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Water deficits can improve winegrape fruit quality and reduce costs associated with irrigation. To maximize these benefits simultaneously, deficits must occur at specific vine canopy or fruit stages of development. Additionally, irrigation savings and fruit quality improvement varies with viticultural region, soil/water resource, variety, and production goal. This paper will discuss the conditions under which these improvements or savings can occur and management techniques used to achieve them.

Effects of Vine Water Supply on Vine and Fruit

The effects of vine water deficits can be both beneficial and harmful to the crop, depending on their timing and severity. When water deficits occur, the vine responds by closing pores in the leaf (called stomata) to limit water loss. Closing of stomata reduces water loss, creating a better balance between water demand and moisture extracted by the roots. This strategy of moderating the severity of water deficits works well initially when deficits are mild, generally limiting the effects to a reduction in vegetative growth. As water deficits increase in severity and duration, the stomata are closed for longer periods of time. Since the stomata are the entry points for carbon used in photosynthesis, severe water deficits limit the time the stomata are open which limits photosynthesis and the production of sugar leading to poor fruit quality and reduced yield.

Vegetative Structures

Water deficits occurring early season (bud break to fruit set) are usually not possible in most viticultural regions. Midseason (fruit set to veraison) water deficits are possible in soils that are shallow or coarse textured which limits (soil) water holding capacity. Areas, which receive low rainfall and most soils in drought years, can also make midseason deficits possible even in deep soils. During this period, shoot development (both shoot length and the number of laterals) can be restricted by water deficits. Reduced canopy development can result in reduced leaf area, which may be insufficient to develop and mature fruit in low vigor situations. However, when vine vigor provides adequate to more than adequate canopy to support the crop load, restricting or controlling additional in canopy (leaf area) may be desirable.

More severe water deficits, occurring in the period between veraison to harvest, can result in senescence of lower and interior canopy leaves providing more light to the fruit. Some loss of leaves in the fruit zone may occur without significantly reducing sugar accumulation. Moderate amounts of irrigation water during this period can successfully moderate water deficits, causing the desired effect. Excessive water deficits can cause defoliation, which can lead to sunburn, “raising” or increased berry temperature, all causing reduced fruit quality.

Irrigation volumes should be adjusted to moderate, not eliminate, the deficit. Excessive irrigation during this period may cause resumption of lateral shoot growth, creating a competitive

sink for photosynthate, which can increase shading, cause bunch rot in susceptible varieties, and delay fruit maturation and harvest.

A continued or increasing water deficit following harvest provides little or no benefit to vine and next year's crop. Root growth, which increases after harvest, can be restricted and can result in early-season nutrient deficiencies the next spring. In colder areas, low temperature injury of permanent wood fruiting structures can also result if too little or excessive water is applied.

Berry Growth

Berry growth begins after anthesis and pollination. It progresses at a rapid rate for 40-60 days. In this period, called Stage I, a berry diameter may double in size. Stage II follows for approximately 14-40 days where the growth rate slows or stops, often called the "lag" phase. The onset of Stage III is marked by veraison lasting until harvest (typically a 35-55 day period) in which berry growth resumes. Berry growth is less sensitive to water deficits than vegetative growth. However, water deficits depending on the timing and severity can significantly reduce berry size.

Water deficits during Stage I of fruit growth are thought to reduce potential berry size by reducing the number of cells per berry. The reduction in cell number can cause smaller berries and reduced yield. However as previously mentioned, water deficits at this time are unusual in most winegrape regions of California. Water deficits occurring during Stage II (lag phase) or III (cell enlargement) can only affect cell size. The common effect of water deficits during these later periods is to reduce berry (cell) size and reduce yield. Severe water deficits can cause reduced berry size at harvest by dehydration.

Yield

Reports on the effect of water deficits on yield are varied. Studies conducted in both the Central Valley and the North Coast show berry weight increases in a linear fashion with the water consumed up to about 80% of full vine water use. From 80%, the remainder of the consumed water supporting increased vegetative growth. In red varieties, water deficits at the same level have been shown to slightly decrease yield (3 to 19%) from that of full potential water use. Additionally, these yield reductions generally require moderate deficits to be repeated for one to two years before the yield reductions occur. Severe water deficits can reduce yield in the subsequent season as a result of reduced fruit load measured as cluster number and berries per cluster (and therefore, berry numbers). Water deficits in red varieties have been associated with increased fruit quality while full potential water use results in reduced fruit quality expressed as reduced color and character.

Fruit Composition

Potential wine quality is largely determined by the composition of the fruit. The solute composition of fruit at harvest is sensitive to vine water status throughout its development. Moderate water deficits can increase the rate of sugar accumulation resulting in an earlier harvest. If deficits are severe and/or the vine is carrying a large crop, sugar accumulation is

generally slowed resulting in delayed harvest. The final increases in sugar are mostly driven by berry dehydration rather than sugar production. The result is a fruit with poor balance of solutes and reduced wine quality potential.

Water deficits result in only moderate decreases in total acidity; however, malic acid is apt to decrease sooner with early-season water deficits. With malic acid declining, the greatest effect of water deficits on the fruit is an increase in the tartaric to malic acid ratio. Juice acidity measured by pH, can also be reduced by water deficits.

Wine Color

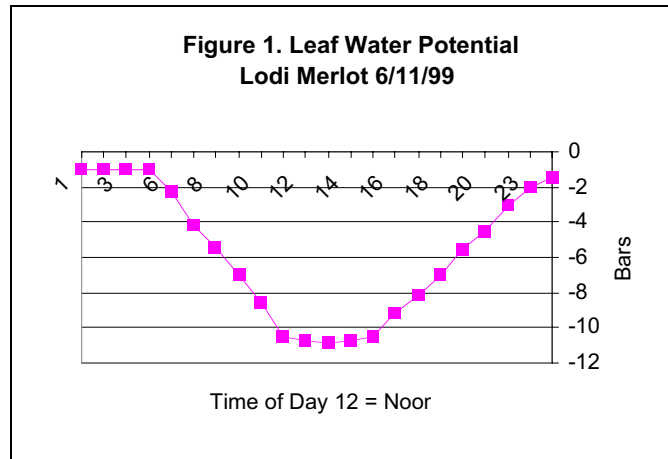
Water deficits can directly increase wine color by enhancing the production of pigments found in the skin of red wine varieties. Reductions in vine canopy using water deficits, also allows light into the fruit zone, which increases skin pigment. Additionally, a decreased berry size may also indirectly contribute to improved wine color by a larger skin to volume ratio. In areas that experience more severe climatic conditions for weeks at a time (Central Valley), excessive fruit exposure can raise the berry temperature, reversing the accumulation of pigments and causing poor berry color. Enhancement of color pigments (anthocyanins) and flavor compounds (phenolics) appears to be a consistent result of better fruit light exposure.

Vine Water Deficits Caused by Reduced Soil Water Availability

As available water to the vine becomes limited through depletion of winter-stored soil water or irrigation water, a level is approached where the vine cannot sustain the full potential water use. It is at this point that the vine begins to undergo a water deficit.

Under normal early-season conditions, (1) water is readily available in the root zone, (2) the vine is not at full canopy expansion, and (3) the atmospheric-driven demand is small. Therefore, under normal early-season conditions, water deficits are uncommon in most if not all winegrowing regions of California. As the season progresses without irrigation, the canopy expands, climatic conditions intensify and the soil is further depleted of available water. It is at this time that the vine's water demand can exceed water uptake from the soil causing water deficits. Cooler growing regions and greater a volume of available water in the soil from winter storage or irrigation will cause water deficits to be postponed to later in the season. Generally, water deficits do not begin to occur until the vine has extracted about 50 percent of the available soil water contained in the root zone. Soil depth, texture and the total water stored in the root zone can influence this rule of thumb.

As water deficits begin, they occur only for a short period of time at the peak water demand period of the day. The vine then recovers from water deficits when atmospheric conditions relax in the later part of the day and during the night. This cycle continues each day, depending on the climate, available soil moisture and to some extent root extensiveness. Without irrigation, the deficits become longer in duration and more severe each day. Water deficits are monitored using a pressure chamber to measure mid day leaf water potential. Figure 1 illustrates a typical mid season vine water status measured over a 24-hour period. More negative numbers indicate more severe water deficits. For scheduling purposes, leaf water potential is measured at the most negative time__at midday.

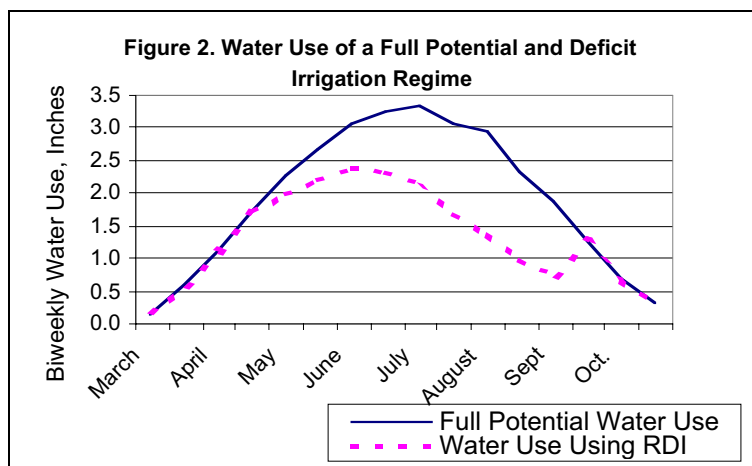


DEVELOPING AN IRRIGATION STRATEGY

Regulated Deficit Irrigation

Regulated deficit irrigation (RDI) is a term for the practice of regulating or restricting the application of irrigation water causing the vine water use to be below that of a fully watered vine. By restricting the irrigation water volumes, soil water available to the vine becomes limited to a level where the vine cannot sustain the full potential water use. It is at this point that the vine begins to undergo a water deficit. RDI can be a consistent reduction (i.e., consistent reduction of planned irrigation volumes over the entire season) or it can vary over the irrigation season to induce the desired vine response at the correct time.

Figure 2 shows the biweekly water use for full potential and the water use of the deficit treatment, which produced the best yield/quality relationship in a mature Cabernet Sauvignon vineyard in Lodi, California, over five years. The upper line represents the full potential water use of a mature vineyard. It is the volume of water consumed by the vineyard that occurs under condition when soil water availability is not limited and canopy size is near 60-70 % of the land surface shaded at midday measured at maximum canopy expansion. About 30% less water was consumed by the deficit irrigation regime.



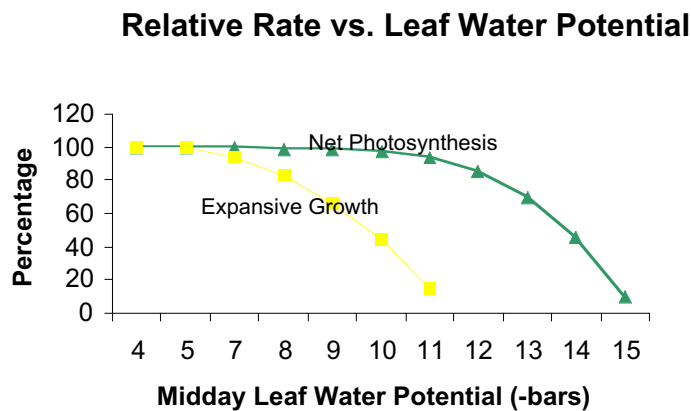
Early Season Water Deficits

A review of vine irrigation research yields two conclusions: 1) pre-veraison / veraison water deficits usually produced higher quality fruit and therefore wines, and 2) pre-veraison / veraison deficits were usually the “best option” treatment for maintaining yields.

Under normal early-season conditions, (1) water is readily available in the root zone, (2) the vine is not at full canopy expansion, and (3) the atmospheric-driven demand is small. Therefore, under normal early-season conditions, water deficits are uncommon in most if not all winegrowing regions of California. As the season progresses without irrigation, the canopy expands, climatic conditions intensify and the soil is further depleted of available water. It is at this time that the vine’s water demand can exceed water uptake from the soil causing water deficits. Cooler growing regions and greater a volume of available water in the soil from winter storage or irrigation will cause water deficits to be postponed to later in the season. Generally, water deficits do not begin to occur until the vine has extracted about 50 percent of the available soil water contained in the root zone. Soil depth, texture and the total water stored in the root zone can influence this rule of thumb.

Using moderate water deficits to control expansive vegetative growth while allowing photosynthesis to continue unabated is the basis for successful deficit irrigation (Figure 3).

Figure 3.



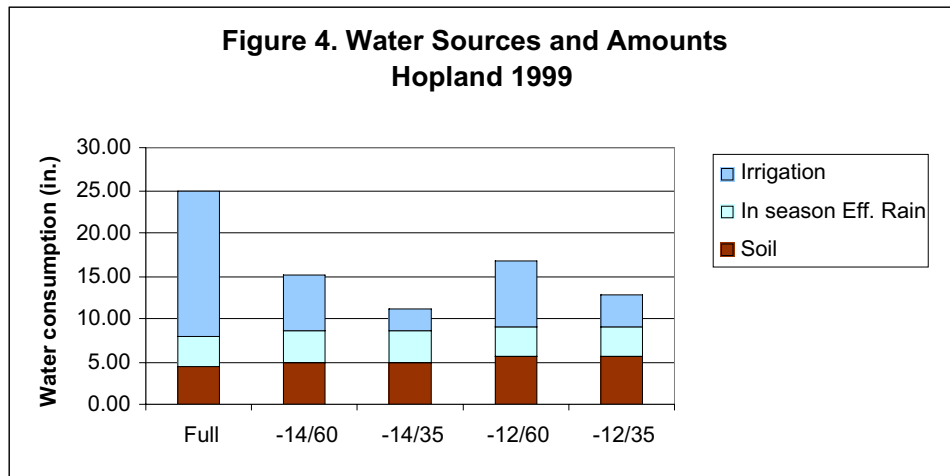
Deficit Threshold Irrigation

The Deficit Threshold Method (DTI) relies on a predetermined level of midday water deficit (the threshold) to begin irrigation. After the threshold is reached, a reduced water regime is used based on a portion of full water use (RDI%). Full vine water use is estimated using weather station data (Reference Evapotranspiration ETo) and canopy factors. The RDI% is the percent of the full water use, which is applied as the net irrigation volume for the period considered (week). The goal of the Deficit Threshold method combined with post threshold Regulated Deficit is to improve fruit quality and minimize yield reductions.

This method requires measurements of vine water deficits. The measurement device is called a pressure chamber often referred to as a pressure bomb. To measure vine water status, a leaf is removed from the vine at midday and placed in the chamber with the petiole sticking out through

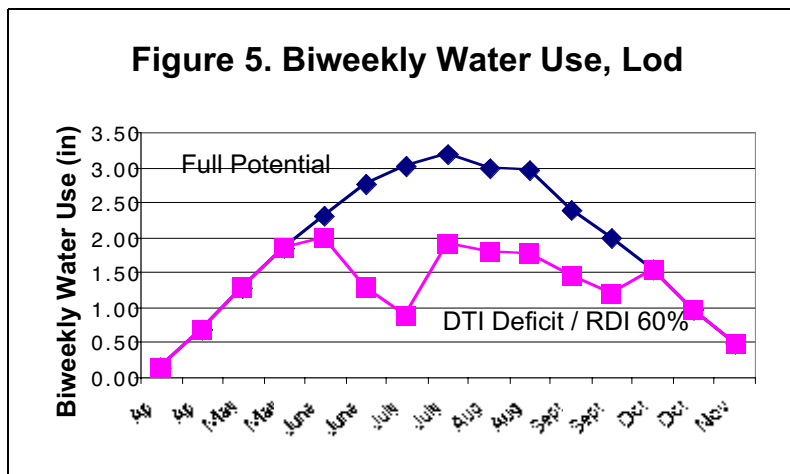
a silicone grommet. The leaf is covered with a plastic bag just prior to removing the leaf to prevent moisture loss while the measurement is made. Pressure is applied in the chamber until the sap exudes from the petiole. The pressure required to exude the sap is an indication of the level of water stress the vine is experiencing. This measurement is called leaf water potential.

Research trials have been conducted in Cabernet Sauvignon, Zinfandel, and Merlot with variable threshold water potentials and post threshold RDI%. Midday leaf water potential threshold of -12 to -15 bars were evaluated with post threshold RDI's of 35 to 60%. These treatments, designated as threshold/RDI% along with the consumed water and water sources, are shown for a Cabernet Sauvignon trial in Figure 4.



Results of higher fruit quality and little yield reduction generally support the -12 bar threshold and 60% post threshold RDI% as successful but conservative. Figure 5 shows the biweekly use of water by a full potential and a -12 bar threshold and 60% RDI in Lodi. The effect of both threshold and RDI% is more complex than indicated in this and is cultivar specific.

The Deficit Threshold Irrigation Method is an easier to use method requiring fewer measurements and fewer variables than the Volume Balance Method and seem to work well in moderate to cool climate regions.



How Much Water Can Be Save Using Deficit Irrigation

The volume of water that can be saved using a deficit irrigation strategy over full irrigation is dependent on the climatic demand, stored available water at bud break, spring-summer rains and the irrigation strategy selected. As an example to compare, we will look at three scenarios: San Joaquin Valley, Lodi and the North Coast. All canopies in size and trellis system are assumed to be the same. All three are drip irrigated. Full water use is compared with a similar deficit strategy in each area. Soils are different in depth and winter rainfall in each area. Values used were estimated on an area wide basis. Table 1 shows the range of the irrigation water volume savings to be 28 to 50%. The higher demand, low rainfall San Joaquin Valley was the least at 28% while the more moderate demand, higher rainfall Lodi area was 50%. The North Coast area was intermediate at 43%. These savings can be achieved while having little to no impact on yield and an increase in fruit quality given the appropriate deficit strategy is selected.

Table 1. Irrigation Water Comparison Full/Deficit in Three Areas

	San Joaquin Valley	Lodi	North Coast
Full water use (in)	29	27	24
Soil storage (in)	4	9	10
Net irrigation requirement (in)	25	18	14
Irrigation efficiency (%)	90	90	90
Gross irrigation requirement (in)	27.8	20	15.6
Deficit irrigation use (in)	22	18	16
Soil storage (in)	4	9	10
Net irrigation requirement (in)	18	9	6
Irrigation efficiency (%)	90	90	90
Gross irrigation requirement (in)	20	10	6.7
Deficit/Full (%)	28	50	43

Impact of Withholding Summer Irrigations in Alfalfa

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INTRODUCTION

Alfalfa has the reputation of being a big water user. In fact in the Central Valley of California the ET for the crop is close to 4 acre-ft and irrigation applications can be in excess of that amount to account for inefficiencies. Alfalfa is harvested for the vegetative portion of the plant. Unlike some crops such as cowpeas, which are harvested for reproductive parts and which can be stressed prior to flower bud formation without having a negative impact on yield, any water stress reduces alfalfa growth and hay yields.

Water use efficiency of alfalfa is less in mid-summer than in spring. In other words, the yield per unit of water transpired is higher in spring than mid-summer (Metochis et al.). Under conditions of limited water supply, it makes sense to use the water in spring when more growth will occur per unit of water transpired than in summer.

In the San Joaquin Valley the dairy market is the major consumer of alfalfa hay and premium prices are paid for “milk cow hay.” The price for high quality hay can be from \$10 to \$30 or more per ton higher than for “dry cow hay.” Due to environmental factors, it is difficult to produce high quality alfalfa hay here in summer. Prices during the season reflect the dairy market with high prices in spring and early summer and lower prices in mid-summer. In a limited water year or expensive water situation, market forces and the difficulty of making high quality hay in July and August indicate it is better to produce hay in spring than in mid-summer.

From both the water use efficiency and the market price perspective, if water is to be saved in alfalfa production in many areas of California, it is best saved during summer. In the 1960’s, it was common for growers in the Imperial Valley not to irrigate in summer. Their motive was to prevent stand loss due to soil saturation under high temperatures. With the use of lasers in ground preparation, irrigating in summer does not cause the stand loss that it once did but that experience with not irrigating in summer has led to the use of “summer dry-down” as a potential strategy for saving water. A number of studies have been conducted to evaluate the agronomic impact of “summer dry-down” of alfalfa on yield and stand.

AGRONOMIC IMPACTS

Starting in the northern Californian alfalfa hay production area, often called the intermountain area, Orloff (personal communication) conducted a trial. In 1995, water was withheld from alfalfa following July 21, August 14, August 30, or September 26. The final alfalfa cutting was on September 7. At the end of the season, yields of the two early cutoff treatments were significantly less than the other two treatments. A “cleanup harvest” of growth in early

November showed a trend for the two early cutoff treatments to have slightly less biomass. By the first cutting in June there were no differences in yield and there were no differences in the second cutting in the latter part of July. In the second year, cutoff treatments were again imposed starting on August 3, August 13, August 30, or October 3. In the September 9 harvest, the first two cutoff treatments were lower in yield. Again when growth was cleaned up in November the two treatments with the early cutoff dates were lower in biomass. In the third year, when all plots were treated the same with no withholding of water, all treatments yielded the same.

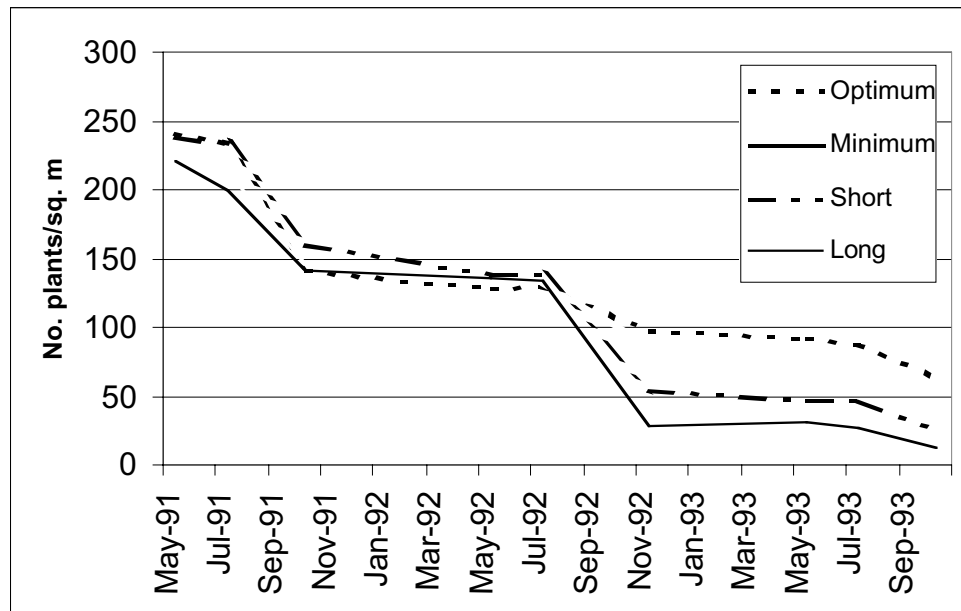
In a study in the San Joaquin Valley, at the U.C. Kearney Agricultural Center from 1986-1988 (Frate et al.), two years of summer irrigation treatments were followed by a third year of normal irrigation for all plots. Treatments included two irrigations between cuttings in summer as the standard, three irrigations between cuttings, a single irrigation between harvests, no irrigation in July and August, and no irrigation following the June cutting until the next spring. Yields in plots where irrigations were withheld were reduced during those cuttings and often for the first cutting following resumption of irrigation. In the third year under uniform irrigation for all treatments, yields did not differ significantly.

Table 1. Data from Kearney Trial, 1986-1988 (Frate et al.)

Treatment	Yield for Year 1 Tons/Acre	Yield for Year 2 Tons/Acre	Average reduction/year in water applied compared to Standard (acre-in)
3 x per cutting	7.3 a	7.8 a	+11
2 x's per cutting (Standard)	7.4 a	7.9 a	-
1 x per cutting	6.3 b	7.0 b	9
July/August dry-down	5.6 c	6.2 c	13
July Termination	4.8 d	5.6 c	16

In a 3 year study in the Imperial Valley, an “optimum” treatment of 3 irrigations in July and 2 each in August and September was compared to a “minimum” stress treatment (3 irrigations in July, and one each in August and September), a “short” stress treatment (3 irrigations in July and none in August and September), and a “long” stress treatment (no irrigations in July, August, and September). Yields were reduced in treatments with deficit irrigation treatments. Average reduction in tons/acre/year for the minimum, short and long treatments were 0.76, 1.67, and 2.51 respectively. Stands were also significantly reduced by the end of November in the second year in the “short” and “long” stress treatments.

Figure 1. Stand counts from 1991-1993 Imperial Valley Study, Robinson et al.



Two studies by Ottman et al. in Arizona were conducted from 1991 to 1992. At the Yuma site, normal irrigation was applied until the first of July. In addition to a control with normal irrigation practices there was a summer termination treatment with no irrigation from July through October and a winter termination from November through February. The alfalfa was harvested 9 times from March 1991 to mid-March 1992. In this trial, yield was negligible in cuttings when water was withheld. Yields in the summer termination treatment did not recover when re-watered and damage from the summer termination treatment appeared permanent due to stand loss. In March 1992 the control had 44 plants per square meter and the summer termination treatment averaged just 16.

At the Maricopa site, in addition to the control there was a summer termination from August through September and a third treatment that included both a summer and winter termination with no irrigations from August through mid-March. The summer irrigation treatment recovered in the first harvest following rewatering in the first year. In the second year, yields for this treatment were significantly lower than the control in 3 out of 4 harvests from November 1991 through May 1992. The combination summer and winter termination treatment reduced yields in 2 of 4 cuttings after the resumption of irrigation in the first year and never yielded as well as the control after the second year of treatments. Stand counts however did not show any reduction in stand from either of the termination treatments.

No one factor has been identified but several reasons have been suggested for explaining why stand decline has occurred in some dry down studies and not others. Sandier soils with low water holding capacity may be more prone to loss of stand than soils with a higher water holding capacity. In the case of stand decline in the Imperial Valley other stresses such as soil salinity and silverleaf whitefly may have contributed to stand loss. Higher temperatures in that study and the Arizona studies may also play a role compared to studies in the San Joaquin Valley or in

northern California. Other reasons to explain long term effects include damage to roots in cracking soils, predisposition to plant diseases especially root problems when irrigation is resumed, subsoil moisture, stand age and the state of root reserves when water stress is imposed.

ECONOMIC IMPACTS

From the studies mentioned above, economic impacts can be estimated using the reported yield reductions from summer dry-down treatments. Withholding irrigations saves on water use and the labor costs associated with irrigation. In some cases insect or weed control applications may not be applied which would also be a savings. When comparing imposed summer drought practices to the yield of irrigated alfalfa, harvest costs must be considered when calculating the cost benefits of one practice over another. Whether it makes good economic sense to a grower to stop irrigating alfalfa in summer will depend on both the price of alfalfa and also on the price and/or availability of water.

Takele and Kallenbach conducted a summer dry-down trial in California’s Palo Verde Valley and included economic analysis in their paper. In this study, irrigations were withheld for a period of 35 days, 70 days or 105 days during summer. The control was irrigated at 100% ET during this period. The economic analysis is based on partial net returns among the treatments which includes only those income and expense items that change due to the irrigation treatments. These include water, irrigation labor, weed control and harvest costs.

Yields were reduced in the first cutting after withholding water. The 35 dry-down treatment however recovered in yield the first cutting after irrigation was resumed. The 70 and 105 day dry-down treatments did not produce yields equivalent to the control until the second cutting after irrigation was resumed. However, the stand count for the 105 day dry-down treatment was only 60% of the control in October and at the final stand count in May of 1998, both the 70 and 105 day dry-down treatments had significantly fewer plants than the control.

Table 1. Yield data from Takele and Kallenbach, Palo Verde, CA 1997.

Dry-down days	Tons/acre					Total
	7/7/97	8/12/97	9/16/97	10/21/97	1/13/97	
0 (control)	1.09	1.20	0.84	1.09	0.28	3.42
35	0.92	0.63	1.01	0.96	0.28	2.88
70	1.07	0.65	0.00	0.72	0.26	1.63
105	1.10	0.64	0.00	0.00	0.33	0.97
LSD (0.05)	NS	0.15	0.05	0.09	0.01	0.21
CV%	8.10	21.20	12.80	14.30	5.30	10.50

Assuming a value of hay to be \$105/ton, their economic analysis indicated that when the cost of water was \$40/acre-ft, it was more profitable to irrigate normally. At \$50.50/acre-ft, it was equally profitable to irrigate normally or to withhold water for 35 days. At \$62/acre-ft, it was most profitable to have a 35 day dry-down period and, at that water price, the standard irrigation practice was equally profitable compared to the 70 day dry-down treatment. In addition to the straightforward analysis based on visible costs, the paper also discusses the potential long-term impacts on alfalfa fields subject to summer dry-down and the potential losses in biological

benefits such as nitrogen fixation and soil microbial activity. Summer dry-down practiced on a large scale could also have adverse impacts on employment and service industry activities.

SUMMARY

There are potential water savings from withholding irrigation from alfalfa in summer and in some cases it appears this can be done without long term negative impacts on the stand and subsequent productivity of the field. However, in some cases significant stand reduction occurs and the factors that determine whether stands undergo permanent damage are not fully understood. High temperatures, soil type, duration of dry-down periods and other stress factors appear to be involved.

Both alfalfa hay and water prices will determine if water savings are worth the loss in yield for an individual grower. These may change from year to year, especially the alfalfa hay price. However, widespread practice of summer dry-down of alfalfa may have an adverse affect on the regional economy.

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Irrigation Practices to Save Energy Costs in Orchards

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INTRODUCTION

Any water savings achieved through irrigation reductions also represent energy savings and sometimes labor savings as well. As long as yield and fruit quality are not sacrificed in the process, the grower will obtain an economic benefit from such practices. The first and most obvious way to improve irrigation efficiency is to eliminate wasted water. Properly graded fields and correctly designed irrigation systems can save an irrigator considerable amounts of time and help place water in the correct location. Regular checking for leaks and plugs can not only save water but also keep trees in a more healthy condition and prolong the life of the orchard. Often, rather minor uncorrected irrigation situations can lead to serious long-term problems in the orchard such as soil compaction, tree stress and even tree death.

Even with good irrigation efficiency it is possible to save additional water in a couple of different ways. First, when establishing a new orchard, much of the water applied is lost through soil evaporation rather than tree transpiration. Approaches to reducing soil evaporation can save substantial amounts of water. Second, in mature orchards, there are periods of time during the season when trees can sustain stress with less damage than other times. Therefore, deficit irrigation might be a useful practice in some situations as long as careful monitoring is carried out.

IRRIGATING YOUNG TREES

Using a large weighing lysimeter at the Kearney Ag Center, we have been studying in detail the water use of peach trees. Crimson Lady peach trees were planted in the lysimeter in February 1999. During the past 3 years we have been collecting daily data on young tree evapotranspiration (ET). Within the lysimeter we are able to switch between a surface basin irrigation system and a subsurface series of drip emitters at both 30 and 60 cm depth. In addition the entire soil surface has been wetted from time to time by rain events during the season. This has allowed us to study soil evaporation under widely varying conditions. As a result, we are in the process of putting together a model that separates out soil evaporation and tree transpiration. Using the model, we can predict the amount of water needed for soil evaporation under different scenarios. Since water evaporated from the soil surface is largely wasted, the goal of efficient irrigation of young trees should be to minimize this component.

Table 1 shows the growth and transpirational component of water use of the Crimson Lady peach trees during their first three years of growth. The trees were trained to a Kearney “V” system (DeJong et al., 1994) in a high density configuration of 4.9m (16 ft) between rows and

1.8m (6 ft) between trees. Also, they grew very well and thus filled their allotted space by the end of the third year as they were intercepting 75% of the available light in the orchard.

Table 1. Tree growth and transpirational water use of Crimson Lady peach trees in a large weighing lysimeter at the Kearney Ag Center.

Year	Tree Age (yrs)	Final Tree Dimensions & Light Interception				Tree Transpiration from 3/1 to 9/30	
		Height (m)	N-S Spread (m)	E-W Spread (m)	Light Interception (%)	(mm)	(in.)
1999	1	2.6	1.8	2.0	31	219	8.6
2000	2	3.8	2.0	3.5	62	701	27.6
2001	3	4.4	1.9	4.0	75	1034	40.7

Using the model we were able to predict the amount of water lost to soil evaporation under different irrigation regimes. For the first year of growth, we irrigated the trees using weekly basin irrigation to replace ET lost during the previous week. The basin was 85 cm (33 in) in diameter until the first of August when it was expanded to 170 cm (67 in). The total soil evaporation under this regime was 37 mm (1.5 in) or 14% of cumulative ET. If the diameter of the irrigation area was expanded to 300 cm (10 ft) (typical of many fanjets) for the whole season, the model predicts soil evaporation to be 206 mm (8.1 in) or 48% of total ET. The savings in irrigation water of 169 mm (6.6 in) is about what one might expect if caps were placed on fanjets to reduce the wetted area under the tree.

Mature trees have greater shading below the canopy so soil evaporation will be somewhat reduced relative to total ET. However, there is still potential for saving water by using an irrigation system that wets less of the soil surface. For example, fanjets with a 360 cm (12 ft) diameter would be predicted to wet about 75% of the total soil surface and lose 350 mm (14 in) of water to evaporation when operated weekly. This is about 25% of the total ET of the 3rd year Crimson Lady peach trees (Table 1). On the other hand, a drip system that may only wet 10% of the soil surface would be predicted to lose less than 75 mm (3 in) to evaporation. Thus, as much as 275 mm (11 in) of water might be saved annually by converting to a different irrigation system.

IRRIGATING MATURE TREES

If sufficient water is available, it is generally recommended to supply 100% ET to the trees through a water budget approach to irrigation scheduling. However, when water becomes very expensive or scarce, certain deficit irrigation strategies have been developed which will generally have a minimal affect on yield and fruit quality. In fact, in some cases fruit quality can even be improved with moderate water stress. When imposing these irrigation strategies, careful monitoring is important to guard against excessive stress that might hurt production or damage and even kill trees.

Deficit Irrigation After Harvest

Many stone fruit varieties grown in California are harvested in May and June and thus have a long postharvest period. The potential exists for saving water by deficit irrigating during this postharvest period since there is no current crop that might be damaged. In addition, any reduction in vegetative growth would generally be considered a positive result. Several different studies have demonstrated the feasibility of this irrigation strategy in peaches (Johnson et al., 1992; Larson et al., 1988) and plums (Johnson et al., 1994). Substantial savings in water have been demonstrated with no loss of production in the following year. The main drawback has been the formation of defective fruit such as doubles and deep sutures (Handley and Johnson, 2000). If the stress is severe enough at just the right time, the percent of these disorders can be very high. Doubles and deep sutures can be minimized by making sure stress in the trees is relieved during the time of flower bud formation. Based on limited microscopic observations, this time seems to be in late August or early September. Therefore, by starting to relieve stress in early August, excessive fruit disorders can be avoided.

Deficit Irrigation Before Harvest

Nearly 20 years ago, reports from Australia indicated water stress could be imposed during the “lag” phase of fruit growth without cutting down on fruit growth or fruit quality. In fact some of the studies suggested fruit growth could actually be improved. Numerous studies around the world were not able to replicate these results (Johnson and Handley, 2000). However, some of our studies in California demonstrated some positive results from this approach to deficit irrigation. Although fruit size is generally reduced, fruit sugar content is often increased (Crisosto et al., 1994). Also, the reduction in vegetative growth accompanying this treatment often leads to better canopy light penetration and increased flower bud production. Therefore, there are situations where this irrigation strategy might be useful for accomplishing specific goals. As with any of these deficit irrigation strategies, it is important to carefully monitor the development of stress using a pressure bomb or other instrumentation. On very shallow soils, severe stress can come on quickly, resulting in defoliation and tree death.

CONCLUSION

Improving irrigation efficiency can save power, water and labor costs. Also, the overall health of the orchard will be improved. Therefore, it is beneficial for a grower to make sure his irrigation system is designed and operated correctly and just the right amount of water is being applied. In some cases, even applying less than full ET can be useful for achieving certain goals.

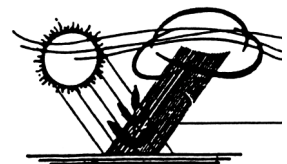
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**PEST
MANAGEMENT
INNOVATIONS**



Walnut Pest Management Alliance

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The Walnut Pest Management Alliance (PMA) is a broad based implementation project designed to encourage adoption of reduced-risk pest management program in walnuts statewide. The PMA project has evolved into a broader program than originally envisioned with individual researchers working closely with the PMA in the area of codling moth and blight. This research feeds directly into the PMA project allowing the PMA project to better focus on testing and demonstration that are near term. Several factors have increased the prospects for development of reduced risk practices for codling moth which is the primary target for broad spectrum insecticides in walnuts. These factors include the documentation of resistance to the most commonly used insecticides and the development of newer pheromone application technologies such as sprayable pheromone and puffers. This coupled with the development of new, more selective insecticides that can help provide control without disruption of naturally occurring biological control. The codling moth PMA project in 2001 was able to successfully demonstrate mating disruption with Consep CM-F sprayable pheromone. Walnut growers can easily incorporate mating disruption into their control programs, since sprayable pheromone is much easier for walnut growers to apply. Blight researchers have developed walnut bud sampling methods, eradicator sprays and a blight model which the PMA has been able to field test for growers in designated demonstration sites as well as helping growers learn to use the blight model, Xanthocast. The PMA plans to continue developing management techniques from research funded by the Walnut Marketing Board, using UC IPM monitoring programs refined by

the walnut PMA, and outreach programs that will result in increased adoption of a reduced-risk walnut program to slow the trend of increased pesticide use in walnuts.

OBJECTIVES

Objective 1: Continue to build upon the Walnut Pest Management Alliance Team for implementation of reduced-risk strategies.

Objective 2: Demonstrate IPM strategies to control codling moth, *Cydia pomonella*.

Objective 3: Demonstrate IPM strategies to control blight, *Xanthomonas campestris*.

Objective 4: Demonstrate the impact of a replanted cover crop, a naturally reseeding cover crop to native vegetation.

PROCEDURES

Objective 1

The Walnut PMA Management Team is the drive behind the Walnut PMA. The Management Team is responsible for directing and implementing reduced risk strategies as well as standardizing treatments. The Team incorporates the various stakeholders into the program and seeks new ideas constantly. By meeting throughout the year to plan, coordinate, and share new ideas, the Management Team is able to work effectively and efficiently to ensure that the PMA gathers the most scientifically reliable and easy to interpret results across the state.

Objective 2

Five blocks of early cultivar orchards were identified with cooperating growers and farm advisors as codling moth sites from Fresno to Tehama county. All orchards were under 35 feet in height and were the Vina variety which is known to be codling moth susceptible. Seven treatments consisted of: Isomate C+ alone, Isomate C+ and *Trichogramma platneri*, Isomate C+ and Lorsban or Confirm, Consep's CM-flowable alone, CM-flowable and Lorsban or Confirm, the Grower Standard, and the untreated control. The Lorsban or Confirm was sprayed depending on the codling moth population level. Treatments were approximately five acres with the exception of the untreated control that was approximately one acre. Isomate C+ was applied once by hand shortly after biofix at a rate of 400 per acre. This is approximately 8 per tree when the orchard is planted at 48 trees per acre. The CM-flowable, a sprayable pheromone, was applied at 30 grams a.i. per acre every 30-40 days starting just after biofix. Lorsban or Confirm was applied during the 1A or 2A flight or as deemed necessary by the farm advisor. *T. platneri* was aerially applied once per week for four weeks during the third generation at a rate of 200,000 per acre. The number of applications were reduced to make the program more economic for growers and to supplement codling moth control when the mating disruption product begins to age later in the season. The grower standard consisted of the growers normal farming practices which includes organophosphate and pyrethroid use. Each orchard was monitored with traps weekly from biofix to harvest and the trap liners were changed as necessary. Delta Traps were used and donated by Trece® along with the Longlife lure (1X) and the kariomone. Each

treatment contained three delta traps, one hung low and two hung high in the canopy in the center of each treatment. In each of the pheromone treatments, the low trap contained the Trece® Longlife L2 lure, one high trap contained the Consep Biolure 10x, and the other had an experimental kairomone lure. The 10X Biolure and the sprayable pheromone were donated by Consep, Inc. The insecticide-only blocks and the untreated controls were monitored with the Trece® L2 lure positioned low and high as well as a trap with the kairomone lure. This protocol was followed because research has shown that the 10x lures (loaded with 10 times the pheromone) are not attractive to codling moth in non mating disrupted orchards. The lures were changed according to the manufacturers instructions. Five trees were selected in a pattern in the center row of each treatment and monitored for damage assessment throughout the season. The overwintering generation was monitored by nut drop recording the total number of dropped nuts under all 5 trees in the treatment, subsequent generations were monitored by canopy count recording the damage in 50 nuts low and 50 nuts high, and the final evaluation occurred with a 100 nut harvest sample from each of the 5 trees.

Objective 3

Four of the participating blight site orchards were surveyed during the winter of 2000-2001 by collecting dormant walnut buds. Bioassays of these buds were conducted for the presence of walnut blight bacteria at Dr. Steve Lindow's laboratory at University of California, Berkeley for the percent of buds containing walnut blight bacteria and the amount of bacteria colony forming units (CFU) in the buds.

University of California Farm Advisors conducted uniform efficacy trials to evaluate reduced risk approaches to controlling walnut blight at the three of the four sites surveyed. The reduced risk treatments includes an eradicant spray containing copper and Manex (where registered) plus the wetting agent Break-thru applied only once at bud break. The PMA also tested the Xanthocast blight model developed by UC researcher Jim Adaskaveg with Manex and Copper treatment timed according to the model. There were 6 treatments total: 1) eradicant treatment only, 2) eradicant treatment +grower practice, 3) grower practice, 4) eradicant treatment + blight model, 5) blight model only, and 6) untreated. This treatments were followed uniformly across 3 sites and each location represents a replication for data analysis.

The materials used were 0.5% Break-thru by volume with the bud break spray, 8 pounds of fixed copper/acre with each grower standard spray plus 58 oz. Manex / acre (where registered) at 100 gallons per acre. Break-thru is a silicon wetting agent used to help carry the Copper/Manex into the buds. An orchard air blast sprayer applied materials at bud-break and/or various other times during the spring.

Objective 4

A cover crop was planted three years ago in Yuba County and replanted in December 1999 to augment reseeding after an herbicide application prevented some of the planted species from reseeding in the middle of the rows. Sampling of plant species present in the PMA and grower standard was conducted using four transects in each plot with 10 quadrats per transect. Each quadrat was a nested quadrat with dimensions of 0.25 m by 0.25 m and 0.5 m by 0.5 m plot.

RESULTS

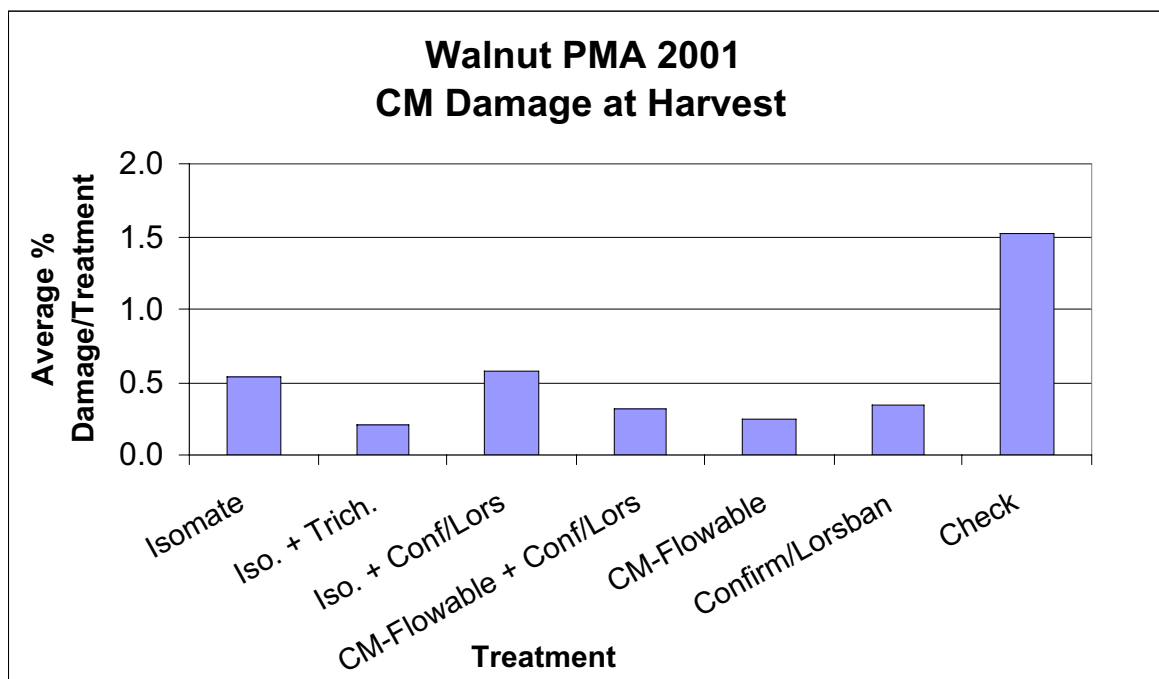
Objective 1. Continue to build upon the Walnut Pest Management Alliance Team for implementation of reduced-risk strategies.

The Walnut Pest Management Alliance Team has been proactive in implementing reduced risk practices and keeping the information moving from Farm Advisors, to field scouts, and to growers. The strength of the PMA comes from the standardized treatments across the state for scientific data analysis. Continuing to publicize results from these standardized sites across the state is the foundation to which reduced risk practices will become more widely used. The PMA Management Team continues to drive the implementation and research required to implement this new practice.

Objective 2. Demonstrate IPM strategies to control codling moth, *Cydia pomonella*.

Nut drop and canopy counts are tools to aid in determining damage and levels after each respective generation and the canopy counts have been good indicators of damage at harvest. Harvest damage is used to determine how well each treatment worked. The data from the Fresno site is reported but was not used in the statistical calculations since there was no codling moth damage across treatments. Graph 2.1 depicts the average percent damage at harvest per treatment.

Chart 2.1. Percent codling moth damage at harvest per treatment in the Walnut PMA 2001.



Significant differences from all treatments to the check at the 5% level.

Objective 3: Demonstrate IPM strategies to control blight, *Xanthomonas campestris*.

Each orchard surveyed in the winter of 2000-2001 had some level of inoculum, as shown in Table 3.1 below. Although all the sites had inoculum present, the growing season of 2001 had environmental conditions that were not very conducive to walnut blight infection, resulting in very little blight pressure in the trials.

Table 3.1. Bioassay results from dormant walnut buds Walnut PMA 2001.

Site	Average Log CFU/Bud	% Buds Infested
Butte	0.79	20%
Yuba	0.71	22%
San Joaquin	0.31	10%
Fresno	0.14	3%

The Xanthocast walnut blight model’s prediction of disease pressure (“blight index”) was made available for no cost on the website www.Fieldwise.com. The blight index was checked daily for spray recommendations by researchers. This information was passed to the cooperating growers who treated the corresponding blocks as indicated by the model.

Blight surveys were conducted in the three participating orchards on June 11, 2001. One thousand nuts per treatment were visually inspected for symptoms of blight infection in the canopy. The results from the various treatments can be seen in Table 3.2. The values are expressed in percent walnut blight. With very little walnut blight present at any location few conclusions can be drawn from this years trial. There was no indication of a single best treatment program. To adequately evaluate these treatments more severe walnut blight conditions need to occur.

Table 3.2. Percent walnut blight Walnut PMA 2001

Treatment Timing:	Butte	San Joaquin	Yuba	Mean *
Bud Break Only	3.37	5.3	1.8	3.49
Bud Break + Xanthocast Model	1.3	11.2	1.07	4.52
Xanthocast Model Only	4	0	4.22	2.74
Bud Break + Grower Standard	4.23	11.7	0.08	5.34
Grower Standard	0.49	2.5	2.9	1.96
Untreated Control	0.67	29	9.3	12.99

. *No significant differences at the 5% level.

Objective 4. Demonstrate the impact of a replanted cover crop, a naturally reseeding cover crop, and native vegetation. The species present at the site are summarized in Table 4.1 below.

Table 4.1. Plant species present at the Yuba County Site

.Grower Standard	Plant Category	PMA	Plant Category
blando brome	F	blando brome	F
burr clover	F	white sub	F
white sub	F	medic	F
Fescue	F	vetch	F
ranunculus	SW	pink nitro	F
sow thistle	SW	crimson	F
foxtail	SW	Fescue	F
dandelion	SW	foxtail	SW
geranium	SW	sow thistle	SW
Polycarpon tetraphyllum, '4-leaf allseed'	SW		
blackberry	SW	ranunculus	SW
trefol	SW	prostrate spurge	SW
prostrate spurge	SW	bur chervil	SW
pineapple	SW	fillaree	WW
prickly lettuce	SW	rye	WW
bur chervil	SW	annual blue	WW
Herniaria hirsuta ssp. Cinerea, 'gray herniaria'	SW	speedwell	WW
annual blue	WW		
fillaree	WW		
speedwell	WW		
chickweed	WW		
miner's lettuce	WW		
wild oats	WW		

Plant category: F = forage, WW= fall or winter weed, SW = spring or summer weed.

DISCUSSION

The walnut PMA has maintained a strong alliance between the industry, UC researchers, UC Farm Advisors, BIOS partners, cooperators and PCA's. Now that the alliance has developed reduced-risk practices that can be demonstrated we plan to strengthen our relationships with growers through more outreach.. The alliance has been instrumental in serving as a communication body between all groups interested in reducing the reliance of pesticides in walnuts. It has helped direct and attract research funded by the walnut board that is directly relevant to the needs of developing economic reduced risk practices for growers. The Farm advisors and BIOS project managers have been able to participate and keep abreast of the reduced-risk practices which they can quickly extend to their local BIOS and extension programs. One of the most significant accomplishments of the walnut PMA is the strength of the management team and its ability to maintain these partnerships that is essential to the eventual success of reducing pesticides on walnuts. The walnut PMA has been able to attract additional researchers to the project since its inception. These include Dr. Steve Welter and Dr. Doug Light. The management team has attracted several parallel projects which will greatly enhance the

adoption of pheromone confusion in walnuts. One project is supported by the Center for Agricultural Partnerships and will have parallel demonstration projects statewide in the same growing regions and will pay PCA's to conduct the demonstration and the monitoring. This will be an important parallel project for including the PCA's which will be the ultimate user ensuring adoption of pheromone confusion with successful demonstrations. At the same time they will be learning how to monitor the effectiveness of mating disruption so that growers do not have failures.

The blight demonstration program has moved along faster than originally planned with the Xanthocast Model becoming available to Sacramento Valley growers through Fieldwise.com and funded by Griffin LLC. As the walnut PMA trains growers on using XANTHOCAST, they are also validating the model at each of the blight demonstration sites statewide. In 2000, it had only been validated at one site in Tehama County. In 2001, the PMA had 3 uniform walnut blight trials across the state to evaluate a weather driven walnut blight control model called xanthocast and to evaluate an early eradication treatment developed by Dr. Lindow. The low incidence of rainfall resulted in low walnut blight damage with no significant differences between treatments. Numerically the best treatment was the eradicate plus grower practice treatment at 2.5% blight. The poorest treatment was the untreated at 1% blight. In the Farmington demonstration the treatment following the model was able to save one spray with no increase in blight. Results look promising for growers to have a tool to help them reduce the number of applications for blight control.

One covercrop trial continues in Yuba County in 2001. A field meeting was held which was attended by 25 people. Results have shown that planting a winter annual self reseeding plot helped reduce winter weed problems, other trials have shown that it has increased water infiltration and decreased run-off. A fact sheet from the walnut PMA will be developed on using covercrops that can be handed out at meetings and posted on the walnut PMA web site.

Methyl Bromide - Alternatives for California

Tom Trout⁶

USDA-ARS-San Joaquin Valley Agricultural Sciences Center

Preplant soil fumigation with methyl bromide (MeBr) has been a standard practice for several California high value crops such as strawberry, sweet potato, and certified nursery stock, common practice for replant of several tree and vine crops, and has also been widely used for pepper, melon, tomato, lettuce, and carrot production. Over 15 million pounds of MeBr was used annually in California through the 1990s, over 90% of which was for soil fumigation. Table 1 summarizes recent MeBr use in California.

Growers have depended on methyl bromide since the 1960s to control several critical soil pests (diseases, nematodes, and weeds), reduce pest control costs, provide increased yields, and reduce risks associated with pests. It has often been combined with chloropicrin for crops susceptible to fungal diseases. Methyl bromide has been very effective on a wide range of pests for a wide range of crops under a wide range of conditions. It also often provides a growth response even when no acute pathogen is known.

Table 1. Methyl bromide use in California in 1996 - 99 (adapted from CA DPR Pesticide Use Reports)

<i>Crop</i>	<i>MeBr use (lbs)</i>	<i>Portion of Crop (%)</i>
Strawberry	4,800,000	94%
Sweet Potato	600,000	42%
Peppers	400,000	9%
Melons	500,000	7%
Other annual vegetables and fruits	1,200,000	
Vineyards	1,700,000	20%
Peach Orchards (all stonefruit)	1,000,000	35%
Walnut	500,000	32%
Almond	800,000	14%
Nurseries	1,600,000	
Cut Flowers	500,000	
Commodity Fumigation	400,000	
Structural Fumigation	400,000	

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Methyl bromide has been determined to be an ozone depleter, and thus is being phased out under the international Montreal Protocol. The manufacture and importation of MeBr (note that “use” is not regulated) is being reduced in all developed countries by 25% in 1999, 50% in 2001, and 70% in 2003, with a complete phaseout in 2005 (with limited “critical use” and “quarantine” exemptions). Consequently, MeBr production/importation is presently set at 50% of use in the “base” year (1991). Actual use in California in 2000 was 10.9 million pounds or about 60% of the base year amount in CA. Developing countries are given longer to phase our MeBr use, although current “import and manufacture” is capped so use can’t increase.

In response to reduced supply, the price of MeBr has gone up substantially in the last 3 years - from about \$1.00 per pound to about \$3.20 per pound in 2001. State regulation of MeBr use has also become more restrictive, resulting in restricted application areas and increased application costs. As a result of these factors, MeBr use is declining, especially for those crops that cannot afford the increased costs (vegetables, trees and vines), or that have identified viable alternatives.

University of California pathologists and nematologists and USDA-ARS scientists are seeking alternatives to MeBr fumigation. USDA-ARS spends about \$16 million per year in research related to MeBr alternatives - approximately 30% of that effort is located in California (Fresno, Salinas, Davis, and Riverside). The effort in CA is targeted primarily at finding alternatives for strawberries, orchard and vineyards, nurseries, and ornamental crops.

The research is two-pronged. For short and medium-term, we are testing alternative fumigants and application methods for fumigants, and cultural practices that make those fumigants more effective. For the longer term, an IPM approach is being sought that requires less chemical inputs. This requires improving our understanding of the pests and soil biology. In some cases, the particular pests that are controlled by MeBr are not even known. For example, the causes of tree and vine “replant disorder” are not known. Multiple pests are often involved, many of which might have been controlled by a single fumigant. Fumigants often give a growth response without an identified acute pathogen. IPM approaches will have to be tailored to specific pests, crops, and conditions. They will often involve cultural practices that improve soil health and reduce pest pressures, breeding for pathogen resistance, and biological control agents. This effort will be ongoing.

I will summarize some of the promising alternatives that are currently being tested, and in some cases, used by growers. The best source of recent information on MeBr alternatives is the annual proceedings of the Annual International Research Conference on MeBr Alternatives and Emissions Reductions (<http://www.mbao.org/>).

Currently Registered Fumigants

Three alternative fumigants are currently registered: 1,3-Dichloropropene (Telone products), chloropicrin, and metam sodium (which produces the fumigant methylisothiocyanate (MITC)). Their use will depend upon regulatory restrictions, effectiveness for the pest and conditions, and cost.

Telone is an effective nematicide and was used widely on tree and vine crops before its use was

restricted in the early 1990s. Since it came back on the market in 1994, its use has increased rapidly, reaching 4.4 million pounds in 2000, and will likely be the alternative of choice for many tree and vine growers and for vegetables that suffer from nematode damage. It is currently a registered treatment for the CA nursery certification program. In combination with chloropicrin, it has been used successfully for strawberries. It is commonly shank applied, but is less mobile than MeBr and thus application methods and conditions are more critical to its effectiveness.

Telone is the only one of the three registered alternative fumigants that has completed the risk assessment and reregistration process. Use conditions will limit its use in some cases. In California, “township caps” will limit use in townships where fumigated crops are concentrated. Overall, about 2/3 of the current MeBr use could switch to Telone, although the impact on particular crops (strawberry and crops in townships where strawberries are grown, sweet potato) will be severe. Telone use also has restrictive Personal Protective Equipment requirements, requires moist soil for application but is ineffective in wet soils, and allowable rates (35 gal/ac) will reduce effectiveness in some cases.

Chloropicrin has been used widely in combination with MeBr for 50 years. In response to increasing MeBr restrictions and costs, it is being used in increasing proportions with MeBr. Chloropicrin use in Ca in 2000 was 3.8 million lbs. It is an effective fungicide and moves well in the soil. As a stand alone product, it has shown good efficacy for strawberry (yields within 10% of MeBr) at high rates (>300 lb/ac). It has also shown very good growth response in the replant of orchards, although it is not known as a good nematicide. Shank-applied chloropicrin is not effective against weeds. Chloropicrin will likely be used in combination with other alternative fumigants. Current labels are not restrictive to use. California has not set use conditions for chloropicrin because it was always used in combination with MeBr in the past. Chloropicrin is currently in the risk assessment process and more restrictive use conditions are expected.

Metam Sodium (*Vapam*, etc.) is the most widely used fumigant in California. As a lower cost fumigant alternative, its use has exceeded that of MeBr the last two years (12.8 million lbs in 2000), and it is used on nearly 3 times as many acres as MeBr, mainly on annual fruit and vegetable crops such as carrots, processing tomato, and potato. MITC does not move as well as other fumigants in the soil, so distribution of the metam sodium is critical to effectiveness. It can be either shank applied, or applied with sprinkler or drip irrigation. Many studies show mixed efficacy results with the poor results usually blamed on poor distribution. Strawberry yields with metam sodium generally are not as good as with other fumigants. Metam sodium is generally considered a good herbicide, and has been used for this purpose in combination with chloropicrin or Telone. The present metam labels are not too restrictive to use, but the product is under CA DPR risk assessment and recent “incidents” have resulted in more restrictive use conditions for “sensitive” areas (large buffers, intensive monitoring, soil seal requirements).

Other Fumigants

The phaseout of MeBr has increased interest in other potential soil fumigants that are in various stages of investigation or registration. Most of these are new looks at old chemistries.

Iodomethane (methyl iodide) has been patented as a soil fumigant by U.C. Riverside and is being tested by numerous people. TomenAgro has rights to the process and is aggressively pursuing efficacy and use information and registration. Iodomethane has shown efficacy and activity similar to MeBr for a range of crops (strawberries, trees, vines). It can be applied either by shank or through drip irrigation. It does not dissipate as rapidly from the soil as MeBr, and phytotoxicity may be a problem with some crops. Registration could be complete as early as 2004. Cost has not yet been determined, but it will be more expensive than MeBr. It will likely be mixed with chloropicrin for most applications to reduce cost.

Propargyl Bromide was patented by Dow in the 1950s as a soil fumigant, and was marketed and used briefly. The material can be unstable, and was taken off the market after an “explosive” incident. USDA/EPA in conjunction with a chemical company (Albemarle) is re-evaluating the product (the patent has expired). Initial results show efficacy similar to MeBr at about one-third the rates. The potential registrant has developed a stabilized formulation that has been granted a DOT permit for shipping and handling. The registrant is still evaluating whether to pursue registration.

Other potential soil fumigants currently in the exploratory stage include sodium azide, furfural and propylene oxide. Several other pesticides are also being tested including fosthiazate, enzone (carbon disulfide generator) and compounds containing iodine. Although MeBr alternatives will be fast-tracked through the registration process at both the federal and state levels, at least three years is generally required to put together the registration package. Thus, these materials would likely not be available until after 2005.

Fumigant Application in Drip Irrigation

Although MeBr is too volatile to contain in water, all of the alternative fumigants currently being studied are either soluble in water, or can be emulsified and held in suspension in water. This allows application through irrigation systems. Due to volatility and air emissions, drip irrigation is the only irrigation application method being considered (except for metam sodium). We have been very successful applying emulsified forms of telone and chloropicrin in surface drip under plastic mulch and in subsurface drip with a surface water seal. Iodomethane and Propargyl Bromide have also been successfully drip applied. Application through drip irrigation systems greatly reduces worker safety issues, because application is through a “closed” system and no workers are required in the field during application. Indications are that application with water may give better efficacy in some cases (because the material is distributed in water and the pest is in a moist environment). We are achieving better weed control in strawberries with drip applied telone and chloropicrin than with shank applied MeBr. Thus far, drip-applied fumigants have produced yields equal to or better than those with shank application. Drip application may also reduce emissions, and thus health hazards and regulatory restriction that result from emissions.

Drip application to crops such as strawberries that are bedded and drip irrigated under plastic mulch can be a simple and low cost alternative. We have developed methods to meter the emulsified fumigants directly into the irrigation manifold from pressurized tanks. For perennial crops that are normally drip or microspray irrigated, we shank in drip tape about 8" below the

surface on about 24" spacings in the treated area and use the existing water distribution system to deliver the water through temporary surface manifolds to the drip tape. The drip tape and installation costs about the same as the cost of plastic mulch. When fumigants are drip-applied, it is critical that the irrigation system is sound and leak free and delivers water uniformly, that the water source is protected from backflow, and that the materials are well flushed from the pipelines.

Good efficacy with drip application requires good distribution of the fumigant. The movement of the fumigant relative to the water depends on the chemical and emulsifier, and to less extent on the soil temperature and condition. If the fumigant volatilizes quickly, it may not travel as deeply as the water moves. Since high soil water content slows fumigant movement, it may also stay in the soil for longer time. We have carried out extensive studies to determine the soil distributions of water applied fumigant/emulsifier combinations.

Drip applied telone (*Telone EC*) and telone/chloropicrin (*InLine*) are currently registered. *InLine* was applied to over 400 acres of strawberries in California last year. Drip application of chloropicrin is also labeled in CA and several hundred acres of field trials have gone in.

Cultural Practices

Cultural practice changes may be required to help bridge the gap between the loss of MeBr and the availability of a full IPM approach. These practices may be in addition to use of alternative fumigants or instead of the use of fumigants, depending on the degree of disease pressure, the cost of the fumigant, and the value of the crop. Plant resistance to target pests, when available, should be used. Strawberry cultivars are now being tested for relative resistance to the primary strawberry fungal pathogens. Crop rotations will become more important to reduce disease pressures. For example, one year of fallow will often significantly reduce the orchard replant problem, and rotating between orchards and vineyards may be an alternative for some growers. Use of systemic herbicides to quickly kill the roots of an orchard crop may enhance the effects of the fallow. Use of non-host cover crops may also increase the fallow effect, although current tests have not shown significant effects.

Improving soil health through the application of organic matter or other materials may help, but costs are often high and little scientific data is available to quantify the benefits. Several biological agents have been shown to have fungicidal, nematocidal, or plant growth enhancement properties. However, it is often difficult translate laboratory or greenhouse results to field scale trials. In one recent test, plant growth promoting rhizobacteria (PGPR) promoted growth in strawberry, but the benefit was small compared to fumigation. However, when PGPRs were applied following fumigation with chloropicrin (so that biological competition was reduced), the benefits were significant.

Non-Chemical Alternatives

Organic growers have shown that, for some vegetable and fruit crops, good yields can be achieved without chemical inputs. However, for some sensitive crops such as strawberries, crop yields without fumigation only reach 50 - 75% of those with fumigation, in spite of good cultural

practices and high inputs. We don't yet know how to achieve the rapid and uniform growth of replanted orchards that fumigation enables. We don't yet have adequate post-plant control measures for many acute pathogens that fumigation controls.

Summary

Progress has been made, and several alternative fumigants, improved application methods, and beneficial cultural practices have been shown to maintain yields nearly as good as those with MeBr. However, there is no drop-in replacement - no silver bullet, and the cost and management requirements of most alternatives will be higher than with MeBr. These alternatives will maintain productivity in most cases in the short term. Most fumigant alternatives are in jeopardy of regulatory restrictions, so we cannot depend completely on one chemical replacement. We must continue to work towards diagnosing, understanding, and targeting specific pathogens and problems, improving germplasm resistance, and improving our understanding of soil biology.

Improving Our Understanding of *Lygus* in the Cropping Landscape

Peter B. Goodell⁷

Lygus (*Lygus hesperus*, Western Tarnished Plant Bug) is an indigenous mirid insect that acts as an economic pest in many crops. Cotton, seed alfalfa, dry beans, strawberries, and lettuce are a few of the economically important crops on which it feeds. In addition, many plants can serve as hosts without suffering damage and include both crops (sugar beets, alfalfa hay, and safflower) and weeds (clovers, mustards, tarweed, Russian thistle).

Lygus population densities are low in spring but build during the late spring and summer. As crops and weeds mature, senesce, and dry out, they become unsuitable hosts, forcing *lygus* to move into adjoining crops. Thus, as the season progresses, *lygus* are forced into a smaller and smaller area and are concentrated into the remaining crops. Our understanding of *lygus* buildup, movement and the relationships between crops is improving.

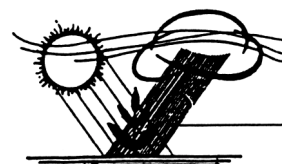
Our work⁸ involves the characterization of the landscape in terms of *lygus* sources and sinks. We seek to identify key crops that act as sources and understand the importance of their placement relative to susceptible crops that act as sinks. We believe that alfalfa hay plays a key role in the landscape of *lygus*. It is a preferred host for *lygus* and is the only crop maintained in perennially immature (vegetative) state. If properly managed, alfalfa can help mitigate its movement into susceptible crops.

The role of alfalfa may be determined by its relative abundance in an area. If an area has an appropriate proportion of its area in alfalfa, little may be required to manage *lygus*; that is insects will move from alfalfa field to alfalfa field. In areas where alfalfa is present but in low abundance, block cutting to stagger harvests or strips might be left to preserve some preferred habitat. In areas where there is no alfalfa in the landscape, consideration might be given to developing a regional management approach in which alfalfa is added to the crop mix.

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⁸ Acknowledgements: This work required the effort of many people. Dr. Charles Summers and Dr. Shannon Mueller are co-investigators. Ms. Kris Lynn and Dr. Stuart McFeeters provided GIS support. Mr. Charles Haas, Ms Cecilia Garcia, Mr. Albert Newton and Ms Susan Mallek provided technical and field assistance. All their contributions are acknowledged and appreciated.

**WATER QUALITY,
AGRICULTURE
AND TMDL's**



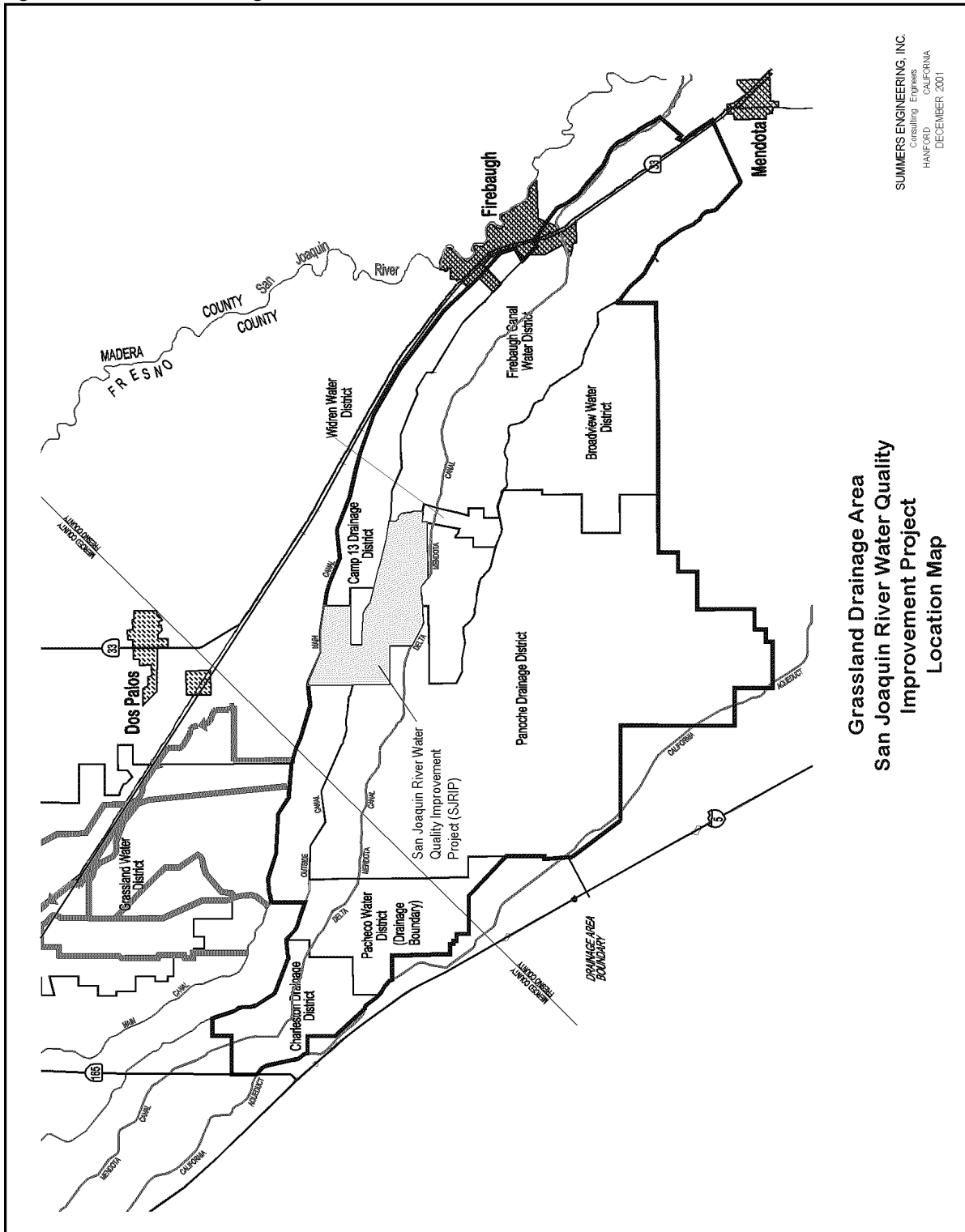
Grassland Area Farmers – Measures to Meet Salt, Selenium, and Boron TMDL's for the San Joaquin River

Joseph C. McGahan, Summers Engineering⁹

The Grassland Drainage (GDA) area is a 97,000 acre irrigated area on the westside of the San Joaquin Valley, south of Los Banos (see Figure 1). The GDA is made up of seven water and drainage districts as well as approximately 7,100 acres of land not incorporated into a district. In 1996, farmers in the GDA implemented the Grassland Bypass Project (GBP) to manage the agricultural drainage discharged from the region. Prior to the GBP, drainage water generated by the region was discharged to the San Joaquin River through a series of wetland channels. Because the drainage water contained high concentrations of salinity, boron, and selenium, they did not meet water quality objectives set for these sensitive wetland areas. As part of the GBP, a bypass canal was constructed to divert drain water around the wetlands, and through a portion of the San Luis Drain, where the drain water is discharged to Mud Slough and eventually to the San Joaquin River. The GBP freed up more than 90 miles of conveyance channels that can now be used exclusively to deliver fresh water to wetlands. However, with the implementation of the GBP and operation of the San Luis Drain came a use agreement that required close monitoring of drainage discharges and Total Maximum Monthly Loads (TMML) for selenium. Figure 2 shows the historic selenium discharge and current and future annual selenium load targets as part of the GBP agreement.

⁹ Drainage Coordinator for the Grassland Area Farmers.

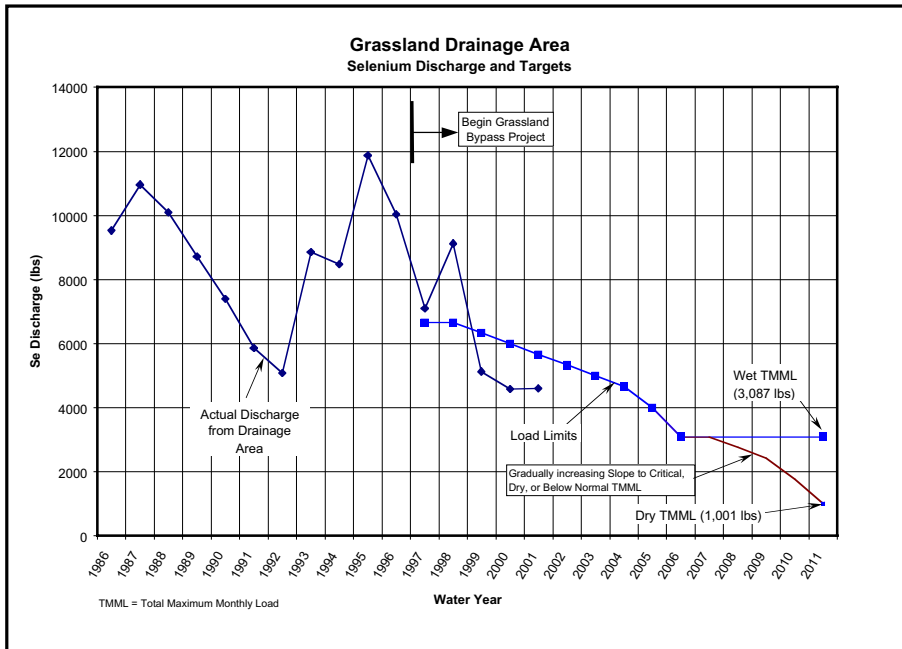
Figure 1: Grassland Drainage Area



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 HANFORD, CALIFORNIA
 DECEMBER 2001

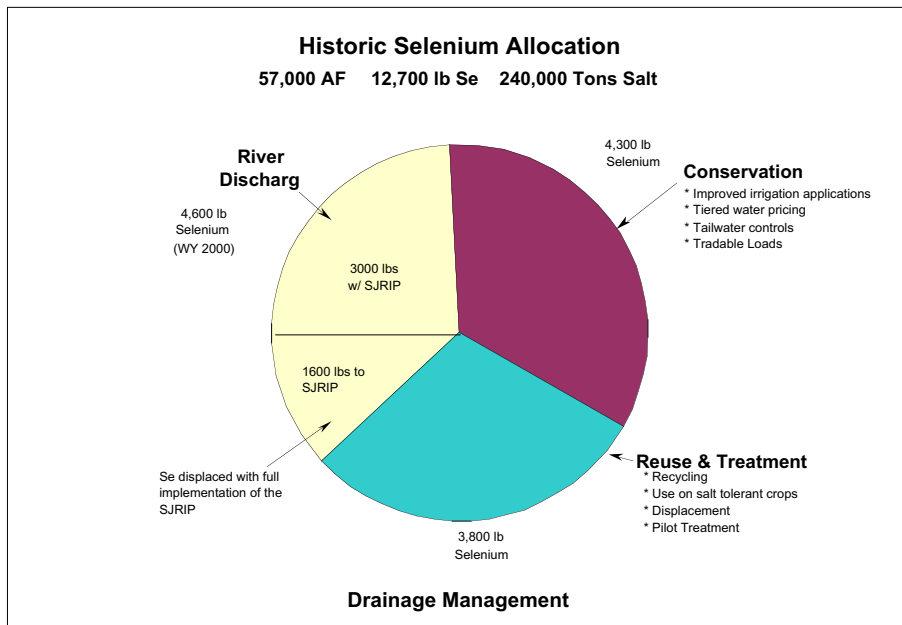
**Grassland Drainage Area
 San Joaquin River Water Quality
 Improvement Project
 Location Map**

Figure 2: Selenium loads and targets



In the first four years of the GBP, farmers within the GDA have been able to reduce discharges to the San Joaquin River by 41% from pre-project levels, with a 55% reduction in selenium discharge. These reductions were made by programs initiated by the districts and farmers within the region. Figure 3 shows a breakdown of selenium load allocations compared to historic discharges for the GDA.

Figure 3: Selenium Load Management Allocation



The Grassland Area Farmers have reduced drainage discharge to meet the TMML's through a variety of management methods ranging from reduction in applied irrigation water, to drainage reuse and treatment.

Water conservation has provided a 34% reduction in historic selenium discharges, accomplished through some key policies implemented by the drainage and water districts in the GDA. The policies include making available low interest loans for irrigation system improvements, tiered water pricing to encourage reduced water use, mandated tail water recirculation, and a tradable loads program to encourage districts to work together to meet the TMML's. Drainage reuse and treatment activities have allowed the Grassland Area Farmers to further reduce their discharges.

By 1998, most of the districts within the GDA had installed recirculation systems to return subsurface drain water to their irrigation systems. This, along with other programs such as pilot treatment and displacement have eliminated some 23,000 acre feet of drain water from discharge. Additionally, in January 2001, four thousand acres of farm land was set aside as part of drainage management project, dubbed the San Joaquin River Water Quality Improvement Project (SJRIP) (see Figure 1).

With the SJRIP, 4,000 acres of farmland will be taken out of regular irrigated agriculture and planted with salt tolerant crops and irrigated with subsurface drain water produced by the districts within the GDA. Currently, 1,800 acres of the project has been planted and, in water year 2001, the SJRIP disposed of 2,800 acre feet of drain water, displacing 1,000 pounds of selenium, 14,000 tons of salt and 62,000 pounds of boron. The full implementation of the SJRIP is expected to remove more than 9,000 acre feet of drain water from the drainage stream, preventing 1,600 pounds of selenium, 34,000 tons of salt, and 120,000 pounds of boron from being discharged to the San Joaquin River.

The SJRIP project is still in development, and other methods of drainage management are being researched, including both reverse osmosis and biological treatment, with ultimate salt disposal. All of these methods show promise as drainage management tools, and the ultimate solution will likely be a combination of many of these tools.

Developing Implementation Plans for San Joaquin River Pesticide TMDL

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Background

Non-point source (NPS) pollution originating from agricultural lands in the San Joaquin Valley has been identified as an important contributor of pesticides, nutrients, sediment and other constituents impairing the San Joaquin River (SJR) and bay-delta system. In response to declining water quality in the SJR watershed, regulatory action focusing on NPS pollution is in the works. Of particular concern is the impending Total Maximum Daily Load (TMDL) for the pesticides diazinon and chlorpyrifos and the expiration of the Waiver of Waste Discharge Requirements for Irrigation Return Flows.

Important components of each of these regulations are the implementation plans. Among other requirements, implementation plans must describe practices that farmers can use to mitigate off-site movement of pesticides from their lands. In general, these plans will need to cover the three sources of off-site movement of pesticides:

- *storm water runoff*
- *irrigation drainage*
- *spray drift*

A group of agricultural interests has been formed to assist in the development and enactment of the implementation plans for pesticide TMDL and irrigation return flow problems on the SJ River. This group, called the *Agricultural Implementation Group (AIG)*, is being organized and collaborated by CURES.

Program Follows Sacramento River Effort

The activities of the AIG are being patterned after similar programs already in place in the Sacramento River watershed. The Sacramento River AIG is a coalition of stakeholders organized by CURES and formed out of the Sacramento River Watershed Program (SRWP), Organophosphate Focus Group (OPFG) subcommittee. The AIG is leading an effort to reduce runoff and pesticide loading from dormant season orchard sprays in the Sacramento River. This effort relies on demonstration farms and outreach and education programs. The primary emphasis of the programs is on storm water NPS runoff. The outreach and education program initiated in Winter 2001/2002 is targeted to farmers and PCAs in the Sacramento River watershed and is being assisted by the AIG members including commodity groups, pesticide dealers, county Agricultural Commissioners and other stakeholders in the watershed.

A similar approach by the SJR AIG is being planned for the SJR watershed. However, due to differences in crop type, hydrology, and constituent effects from both dormant spraying and irrigation runoff, the emphasis in the SJR watershed will be adjusted to ensure that management efforts are appropriate to the region. Successful practices identified in the dormant orchard demonstration farms in the Sacramento River watershed will be useful to the program developed for the SJR watershed.

Emphasis on Demonstration and Education

As in the Sacramento River watershed, efforts in the SJR watershed will rely on demonstration and education/outreach projects. One important program where funding is currently being pursued is focused on identifying and evaluating region-specific, feasible management practices (MPs) with the highest potential for reducing or eliminating pesticide, nutrient and other contaminant loads carried by irrigation return flows. Findings from this work will be communicated to farmers, agriculture professionals, regulatory agencies and irrigation districts through demonstration sites and outreach programs.

A primary component of the SJR AIG is working closely with multiple, local stakeholders in the SJR watershed. The AIG has the support of the commodity groups that represent the primary crops grown in the region (almonds, stone fruit, alfalfa, canning tomatoes); all the Agricultural Commissioners whose counties encompass the SJR watershed; the major retail sellers of fertilizers and pesticides who operate in the SJR watershed; CAPCA, the regional chapter and state organization representing PCAs; the largest irrigation districts operating in the project area; among other local groups. These organizations represent San Joaquin Valley farmer's primary source of information about agriculture, irrigation and crop production techniques. The AIG will facilitate efforts to provide solutions to the irrigation return flow problem while availing itself to the wealth of expertise afforded by this close relationship.

AIG Goals

The goal of the AIG is to evaluate, demonstrate and promote the voluntary adoption of MPs by landowners who may be impairing the SJR. The efforts will aim to identify promising MPs for the region and effective outreach programs to promote MPs; facilitate the development and transfer of MP information to farmers, and increase awareness levels and voluntary use of MPs.

CURES is a non-profit organization formed to address environmental stewardship issues relating to the safe use of crop protection products. CURES operates by forming coalitions with interested groups in agriculture, industry, academia and government to develop funding and work on solutions to pesticide and nutrient-related problems. The CURES Board of Trustees is made up of individuals committed to this goal. Parry Klassen, the CURES Executive Director, is himself an orchard grower whose career in agricultural communications spans 20 years. The independent Board of Trustees, chaired by Len Richardson, editor of *California Farmer* magazine, sets priorities for CURES. Additional CURES board members include; Lon H. Records, President, Target Specialty Products; Jim Poorbaugh, Vice President, Monrovia Nursery; R. Mark Layman, Division Manager, Helena Chemical Company; Dennis Kelly, Syngenta; and Bryan Stuart, Dow AgroSciences.

The Phosphorus Index: A tool for producers facing a TMDL

Bob Fry, State Agronomist
NRCS, California

Summary: The California Phosphorus Index (PI) is a tool designed to identify, and guide the treatment of, fields with high risk for the loss of P to surface water. The PI will also identify fields with low risk for P loss. The PI can not be used to measure or estimate the amount of P that will be lost from a given field. It will not help producers measure reductions in P loss from their fields, which may be required in a TMDL watershed. It will help target resources to high-risk fields and identify site specific practices needed to control P loss. As such, it can be a valuable tool for logical implementation of TMDL requirements. Local use may suggest modifications in the initial PI format. A process for local adjustment is in place. The PI is intended for use on land upstream or adjacent to surface waters impacted by P from agricultural sources. A screening process is used to assure the PI is not applied to fields that pose no significant risk to surface waters. However, NRCS will assist any producer concerned with the risk his/her operation may pose to surface waters who chooses to use the PI.

Introduction

The California Phosphorus Index (PI) is a tool designed to identify, and guide the treatment of, fields with high risk for the loss of P to surface water. The PI will also identify fields with low risk for P loss. By distinguishing between high and low risk fields the PI can help producers and regulators efficiently use resources for P control. Areas with high risk can be identified and treated, while areas of low risk will not receive the investment and effort needed to address P loss. The three specific pathways of P loss are erosion, surface runoff, and leaching. These are analyzed separately to ensure the highest risk condition is identified and the appropriate treatment is planned.

The PI was developed by NRCS with the close assistance of the University of California Cooperative Extension, the Potash and Phosphorus Institute, private industry, a regulatory agency, and California Certified Crop Advisors¹. Over a period of nine months this first draft of the PI was prepared, and is being offered for field review. Field review is needed to determine the appropriateness of the criteria used to assess risk, and to set the scoring levels that best indicate the severity of risk. The PI is not expected to work throughout the state of California without local modification. After field review we expect several approved localized versions of the PI to be in use. Approval of local versions is obtained using the NRCS Field Office Technical Guide Committees established at the regional and state levels. A Technical Note containing more detailed guidance is being prepared to support field testing and planning use of the PI.

Working with NRCS is voluntary. A producer may ignore a PI rating with no consequences, though it may disqualify him/her from financial assistance if control of P loss is an objective of the contract. Ultimately, progress in control of agricultural non-point source pollution is in the hands of owners and operators of farmland. They must decide to take on the job. NRCS hopes to assist as a partner.

TMDL and the P Index

Phosphorus is a pollutant in fresh surface waters primarily because it can stimulate algae growth. Algae is undesirable for aesthetic reasons, for the unpleasant flavor, odor, and treatment expense it adds to drinking water, and for its ability to create substantial reductions in Dissolved Oxygen (DO) when a major algal die off occurs. Aquatic life may die or avoid areas with low DO. This can affect local aquatic populations and hinder migration of fish.

P from agricultural sources has not commonly been documented as a problem in California. This may be due in part to: 1) a lack of monitoring, 2) the receiving waterbody is not a source of drinking water, 3) there are plenty of other problems to keep us busy, or 4) there is no major problem. There are probably several more reasons.

In some areas of California P may be identified as a pollutant that must be controlled to achieve water quality standards. The Regional Water Quality Control Boards may be receiving funding to expand a water quality monitoring program. If funded, SWAMP (Surface Water Ambient Monitoring Program) will result in systematic sampling of water bodies in search of pollution problems. A water body with a pollution problem will be listed on the “303d” list of impaired water bodies. A TMDL may then be prepared. At that time, for each water body with P related impairment, sources of P pollution will be assessed, water quality targets set, and actions prescribed to reduce discharges of P. If agriculture is found to be a contributor, producers may be asked to reduce their discharge by specified amounts, and could be subject to monitoring and legal action if they fail.

A commonly held view is that it is not effective to lower the P level for algae control in receiving waters unless the level is lowered below the threshold for algae growth, or the “growth limiting” level. However, studies in Europe² have shown that by lowering the P concentration algae levels will be reduced in waters where P far exceeds the “growth limiting” level. In situations with very high P levels in receiving waters producers may be asked to reduce P discharges, even when P levels will remain high with controls in place. Other alternatives can be considered for these water bodies, but the long-term solution may involve on-farm measures.

TMDLs rely on numerical goals for discharges to improve water quality. The PI can not be used to measure or estimate the amount of P lost from a given field before and after treatment. Even so, it has use in a watershed facing a TMDL for P. The PI will be useful to a producer who must plan a strategy for compliance. The PI can be used to target actions appropriately, and to find the most effective and least cost alternative for reducing P losses.

The Regional Water Quality Control Board, not NRCS, declares water bodies to be impaired by P. NRCS offers the PI as a tool to producers who must respond to such a declaration. NRCS will not require our staff to apply the PI where there are no known impacts from agricultural P on surface water. However, NRCS will assist any producer who wishes to assess the risk his/her operation may pose to surface waters, and who chooses to use the PI as an assessment tool.

Technical basis of the P Index

For P to enter a surface water body there must be both a pathway and a P source available. These are referred to as the “Transport” and “Source” factors, respectively. These factors are evaluated independently and multiplied together to determine the final field risk rating. Typical “Transport” factors are soil erosion, irrigation tailwater, rainfall runoff, and the type of drainage system in place on the field. Typical “Source” factors are the level of plant available P in the soil, the amount and type of P applied, and the method of P application. Each of these factors is evaluated for each field, or group of fields with nearly equivalent conditions.

P leaves the field in three ways: 1) Attached to, or mingling as a particulate among eroding soil particles, 2) dissolved, or suspended within organic material, in water that runs off the field, or 3) dissolved in water that leaches through the soil profile and is extracted by pumping from less than 50 feet deep without use for irrigation, withdrawn from a tile drain, or that seeps from the soil to surface water. For the PI, there must be an extraction or seepage outlet point within 500 feet of the field to have risk from leaching. Each of these pathways is analyzed individually in order to focus attention on the highest risk factor for the field. Tables 1 and 2 show the PI factors used to calculate risk from the three pathways. The RUSLE soil erosion estimation tool needed for a PI evaluation is not yet available in California. The older tool, USLE may be substituted temporarily.

With a few exceptions where calculations are used, the PI considers management actions and the on-farm decision-making process when preparing an evaluation. This is because, for planning purposes, it can be more useful to evaluate how things are done, rather than carefully measuring a single situation. For example, how accurately can we measure the rate and evenness of manure application on the farm? There are a large number of variables that make this difficult, and our measurements would only be valid for the particular time the evaluation was performed. If we know how the producer decides on the amount of manure to apply, and how he/she decides to apply it we have a better measure of the long-term risk on the field. This does not discount the importance of testing. Consistent use of soil, tissue, and manure sampling is key to routine management of organic and commercial fertilizers, and is used as a low risk indicator.

Risk Assessment Estimates

The results of the PI analysis will assign a field a “Risk Rating”. The four ratings are Low, Medium, High and Very High. For fields with **Low risk** the producer is expected to apply commercial fertilizer in accordance with UC guidelines based on soil and tissue sampling where available for the crop. Manure is applied according the N requirement of the crop and the N content of the manure. A **Medium risk** field would receive the same recommendation as a low risk field, but with recognition that the risk may increase with no changes in management. Future risk assessment is suggested. **High risk** fields may receive manure, but at a P based rate. That is, the amount of manure to apply will be limited to the amount needed to meet crop P requirements based on the P content of the manure. This will usually mean that extra nitrogen will need to be applied. Commercial fertilizer is to be applied with the same guidelines as the two lower risk categories. A plan must written and followed to lower the risk rating to Medium or less. A **Very High risk** rating excludes the application of manure. Commercial fertilizer may be applied according to UC published guidelines based on soil and tissue sampling. If soil test P exceeds a certain level then no P may be applied from any source. An exception is provided for a starter fertilizer injected during seeding of winter planted vegetables. A plan must written and actively applied to lower the risk rating to High or less. When a follow-up assessment shows that the risk is lowered, then the requirements at the new rating will apply.

Table 1 Transport Factors used to calculate field Risk Ratings

Transport Factors:	Erosion	Runoff	Leachable
Soil Erosion - RUSLE	X		
Irrigation induced erosion	X		
Ephemeral gully erosion	X		
Irrigation Tailwater		X	
Runoff Class		X	
Subsurface Drainage			X
Drainage system type	X	X	X

Table 2 Source Factors used to calculate field Risk Ratings

Source Factors:	Erosion	Runoff	Leachable
Soil Test P (Olsen or Bray)	X	X	X
Commercial P Application Rate	X	X	X
Commercial P Application Method	X	X	
Organic P Application Rate	X	X	X
Organic P Application Method - Solids	X	X	
Organic P Application Method - Liquids	X	X	

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Terry Bechtel, RWQCB, Region 5

Many others were consulted to whom we owe thanks.

2/ Albrechtel, Detlef R “Results of Fifteen Years of Continuous Monitoring of Water Quality in the Ruhr River Heavily Affected by Residual Point and Nonpoint Pollution,” American Water Resources Association’s *Nonpoint Pollution: 1988-Policy, Economy, Management, and Appropriate Technology*, pp271-280, November (1988).

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Newport Bay/San Diego Creek Agriculture, Nursery, and Landscape TMDL Project

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Introduction

Agricultural and nursery production, and urban landscapes in the Newport Bay/San Diego Creek Watershed are considered to be potential sources of pollutant loading to San Diego Creek, the main tributary for the Newport Bay. Due to the ecological importance of the Newport Bay, San Diego Creek was placed on the state's 303(d) list for impaired waterbodies, a listing that requires the development of a Total Maximum Daily Load (TMDL). The goal of the TMDL is to return the waters to a condition where its beneficial uses are no longer impacted by the identified pollutant(s). The process to reach this goal is both costly and time-consuming.

The development of a sediment and nutrient TMDL for the Newport Bay Watershed proceeded rapidly in response to litigation. This required the Santa Ana Regional Water Quality Control Board (SARWQCB) to identify sources of pollution and allocate loads for those sources. Lack of data and time forced the SARWQCB to estimate nitrogen and phosphorus loads in agricultural surface runoff. Agricultural baseline flow and nutrient data were limited to that collected by three large wholesale nurseries to meet their waste discharge requirements. The timeline required for TMDL development was not sufficient, however, for baseline monitoring of surface runoff from agricultural fields. In order to address this problem, SARWQCB utilized a phased approach that allows for incremental reductions in loads over several years as well as the opportunity to revisit loads previously set when new information becomes available. Currently load reductions have been established for the end of 2002, 2007, and 2012. The final goal is to reduce total nitrogen and phosphorus loading by 50% in 2012.

Agricultural producers in the Newport Bay Watershed, in order to meet the goal of a 50% reduction by 2012, will need to implement additional Best Management Practices (BMPs) that specifically address the movement of nitrogen and phosphorus compounds in surface runoff. The agriculture and nursery project seeks to establish baseline loads of nitrogen and phosphorus in surface runoff from agricultural and nursery fields. The data will then be used to evaluate the effectiveness of implementing BMPs to improve the quality of surface runoff from both row crops and nurseries.

Currently, assessments are being conducted by the SARWQCB in preparation for the writing of TMDLs for diazinon, dursban, selenium, legacy pesticides (DDT and other organochlorines), heavy metals, and fecal coliform.

DESCRIPTION

Agriculture project:

The initial phase of the project involved developing an accurate database of agricultural crops and their acreage in the watershed. Agricultural sites that represent the various types of production occurring in the Newport Bay Watershed were then selected for monitoring to develop baseline data. Other selection criteria included the following: the accessibility of site; the ability to install flow monitoring and water sampling equipment without drastic changes in a grower's existing drainage design; and the willingness of a grower to implement BMPs following the collection of baseline data.

Each site consists of two plots, a control plot and a treated plot. A monitoring program was initiated on both plots to collect both baseline flow data and nutrient concentrations. The monitoring program was conducted through the end of 2000. The implementation of BMPs on treated plots began in 2001 following an evaluation of the baseline flow and nutrient data.

The baseline-monitoring program consists of the placement of automatic water samplers in the field once a week to sample surface runoff for a 24-hour period. Surface runoff flow is measured continuously with an area-velocity flow meter thus allowing for the estimation of nitrogen and phosphorus loads. Conditions when monitoring equipment cannot be utilized such as during field preparation, is replaced with grab samples if surface runoff is present. Water quality parameters consist of pH, electrical conductivity (EC), (NO₂ + NO₃)-N, NH₄-N, TKN, PO₄-P, and total-P. All nutrient analyses are being conducted by Irvine Ranch Water District's EPA approved water testing laboratory while EC and pH measurements are completed in the field.

Total flow measured from row crop fields during both the summer season (April – September) and the winter season (October – March) beginning April 2000 to the present are shown in Figures 1 and 2. The majority of flow occurs during the winter season and the establishment of strawberry transplants in September and October when overhead sprinklers are used to irrigate. The utilization of drip irrigation following transplant establishment results in no surface runoff, if managed correctly, for a majority of the growing season. Surface runoff present during the summer season can be attributed to excessively long run times for leaching, leaking systems, or the use of overhead irrigation to produce a bean crop, although this occurs on a very small percentage of the total acreage. Rainfall levels greater than 1" were characterized by substantial sediment loads that interfered with flow monitoring. Errors in flow readings due to equipment failures caused by sediment occurred on four occasions (Fig. 2; Jan-01, R3; Jan-01, R6; Feb-01, R3; Feb-01, R7).

Figure 1. Monthly Flow from Row Crop Fields During Dry Season (April-September)

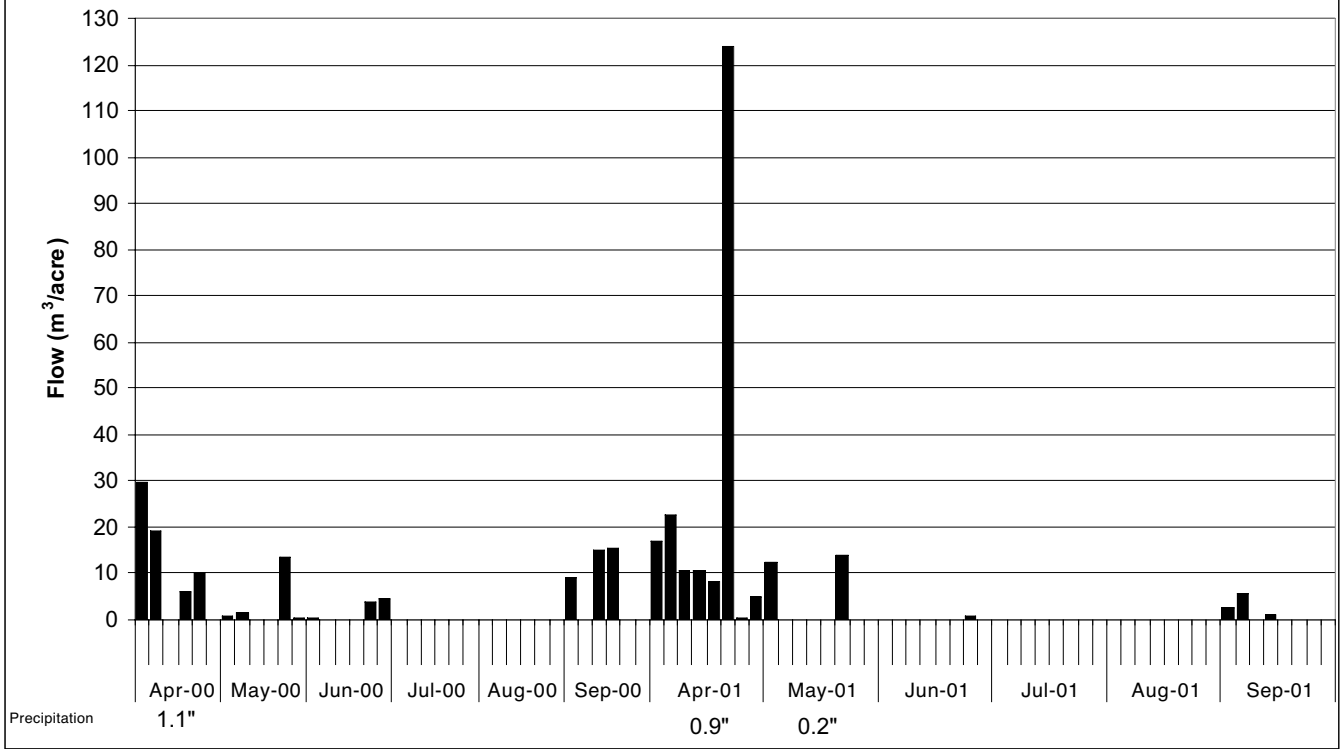


Figure 2. Monthly Flow from Row Crop Fields During Wet Season (October-March)

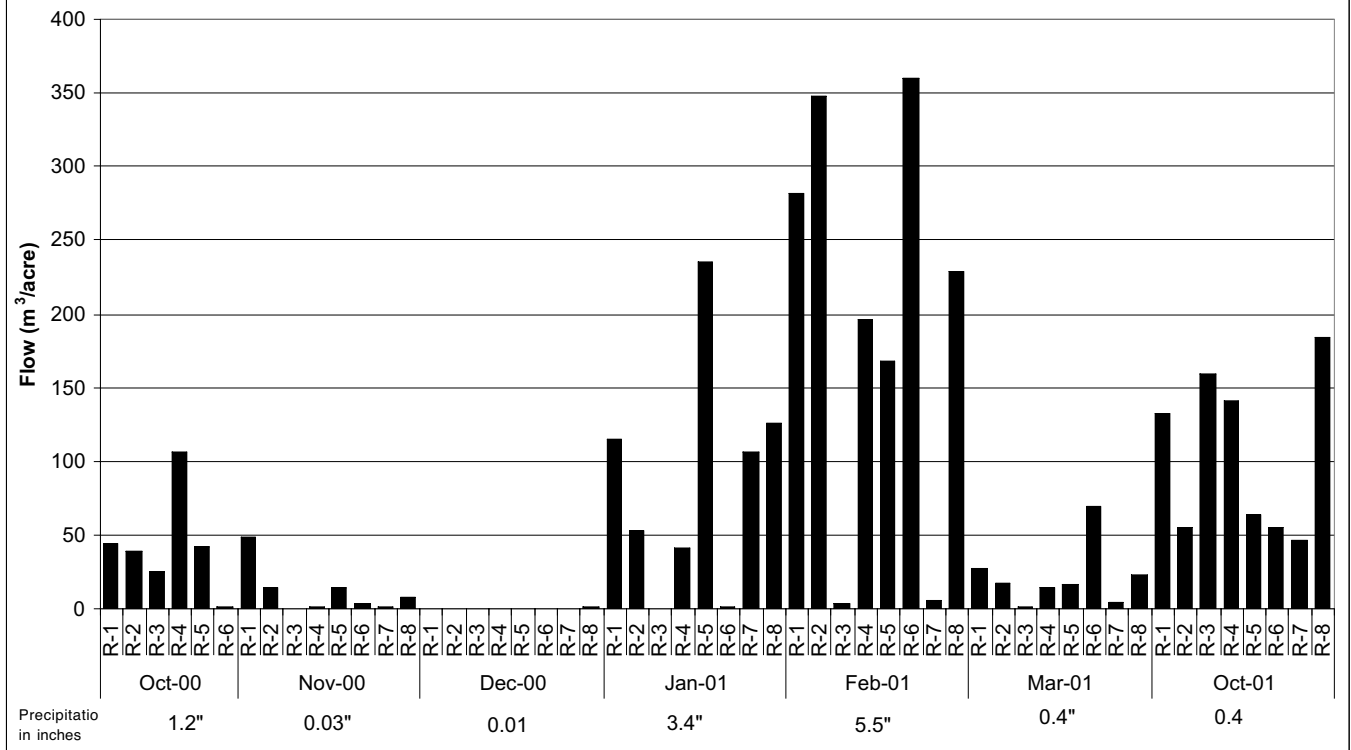
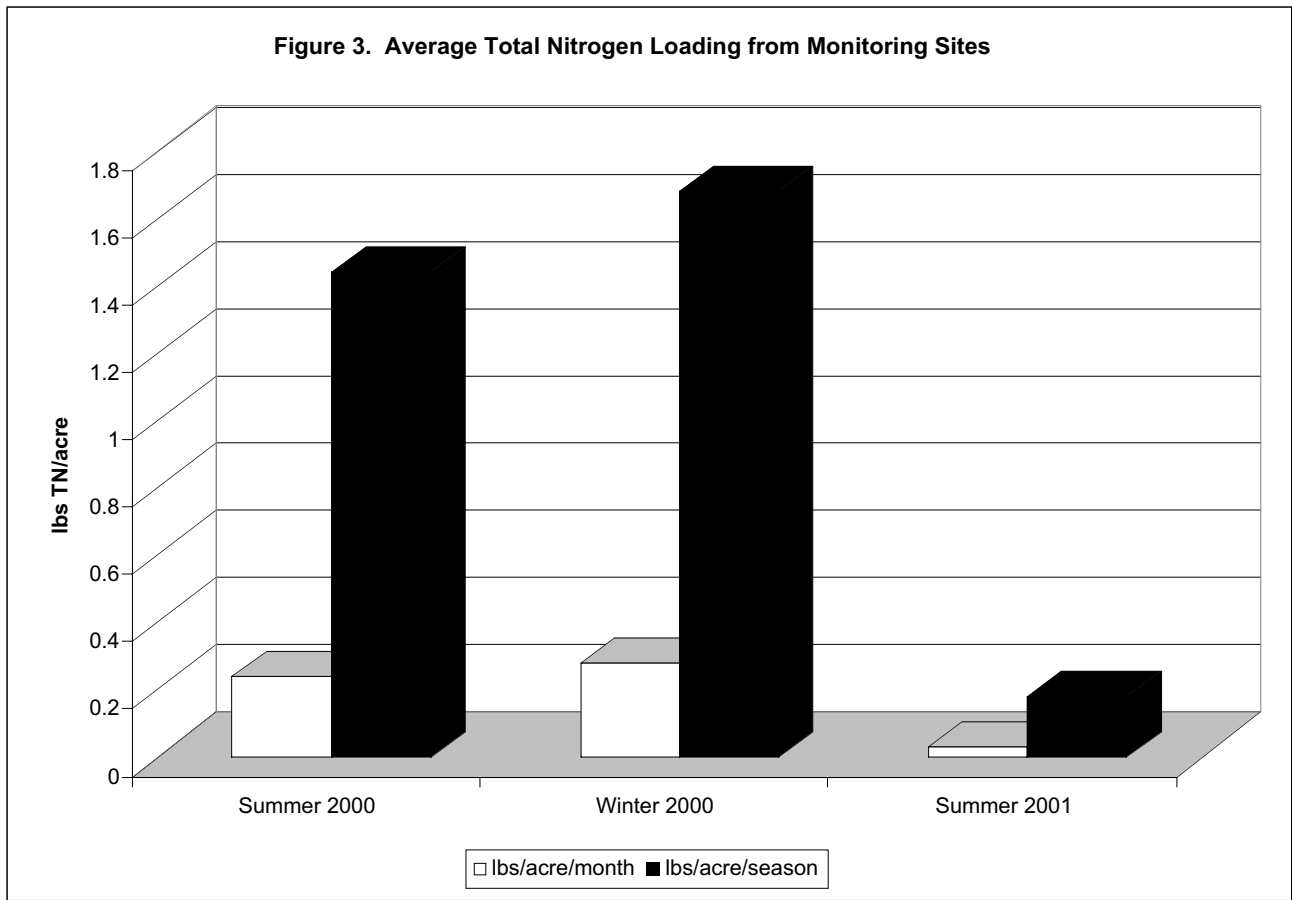


Figure 3. Average Total Nitrogen Loading from Monitoring Sites



Nursery and Landscape:

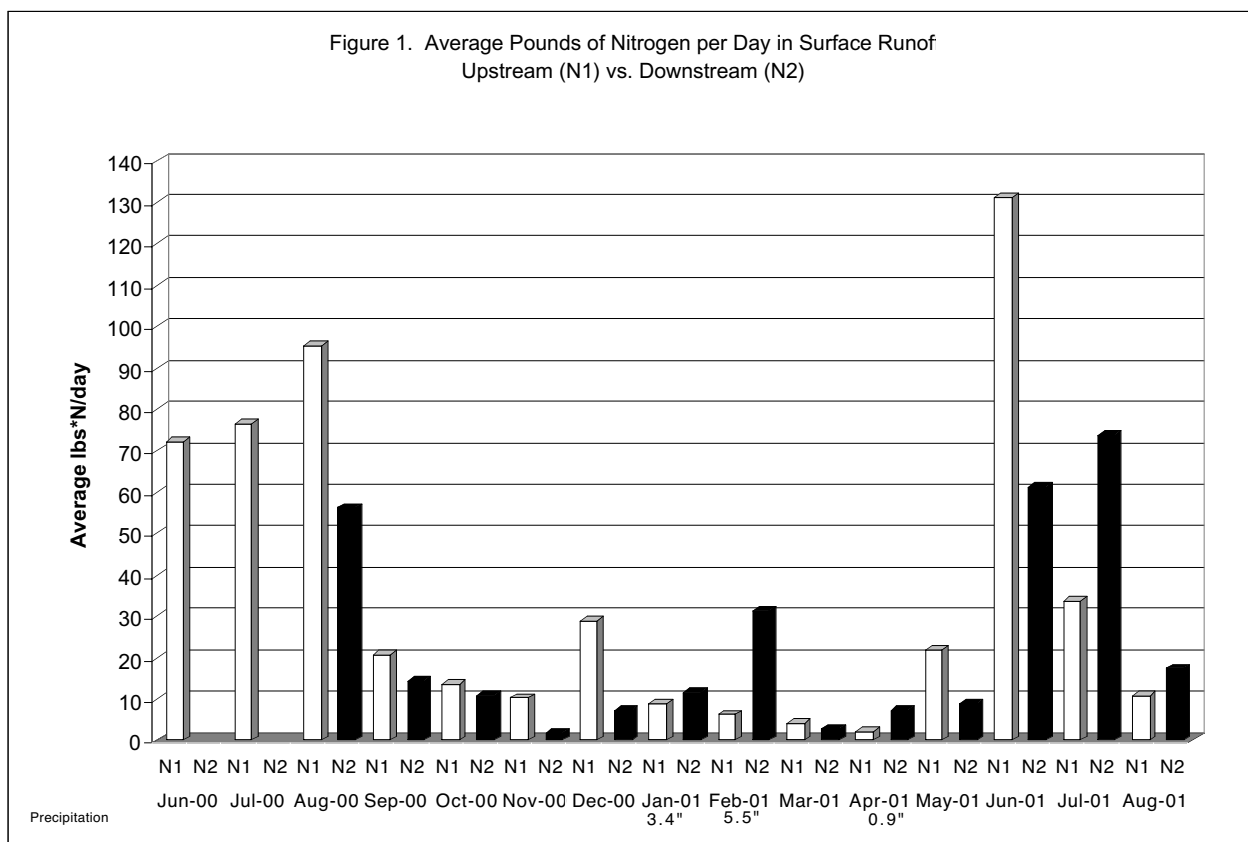
Currently, scientists from the University of California Division Agriculture and Natural Resources division (UC ANR) are involved in the monitoring of pesticide runoff from nurseries and urban landscapes in collaboration with the California Department of Pesticide Regulation (CDPR), California Department of Food and Agriculture (CDFA), SARWQCB, Orange County Public Facilities and Resources Department (OC PFRD), and the nursery industry.

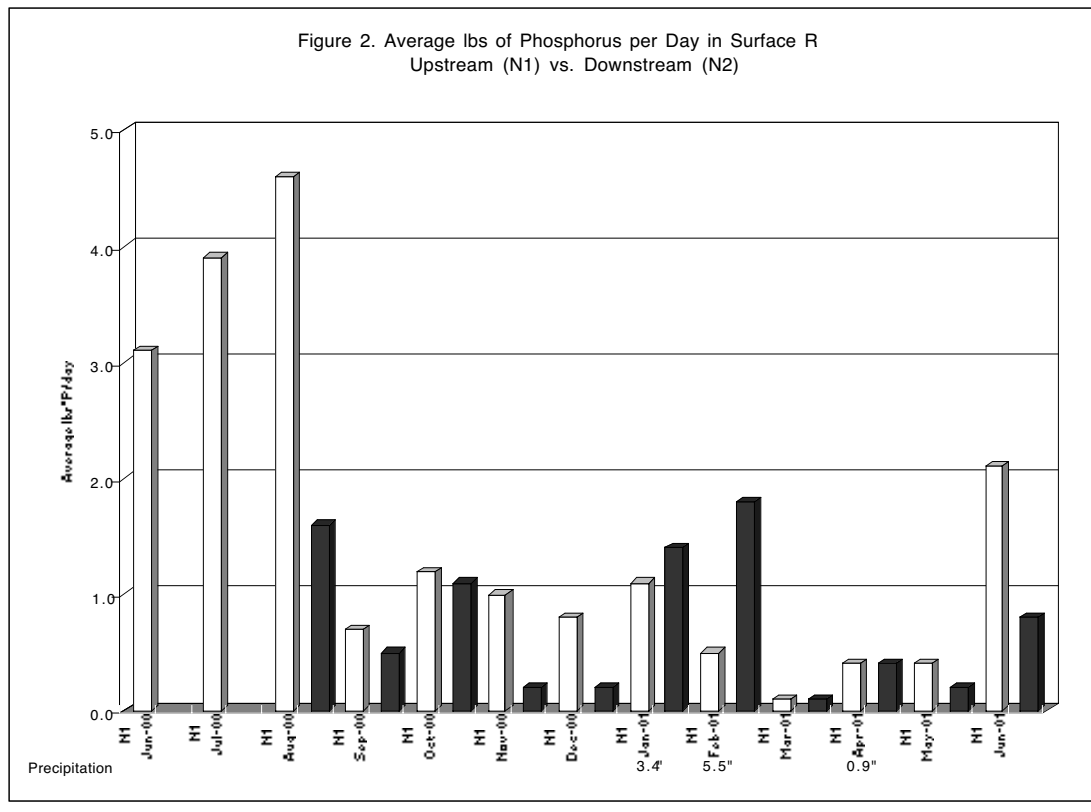
The nursery industry and urban landscapes have been identified as a potential source of pollutants that could be contributing to the impairment of local water bodies. Surface runoff originating from irrigation practices and rain events contain fertilizers and pesticides utilized during production and maintenance.

The Newport Bay/San Diego Creek Watershed Nutrient TMDL, adopted in 1999, includes individual load allocations for three large nurseries and single load allocation for a group of smaller nurseries. Load allocations for each of the three larger nurseries were based on data collected from individual Waste Discharge Requirements (WDRs) permits issued in the late eighties.

Two of the three larger nurseries addressed the discharge of surface runoff by constructing reservoirs and implementing an irrigation-recycling system. However, due to the high upfront costs and the dedication of usable land for the reservoir, smaller nurseries are not as likely to implement this practice. The third nursery, in conjunction with the UC ANR, CDFA, and CDPR, implemented a variety of low-cost mitigation practices (polyacrylamides, sediment traps, sediment pond, and vegetative filter) that not only resulted in the reduction of the concentration of pesticides and nutrients in surface runoff, but also the awarding of an IPM Innovator Award from CDPR.

During the summer season, the vegetative filter strip is effective in reducing the average lbs N/day and P/day leaving the nursery. The concentration of nutrients in the runoff remains fairly constant from inflow to outflow monitoring stations. However, the overall flow is generally significantly less at N-2 compared to N-1 resulting in lower nitrogen and phosphorus loading at N-2 (Figure 1 and 2). The measurement of higher flow levels at N-2 is a result of inputs such as direct rainfall into the channel or excessive irrigation in a plot located next to the filter, but below the N-1 sampling point. During July and August of 2001, excessive water and fertilizer inputs into this plot resulted in both higher flow and nitrogen levels. During the winter season, rainfall and cooler temperatures reduces the effectiveness of the vegetative filter.





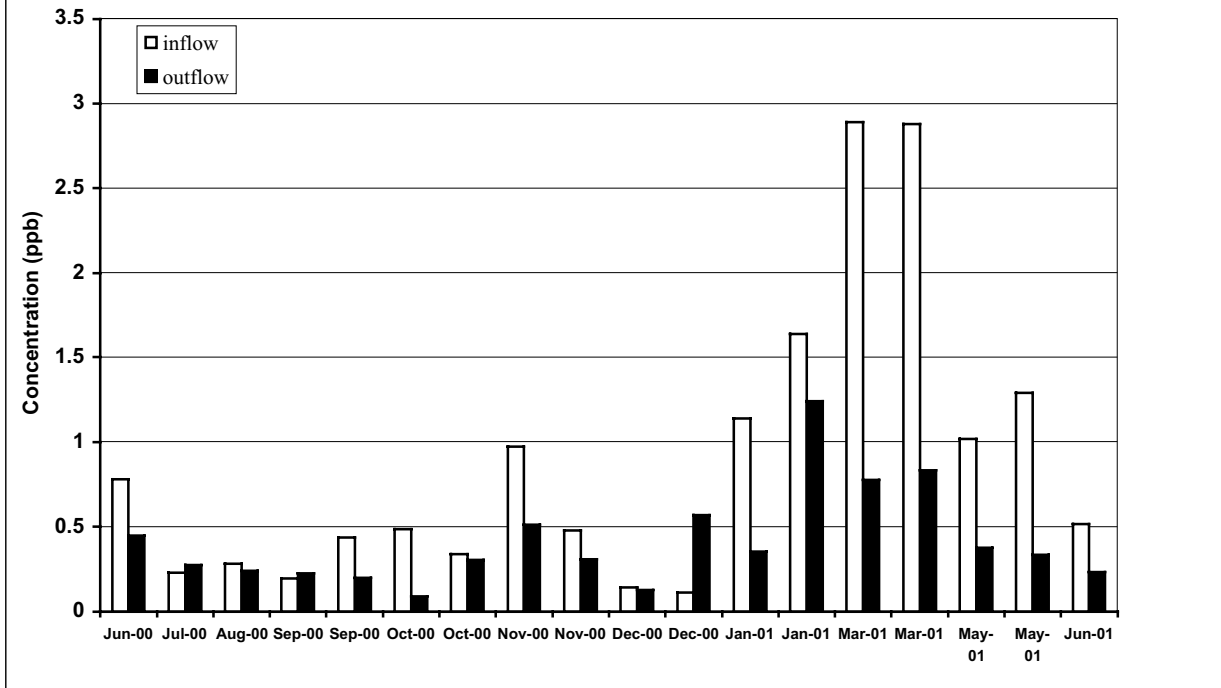
Monthly pesticide sampling is conducted by CDPR to monitor the movement of pesticides utilized by the nursery to meet quarantine requirements for the Red Imported Fire Ant (RIFA).

Bifenthrin, an insecticide incorporated into potting mix for control of RIFA, has a low water solubility and high soil adsorption coefficient. These properties should keep bifenthrin out of surface runoff and bound to soil particles. However, surface runoff from the nursery contains high sediment loads that contain soil bound pesticides, especially bifenthrin. The monthly sampling by CDPR has detected levels of bifenthrin in surface runoff and sediment samples that are toxic to the indicator species, *Ceriodaphnia dubia* (0.076 ppb). The vegetative filter successfully reduces the levels of bifenthrin in the water column (Figure 3). However, the resident time of water within the filter is not sufficient in length to allow the biological breakdown or uptake of bifenthrin to lower the levels below the toxicity *C. dubia*.

The installation of a sediment trap and the addition of PAM to surface runoff was initiated in late December 2001 therefore their effectiveness has not been established, however preliminary results look very promising. Water quality data has been collected with the vegetative filter and the sediment pond in place for over a year.

Figure 3. Bifenthrin Concentrations in Vegetative Filter Strip

[Data courtesy of Dr. Kean Goh, CDPR]



The educational component of this project is comprised of a series of forums and workshops. Forums are informal meetings between agriculture operators, nursery growers, UCCE project staff, public agencies, and representatives from the SARWQCB. The meetings provide the opportunity for updates on the project as well as interaction between the agency developing TMDLs and those that are directly affected it.

Workshops focus on management strategies that are useful to both agriculture, nursery operators, and public agencies maintaining urban landscapes, in reducing nutrient loads in surface runoff. The meetings are held several times during the year focusing on specific topics such as nutrient and irrigation management. New technologies are demonstrated in an effort to expose growers and maintenance personnel to equipment available to assist them in making sound nutrient and pest management decisions.

Farmer-led Effort to Protect Water Quality

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The Coalition of Central Coast County Farm Bureaus (Coalition) represents six County Farm Bureaus in a voluntary farmer-led program to protect water quality. The Coalition's Agricultural Water Quality Program (Program) is truly a proactive effort on behalf of the agricultural industry and is unique in that it began prior to the development of total maximum daily load regulations in most Central Coast watersheds.

History

The Program covers watersheds that drain to the Monterey Bay National Marine Sanctuary (Sanctuary) from San Mateo, Santa Cruz, San Benito, Santa Clara, Monterey, and San Luis Obispo counties. The Coalition was formed four years ago in response to a DRAFT Water Quality Action Plan for agriculture developed by the Sanctuary. Representatives from the Six County Farm Bureaus met with Sanctuary staff for over two years in discussions on how to make the Action Plan more practical and realistic for agriculture. The final Action Plan was completed in October 1999. It includes commitments from the agricultural industry, regulatory & technical assistance agencies, and agricultural organizations. The Coalition agreed to take the lead in providing the structure to meet the commitments made on behalf of agricultural producers. All of the Action Plan's strategies are aimed at making it as easy as possible for individual agricultural landowners and managers to address water quality protection voluntarily, without prescriptive regulations dictating how they do it. Because local involvement will determine how water quality regulations are enforced, there is a need to have an organization with widespread local presence and an understanding of agriculture to take the lead in outreach. Farm Bureau fills that role with its network of farmers and ranchers throughout California.

Structure

The Coalition structure consists of three levels. The Coalition Coordinating Committee with representatives from Six County Programs, the County Farm Bureau Programs, and the Watershed Working Groups. The most important component of the program is the watershed working group made up of agricultural landowners and managers along a stream or a portion of a river. The focus of the groups is to look at water quality issues in their watershed, determine where the issues are related to agriculture, and ultimately to make water quality improvements with minimal burden to individual operations. Watershed working groups meet with local researchers and regulatory agency representatives to discuss research findings and to contribute information. The Coalition is working with Regional Water Quality Control Boards and water quality experts to develop a consistent way of monitoring and tracking the successes of watershed working groups in the Six Counties in a way that respects privacy issues. The watershed working groups report existing efforts and planned projects to protect water quality through a watershed report submitted to the Regional Boards. In addition, watershed working groups hold regular meetings to exchange experiences with conservation practices, and participate in University of California Cooperative Extension (UCCE) short courses where they

develop individual water quality plans. The Regional Boards have committed resources to conduct long-term water quality monitoring in watersheds that have watershed working groups.

Each County Farm Bureau has an Agricultural Water Quality Coordinating Committee to oversee the County Program. The committees are responsible for setting priorities, developing county action plans, and retaining staff to conduct county programs. At the regional level the Coalition Coordinating Committee meets quarterly with representatives of each county program to share information and act as an umbrella for developing consistent procedures, communicating with public and regulatory agencies, and providing funding. At the state level, California Farm Bureau Federation has created the Agriculture Clean Water Initiative Foundation (ACWI) to support programs like the Coalition's around California.

Case Study: Chualar Creek Watershed Working Group

During the first two years of the Program Chualar Creek Watershed Working Group was organized as a pilot. Chualar Creek Watershed runs from Chualar Canyon into the Salinas River in Monterey County. The top of the watershed is dominated by grazing lands with scattered vineyards. The Creek travels through a rural residential area with upwards of seventy homes, and finally drains irrigated agricultural land before meeting with the Salinas River mainstem. The Creek is intermittent with a sandy bottom and transports irrigation tailwater during the summer months. The Salinas River is listed as an impaired waterbody by the State of California to U.S. EPA under provisions of the federal Clean Water Act. The pollutants of concern are nutrients, pesticides, salinity, Total Dissolved Solids, chlorides, and sedimentation/siltation. The state is required by law to set Total Maximum Daily Loads (TMDLs) for the amount of each of the listed pollutants the river can handle on a daily (or annual) basis. Agricultural landowners and managers in the Chualar Creek watershed developed an agricultural watershed plan that has been submitted to the Central Coast Regional Water Quality Control Board for consideration.

The group enlisted the services of a coordinator who conducted individual farm site visits and an inventory of existing water quality protection practices and commitments for future improvements. Roughly seventy percent of the irrigated agriculture acreage in the watershed was represented in the first inventory with additional farms agreeing to participate in the future.

Participants are working directly with local researchers who are monitoring for the presence of pesticides, nutrients, and sediment in Chualar Creek. The participants provide access to their properties and essential local information for the research. The Central Coast Regional Water Quality Control Board is assisting the group in analyzing monthly water quality samples taken in Chualar Creek above and below the group. Recognizing the importance of maintaining records of their efforts to protect water quality, many participants are in the process of developing a tracking system on their farms. Using simple, low-cost methods participants are recording practice implementation on their farms as well as observing general indicators of their practice effectiveness in protecting water quality. In January 2001 watershed working group participants completed fifteen hours of UCCE training and individual farm water quality plans were developed for thirteen farms covering 4724 acres in the watershed. The participants manage over 25,000 acres in total (inside and outside of the Chualar Creek Watershed). Participants meet regularly to become informed on current water quality research and water quality protection practices in and around Chualar Creek and on regulations pertaining to water quality. Participants rely on technical assistance from the local Resource Conservation District, Natural Resources Conservation Service, Community Alliance with Family Farmers, and University of California Cooperative Extension.

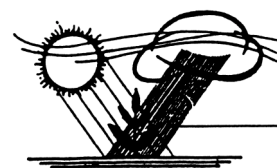
Partnerships

Referring back to the Sanctuary Action Plan, commitments were made by technical assistance and regulatory agencies to support the agricultural watershed working groups. In addition there are programs that were developed prior to the Action Plan that support voluntary efforts to protect water quality. The Coalition meets regularly with representatives from UCCE, USDA Natural Resources Conservation Service (NRCS), local Resource Conservation Districts (RCDs), and the Sanctuary to avoid overlap and coordinate activities related to carrying out the Action Plan. The Coalition organizes individuals into groups to more efficiently utilize agency assistance. UCCE provides technical assistance to watershed working groups by offering water quality short courses where participants develop nonpoint source water quality plans for their farms or ranches. Local Resource Conservation Districts offer workshops, trainings, demonstration projects, watershed planning and management practice technical assistance. NRCS offers technical and financial assistance for water quality protection practices and encourages regulatory coordination (aka permit streamlining) for water quality improvement projects. The watershed working groups and County Farm Bureaus combine efforts with other organizations and agencies on the local level including the Central Coast Vineyard Team, Community Alliance with Family Farmers, water districts, and citizen monitoring groups.

Where Are We Now?

Consistent methods for outreach to form watershed working groups and to monitor their effectiveness have been developed over the last two years through the Coalition Program. Six formal watershed working groups have been developed in four counties. Participants from six watershed working groups developed individual water quality plans in UCCE Farm and Ranch Water Quality Planning shortcourses. Twenty four more courses will be offered to new watershed working groups over the next two years through a partnership between the Coalition and UCCE. County Farm Bureau coordinators have been hired to assist in creating new watershed working groups in the Six Counties. The Coalition has received financial support from State Water Resources Control Board, CDFG, Sanctuary, Philip Morris and many local organizations. Other County Farm Bureaus around California are considering undertaking similar programs modeled after the Coalition's.

**ADVANCES IN
NUTRIENT
MANAGEMENT**



Nitrate Distribution in a Deep, Alluvial Unsaturated Zone: Geologic Control vs. Fertilizer Management

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Introduction

For decades, nitrate leaching from agricultural sources (among others) has been a concern to agronomists, soil scientists, and hydrologists. Federal legislation first recognized the potential impacts to water resources in the early 1970s, when the Clean Water Act (CWA), the Safe Drinking Water Act (SDWA), the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and other water pollution related legislation was enacted. Since then, countless efforts have been mounted by both the scientific-technical community and the agricultural industry to better understand the role of agricultural practices in determining the fate of fertilizer and pesticides in watersheds (including groundwater) and to improve agricultural management accordingly.

From a groundwater perspective, much of the scientific work relating to nitrate has focused on two areas: documenting the extent of groundwater nitrate contamination; and investigating the fate of nitrogen in the soil root zone (including the potential for groundwater leaching) as it relates to particular agricultural crops and management practices. Rarely, these two research areas are linked

within a single study and if they are, groundwater levels are typically close to the soil surface (less than 10 feet).

In California's valleys and basins, particularly in Central and Southern California, groundwater levels are frequently much deeper than 20 feet. The unsaturated zone between the land surface and the water table may therefore be from 20 to over 100 feet thick. Very few studies have investigated the fate or potential fate of nitrate in such deep unsaturated zones. Pioneering work on nitrate in deep soil profiles was presented by Pratt et al. (1972). They investigated nitrate profiles in a southern California citrus orchard to depths of 100 feet. The experimental site was subject to differential nitrogen treatment for 35 years from 1927 to 1962. Nitrogen treatments ranged from 50 to 350 lbs/ac. During the period from 1963 to the time of sampling in 1969, uniform treatment was applied at a rate of 150 lbs/ac. From their observations, the authors estimated that it would

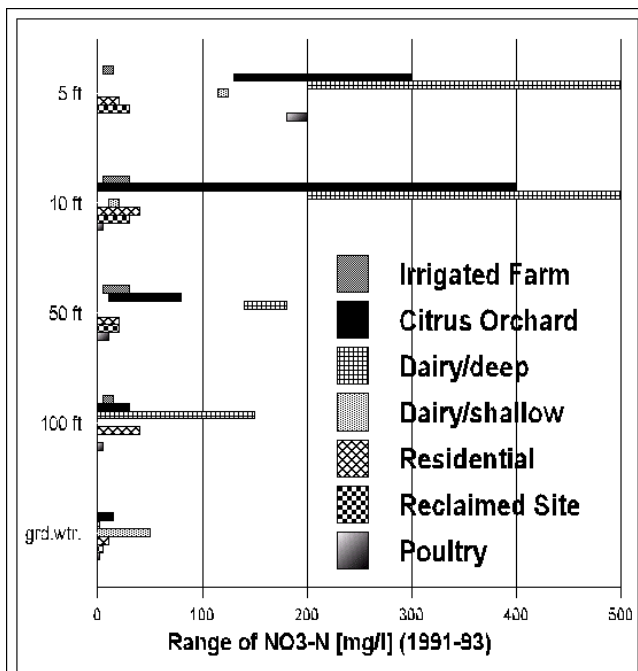


Figure 1. Range of nitrate-N concentrations at the bottom of the root zone and in the deep vadose zone. Water samples from the unsaturated zone and from groundwater were collected from seven instrumented access boreholes at seven sites in the Hemet basin, Southern California. Measurements were taken over a two year period (data from: Rees et al., 1995).

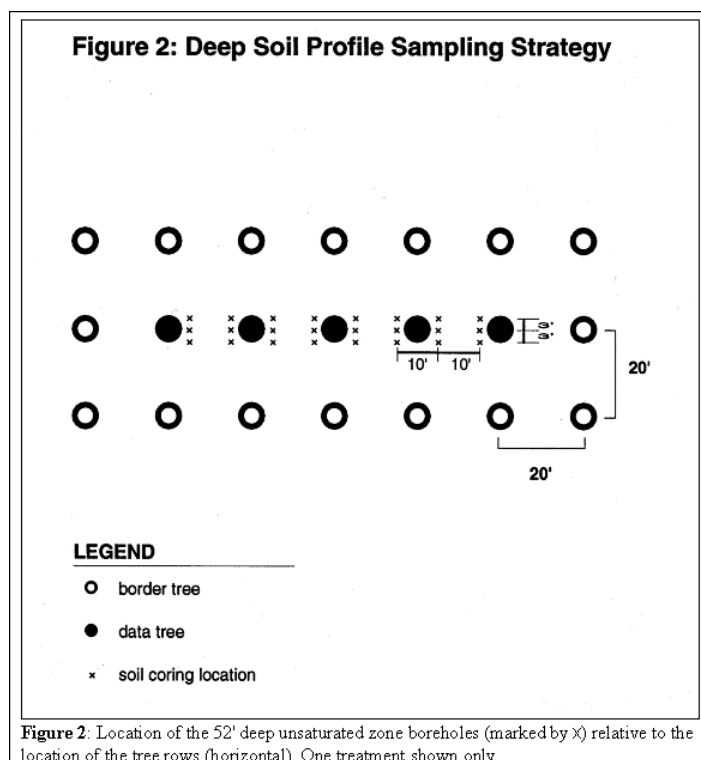
take between 10 and 50 years to leach nitrate to a depth of 100 feet. Average nitrate-nitrogen levels below the root zone varied from 15 to 35 ppm under the 50 lbs/ac treatment and from 35 to 55 ppm under the 350 lbs/ac treatment. Based on gross mass balance estimates, denitrification at that site may have accounted for up to 50% of nitrate losses in the thick unsaturated zone profile where application rates were high. Lund et al. (1974) argued that nitrate losses (presumed to be due to denitrification) were strongly correlated with the textural properties of the soil. High losses were found in soils with pans or textural discontinuities, while losses were limited in relatively homogeneous, well draining soils. Later work by Gilliam et al. (1978), Klein and Bradford (1979), and Rees et al. (1995) in other areas of southern California supported these observations (Fig. 1), but provided little quantification of these losses.

We have recently initiated the development of a deep unsaturated zone hydrology research site, located in a former ‘Fantasia’ nectarine orchard at the Kearney Agricultural Center, Fresno County, California. The objective of our work is to provide a comprehensive assessment of the fate of nitrate in a 50 feet deep alluvial unsaturated zone that is not untypical of many agricultural areas in California. The site had been subject to differential nitrogen treatments during a 12-year experiment prior to an extensive drilling campaign in 1997. The assessment includes extensive geologic, hydraulic, as well as geochemical characterization. In this paper, we investigate the spatial distribution of nitrate in the deep vadose zone and analyze its relationship to the geologic framework of the site (intrinsic control) and the amount of nitrogen application (extrinsic control). Results have relevance with respect to the potential for denitrification before leaching soil water reaches the water table; and also with respect to designing a monitoring program of the deep vadose zone.

Methods

A 12-year fertilizer management experiment (from 1982 to 1995) was implemented in a nectarine orchard that consisted of 15 rows with 15 trees per row (Johnson et al., 1995). The orchard is located at the southern end of the research farm at the Kearney Agricultural Center near Parlier, Fresno County. Tree spacing within rows and between rows was 20 ft. The fertilization experiment consisted of five application treatments in a random block design with triple replicates. Treatments included nitrogen application rates ranging from 0 to 325 lbs/acre/year (not including nitrogen applied via irrigation water). Treatment plots consisted of five trees. Two border trees and one border row on either side separated treatments. For the subsurface characterization, three treatment plots were selected (0, 100, and 325 lbs/acre/year). In 1997, undisturbed soil cores were drilled with

a direct-push drilling technique to a depth of 52 ft. At each of the three treatment plots, 18 cores were obtained (Fig. 2) and an additional six cores were drilled along a cross-section N-S through the entire orchard. A complete sedimentologic description by color, texture and moisture was made directly on the continuous core, prior to sample collection. 1,200 samples were collected (approximately one



sample every 2.5 feet). Samples were collected for each sedimentologic stratum or sub-stratum. Soil (or more precisely: sediment) samples for nitrate analysis were two inches in length and 1.5 inches in diameter. Samples were preserved and stored for later analysis of physical and biogeochemical properties including soil texture, soil hydraulic properties (water content, unsaturated hydraulic conductivity and water retention functions; Tuli and Denton, 2001), and analysis of soil biochemical properties (pH, dissolved organic carbon, nitrate-N; Horwath & Paul, 1994). We are currently developing a protocol to also analyze for nitrogen and oxygen isotopic composition on low volume samples.

Results

Geologic Framework (Intrinsic Control)

The site is located on the Kings River alluvial fan, approximately 2 miles west of the current river channel. The alluvial unconsolidated sediments are derived exclusively from the hard, crystalline Sierran bedrock. They appear as intercalated, thick and thin lenses of clay, silt, sand, and gravel. The deposits contain fairly well sorted subangular to subrounded sand and gravel, and intercalated lenses of silt, sand and gravel with some lenses of clay, showing a downstream decrease in grain-size (Page and LeBlanc, 1969).

The material obtained in the borehole cores is exclusively composed of unconsolidated sediments. The top section of the core material is a recent soil (Hanford fine sandy loam). The sediments can be classified into textural groups ranging in grain-size from clay to pebble and cover a wide spectrum of silty and sandy sediments in between. The colors of the sediments range from grayish brown to yellowish brown, more randomly to strong brown (no significant reduction zones). The thickness of the beds varies from less than 1 cm for clayey material to more than 2.5 m for sandy deposits. Both, sharp and gradual vertical transitions are present between texturally different units. Five textural units are found the cores: 1) sand, 2) sandy loam, 3) silt loam/loam, 4) silt/clay loam/clayey silt/clay, 5) paleosol. The relative occurrence of each category in percent of the vertical profile length (in 5 cm sections) are 17.2% sand, 47.8% sandy loam, 13.8% silt loam/loam, 8.3% clay loam/clay and 12.9% paleosol.

The sand is quartz-rich, contains feldspar, muscovite, biotite, hornblende and lithic fragments consistent with the granitic Sierran source. Cross-bedding at the scale of few cm could be observed occasionally within fine-grained sand, showing reddish-brown layers intercalated with gray-brown ones. The dominant color of the sand is a light gray to light brown, the brown hue increasing with increasing loam content. The thickness of the sand beds is as much as 2.5 m and is dependent on the location of the core relative to the course of an ancient secondary distributary channel in which the sediments deposited. The channel appears to have a northeast-southwest orientation, diagonally through the orchard site. The mean thickness is 1.7 m. Very coarse sand and particles up to pebble grain-size (up to 1 cm) could be observed occasionally at the bottom of sand units, but were not present in all the cores. These are probably channel lag deposits and were laid down in deeper parts of the channels.

Sandy loam is the most frequent category within the profile. The color is usually light olive to yellowish brown. Some of the sandy loam sediments are considered to be weakly developed paleosols because of their stronger brownish color, root traces and presence of aggregates. Mean bed thickness is 50 cm. Individual beds can be as much as 2 m thick. The sorting is moderate to good. Clay flasers and thin (0.5-1 cm) clay layers occasionally occur in sandy loam units. Sandy loam sediments are assumed

to have developed at the edge of channels, as levee or as proximal floodplain deposits near the channels.

Silt loam, loam and silty clay loam are usually slight olive brown to brownish gray in color. The bed thickness is within a scale of a few cm to dm. Fine grained sediments often show sharp contacts between the units. Changes from one unit to the next exist on small distances. Cross-bedding can more frequently be observed within silty sediments than in fine sands. Root traces and rusty brown colored spots are quite common. The depositional environment was presumably the proximal to distal floodplain of the alluvial fan, an area dissected by distributary branched braided streams.

The finest sediments are grouped in the 4th category: Silt, clay and clay loam. These are believed to have been deposited in the distal floodplain and in ponds that developed in abandoned channels. The main color is brownish gray to olive brown. Fine, less than 1 mm thick root traces and rusty brown spots are quite frequent also in the clay sediments. Statistics for the thickness of clay layers in the unit between 8 and 13 m depth show a mean thickness of 12.8 cm, but the mode is about 3 cm. A thick clay bed even extends to 50 cm and is observed in most of the cores.

Paleosols could be recognized in different stages of maturity. They show a brown to strong brown, slightly reddish color, exhibit aggregates, ferric nodules and concretions, few calcareous nodules and hard, cemented layers. They also display a sharp upper and a gradual lower boundary as is typical for paleosols (Retallack, 1990). Clay content decreases downwards in the paleosols. Another feature are fine root traces. Paleosols formed in periods of stasis marked by non-erosion and non-deposition, during the interglacials. Thickness of the paleosol horizons ranges from 50 cm to about 2 m.

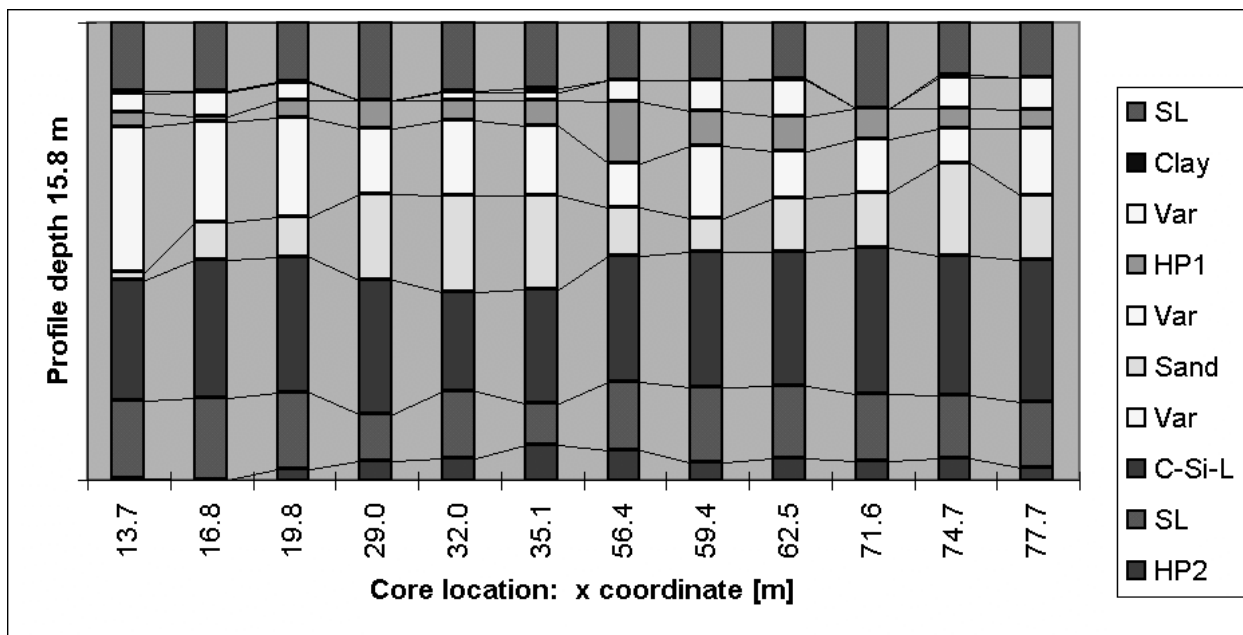


Figure 3: Stratigraphic cross-section along a tree-row showing the major stratigraphic units.

Several thicker units are recognized throughout the orchard and are used to construct a large scale geologic framework for the research site (Fig.3): The deepest parts of the cores from 15.8 to 15 m display a strong brownish colored, partly clayey paleosol hardpan. This paleosol marks the top of the Turlock Lake II formation (see below). From a depth of 15 to 12 m below surface, the main textural

units are sandy loam to fine sandy loam, occasionally coarse sand and gravel, and occasionally fine-grained sediments right on top of the paleosol. In the cores with fine sediment at the bottom of this unit a coarsening-upward, in the other cores a fining-upward cycle can be observed. The sediments show a remarkable wetness due to proximity to aquifer water table. The sediments are vertically and laterally quite heterogeneous with relatively thin bedding (thickness cm to dm) between about 12 and 8 m depth, consisting mainly of clayey, silty and loamy material. Another strong brownish paleosol can be distinguished at a depth of 9-10 m. Between 9 and 6 m below surface a sand layer is found with laterally varying thickness averaging 1.7 m. A weak, mostly eroded paleosol is developed on top of the sand unit. Up to about 4-3 m below surface, sandy loam with intercalated sand, clayey and silty material is found. Different trends of upward-fining and -coarsening are found on top of each other and laterally next to each other within this unit. A 0.2 m to more than 1 m thick paleosol hardpan occurs at a depth of about 4-3 m. This paleosol marks the top of the Modesto formation. Sandy loam and subordinated loamy sand and loam are present from the top of the hardpan to the surface. 2.5 m below surface a laterally continuous clay horizon with a thickness of few cm is found in most of the cores.

Stratigraphically, the Quaternary deposits in this part of the valley can be divided into four units (Marchand and Allwardt, 1981). The Turlock Lake, Riverbank and Modesto Formations are of Pleistocene age (which began 2 million years ago). The Post-Modesto Formation belongs to the Holocene (which began 10,000 years ago). Most of the stratigraphic units found at the site are believed to represent separate alluvial episodes related to Sierran glaciations. The deposits are likely related to flood events that predominantly occurred during the end of a glaciation period. Paleosols, on the other hand, are indicative of substantial time intervals (several thousands to tens of thousands of years) between periods of aggradation (Marchand & Allwardt, 1981) and represent stratigraphic sequence boundaries. Paleosols are buried soil horizons that were formed on stable upper-fan, terrace or hillslope surfaces during interglacial periods (Lettis, 1982). At the site, they consist of strongly cemented sand to sandy loam with a characteristic reddish-brown color. Cementation is primarily by Fe-oxide and Mn-oxide, but also from calcification. They result from initial stratification or drainage boundaries in soil parent material (Harden & Marchand, 1977). Soils that formed on top of the upper Turlock Lake Formation are estimated to be 600 Ka (1Ka = 1000 years) old (Harden, 1987). The estimated age of the Riverbank formation is 130-450 Ka. The Modesto Formation corresponds to the most recent glaciation period (Huntington, 1980).

Nitrate Applications (Extrinsic Control)

Annual fertilizer applications in the three plots were 0 lbs/ac, 100 lbs/ac, and 325 lbs/ac. Granular N fertilizer was applied to the 14 - 16 feet wide, shallow broad furrows, but not to the center berm of the tree-row, which is 3-5 feet wide (tree spacing is 20 feet in either direction). The first 100 lbs were applied in the fall of each year using a tractor mounted spreader. Application uniformity was not measured, but anecdotal evidence indicates that higher amounts were applied near the edge of the furrows and less in the center of the furrows. In plots with N treatments above 100 lbs/ac, additional fertilizer was manually applied in the spring of each year. Application was limited to the area around individual trees (in a 3 x12 sq.ft. area in the furrows on either side of each tree). The orchard received further nitrogen from nitrate in precipitation (less than 5 lbs/ac) and from nitrate in irrigation water (30 - 50 lbs/ac assuming 4-5 mg/l of nitrate-N in 3-4 acft/ac of irrigation water). Nitrogen losses from the orchard are predominantly by fruit harvest. While crop yields varied little between treatments, fruit N levels varied greatly from treatment to treatment. For the three treatments, harvest is estimated to remove 35, 70, and 110 lbs N /ac, respectively (*Scott Johnson, personal comm.*). Leaf N uptake and cover crop N uptake are assumed to be returned to the soil via leaf fall, decomposition, and mechanical incorporation into the soil. From an agronomic perspective, annual nitrogen leaching losses (either to

leaching below the root zone or to denitrification) can be estimated based on a simple mass balance model for the root zone:

$$\text{net N Losses} = (\text{Fertilizer N} + \text{Irrigation water N}) - \text{Harvest N}$$

This simple approach neglects N volatilization during plant material and root decay. Based on this equation, net N losses are estimated to be on the order of 0 lbs/ac, 70 lbs/ac, and 250 lbs/ac, respectively. In the 0 lbs/ac plot, it is assumed that irrigation water N supplied the bulk of the nitrogen, while large lateral roots into neighboring tree-rows may have captured additional N. If all losses go to groundwater (no denitrification), at an annual net water leaching rate of approximately 2 acft/ac, the resulting concentration in the deep unsaturated zone leachate should be 0 mg/l, 10 mg/l, and 50 mg/l for the three plots, respectively.

Nitrogen Profile

Nitrogen profiles in individual boreholes are highly variable with little apparent correlation between adjacent boreholes (Fig. 4). Average nitrate concentration in deep soil water of the 0 lbs/ac and 100 lbs/ac treatment were 5 mg/l and 2 mg/l, respectively. Variability of nitrate concentrations in both plots is found to be very large, ranging from less than 1 mg/l in many samples to over 100 mg/l in a few soil samples. The 325 lbs/acre nitrogen treatment yielded the highest average nitrate-nitrogen concentrations in soil water (10 mg/l) due to a much larger number of samples with high N values: Almost a third of the nitrate-N samples exceeded concentrations of 10 mg/l (the maximum allowable groundwater quality limit). Much fewer samples than in the other two plots are found with nitrate-N levels less than 1 mg/l. Despite the large variability, the nitrate application rate can be shown to have a statistically significant effect on mean nitrate levels (one-way analysis of variance at a p-level less than 0.05).

Nitrate samples were also grouped by depth, using the average thickness of the seven major stratigraphic units (Fig. 3) as an indicator. After log-transformation of the nitrate-N data (to account for their highly skewed distribution), statistically significant differences are found between mean nitrate levels in different stratigraphic units. However, depth-dependence is highly non-linear, that is, no general trend exists for either decreasing or increasing nitrate-N with depth. Depth-dependent mean N were grouped by treatment plots measure the interaction between the most prominent extrinsic control (fertilizer treatment) and the most prominent intrinsic control (geologic layering). Depth and treatment dependent nitrate-N mean (and confidence intervals) are shown in Fig.4. Analysis of variance at $p < 0.05$ shows that the depth X treatment interaction is statistically significant, yielding distinctly different profiles at each treatment plot.

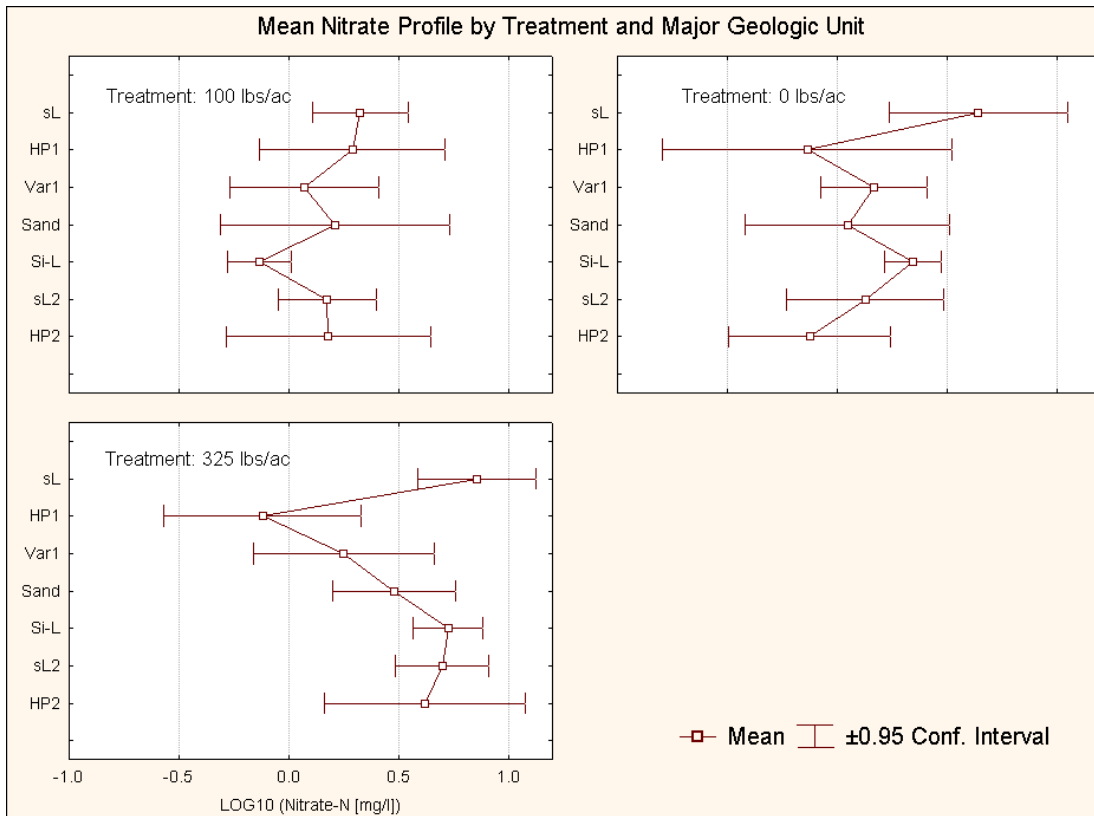


Fig. 4: Geometric mean nitrate profiles (arithmetic mean of the log₁₀ of N) computed by taking group means for all possible treatment X depth (stratigraphic unit) combinations. Note that the x-axis shows Log₁₀ of nitrate-N [mg/l], where -1 is equal to 0.1 mg/l, 0 is equal to 1 mg/l and 1 is equal to 10 mg/l.

Discussion

Given the small sample size, the large amount of spatial variability in the nitrate distribution is not surprising. Similar variability is found in other soil studies where soil samples have not been composited. The variability in nitrate levels is due to the high amount of spatial variability of both, the intrinsic and extrinsic controls. The fertilization treatment and the major geologic stratification depicted in Fig. 3 serve to explain only some of the observed variability in nitrate distribution. They only represent the most obvious spatial variability. Random within-treatment variability (random effects in extrinsic controls) and the high stratigraphic variability within each of the major geologic units further affects the nitrate distribution.

Extrinsic control. Random effects in the nitrogen loading distribution at the soil surface (extrinsic control) stem from the nonuniformity of the fertilizer application as described above. Limitations in the mechanical spreading and the intensional non-uniform distribution of the spring fertilizations immediately around the tree account for loading differences across spatial units that have length scale of one to several feet, but also at much smaller scales. Further random effects stem from the non-uniformity of the irrigation: at the largest scale, the top of a tree-row generally receives higher amounts of irrigation water than the bottom part of the tree-row. In the orchard, furrrow lengths were 300 feet and irrigation typically occurred over a 24 hour period. It is likely that the 0 lbs/ac and 325 lbs/ac treatments have received more irrigation water (and, hence, been subject to more nitrate leaching) than the 100 lbs/ac treatment, located within the bottom half of the orchard. This may partly explain why

the 100 lbs/ac treatment has the least nitrate in the soil profile.

Laterally across furrows, irrigation uniformity was also limited due to undulations at the furrow surface. No nitrate loading occurred from the berms. However, no apparent differences are observed in the profile N concentrations in boreholes located under the center of the berms, when compared with those located in the furrow. The shallowest samples are taken at depths of 2 - 4 feet. The fact that these are not significantly nitrate-N depleted relative to the furrow boreholes indicates that lateral water movement redistributes nitrogen from the furrow into the berm area over a relatively short depth interval near the soil surface.

Random effects in unsaturated zone nitrate loading below the root zone may also be due to the non-uniformity of root nitrate uptake. Roots are clustered near the tree, although tree-roots may be several tens of feet long. These effects cannot be evaluated with our sampling scheme, since all boreholes are approximately the same distance from trees (~ 5 to 6.5 feet).

Finally, the top 10' (comprised primarily of fine sandy loam, sL) is considered to be also affected by the change in fertilization regime during the year prior to drilling: a single fall application of 100 lbs/ac occurred across all treatments after the original project was completed.

Intrinsic control. Effects of variability in geologic (intrinsic) control are more difficult to evaluate by statistical means alone. Uneven layering, small slopes of stratigraphic boundaries - even minor boundaries, and the random, intercalated occurrence of finer textured material are likely to lead to significant lateral (i.e., horizontal) water movement across distances of several inches to several feet (Harter et al., 1996). The lateral mixing of recharge water throughout the 50' unsaturated zone effectively disperses nitrate laterally across soil or sediment horizons. Within a few feet of the surface, such lateral water movement may completely mask the nitrogen variability imposed by spatially variable nitrogen loading at the surface. Over a depth of several tens of feet, lateral water (and nitrate) movement induced by the intrinsic heterogeneity of the unsaturated zone, may lead to a significant exchange of nitrogen even between treatment plots and neighboring tree rows, which receive a control application of 100 lbs/ac. If lateral mixing is significant, an increase of nitrogen with depth should be observed in the 0 lbs/ac treatment, whereas a decrease of nitrogen with depth should be observed in the 325 lbs/ac treatment (absent of any major other controls such as denitrification). While no such trend is apparent in the profiles of either the 0 lbs/ac or the 325 lbs/ac treatment, the overall nitrogen levels in the unsaturated zone differ much less from one another than would be expected based on the mass balance for each treatment: whereas mass balance predicted a difference in nitrate-N concentration of 50 mg/l, the actual difference is an order of magnitude smaller due primarily to much lower than expected N concentrations in the 325 lbs/ac treatment, but also due to higher than expected N concentrations in the 0 lbs/ac treatment. This is a strong indication for lateral exchange of nitrate between treatment and control plots.

The overall N loading from a field or orchard to groundwater, however, is not controlled by small scale variabilities in N application (random effects of extrinsic control). Generally, it is not even controlled much by the lateral movement of water within the unsaturated zone (random effects of intrinsic control) due to the limited extent of such movement relative to the size of a field. But it may be strongly controlled by the potential for denitrification between the root zone and the water table.

Intrinsic control of denitrification. Nitrate concentrations in the 325lbs/ac treatment are only 20% of the concentration expected from mass balance analysis indicating a significant potential for denitrification. However, a direct computation of the denitrification rate is not possible (without further

modeling) due to lateral mixing effects and subsequent dilution underneath the research plots. The occurrence of denitrification is supported by preliminary isotope data.

On the other hand, if denitrification is significant, average nitrate concentrations should generally decrease with depth, particularly in the 325 lbs/ac and 100 lbs/ac treatment (no lateral inflow of higher nitrate levels from neighboring tree rows). But none of the three mean profiles show a monotonic decrease of nitrogen with depth. On the contrary, the 100 lbs/ac profile appears relatively uniform. The two other profiles have high concentrations in the top ten feet and very low nitrate concentrations in the upper hardpan at 10 - 12 feet (HP1). Below the hardpan N levels increase across the sand and into the silt-loams at depths of 30 - 40 feet. The nonuniformity of the mean profiles is surprising, given that the profiles are 50' deep, represent several years of consistent fertilization and water management and given that the signature of individual pulses of nitrogen applied at the surface are likely to dissipate within the top 10 to 15 feet due to dispersion. It is possible that the low nitrate samples from the upper hardpan represent stagnant pore water that was subject to temporary anaerobic conditions, particularly during the winter or during the irrigation season (ponding of water on top of the hardpan). However, the fact that nitrate concentrations are again higher below that hardpan indicates that significant amounts of nitrate-laden water pass through the hardpan quick enough to avoid denitrification.

Conclusions

1. Variability of nitrate concentrations throughout the unsaturated zone is extremely high, in part because of the small size of the samples, which were not composited.
2. The high variability underscores the importance of sampling from a large number of borehole samples at a given site. We question the significance of sampling only one or a few unsaturated zone boreholes to great depths. Results are uninterpretable with respect to the vertical distribution of nitrate or other solutes and have only limited statistical meaning with respect to the overall N content of the deep unsaturated zone. This finding has important consequences for monitoring of deep unsaturated zones: Since practically all standard observation tools of moisture and solutes in the unsaturated zone measure only small volumes (~ 1 liter or less), monitoring networks for individual sites must include multiple access holes (û10) to provide an adequate sample size.
3. We do not observe a strong stratigraphic control of denitrification with the exception of the hardpan, where significantly lower nitrate concentrations are observed in two of the three treatments. However, this may represent stagnant local water, since more mobile water that has moved below the hardpan has higher nitrate concentrations.
4. Preliminary isotope data and comparison of total N load in the deep unsaturated zone to that predicted from root zone mass balance suggest that some denitrification occurs, particularly where the N loss to below the root zone is relatively high.

To evaluate the effect of the spatially variable controls on N fate and transport in more detail, we are developing a deep unsaturated zone flow and transport supported by extensive hydraulic and geochemical field characterization. The model will allow us to evaluate effects of lateral water movement, superimposed by variability of both extrinsic and intrinsic controls on nitrate fate and transport. We hope to test several scenarios and hypotheses that have been raised by this analysis.

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Relationship Between Fertilization and Pistachio Diseases

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Introduction:

Fertilization side effects, both good and bad, make it increasingly important to apply fertilizers as efficiently as possible. This is particularly true since the amounts of fertilizers applied can influence pathogens and insect pests of fruit and nut trees. It has long been recognized that nitrogen (N) fertilization affects not only the yield of plants but also levels of plant disease (Huber and Watson, 1974). Fertilization of pistachio trees from a very young age is routinely applied in commercial pistachio production in California. *Botryosphaeria* panicle and shoot blight caused by *Botryosphaeria dothidea* has become a disease of major importance for pistachios grown in California since the late 1980s. Initially only pistachios grown in the Sacramento Valley were affected but in 1995 and 1996, severe levels of the disease reduced yields and fruit quality in many orchards in the Central Valley. *Botryosphaeria* blight losses in the San Joaquin Valley were minimal in 1997 but continued to be severe in Sacramento Valley orchards. In 1998, the disease was very severe throughout pistachio plantings, except those in the southern part of Kern County and orchards west of freeway 99 in the Central Valley. Because *Botryosphaeria* blight attacks fruit clusters and kills them within a short time and because of the magnitude of the destruction this disease can cause, it may be considered the most serious threat to pistachio trees grown in California.

Alternaria late blight, caused by *Alternaria alternata*, is also a devastating disease which occurs annually in California pistachio orchards. This disease has caused significant losses to the industry in the last decade. Losses occur mainly because of early defoliation, which is often severe enough to cause difficulties during harvest as well as undesirable staining of fruit (Michailides & Morgan, 1991). According to pistachio growers, estimated losses up to \$1,000 per acre have been reported in some orchards because of inferior nut quality caused by *Alternaria* late blight. Besides early defoliation and shell staining, invasion of kernels by *A. alternata* can result in moldy nuts (Doster & Michailides, 1999; Michailides & Morgan, 1991).

Pistachio growers use different amounts of fertilizers and follow various practices when they fertilize their orchards, and we raised the question, how do these different fertilization rates affect diseases in pistachios grown in California. In other words, we wanted to investigate the relationship between fertilization levels of the macronutrients (N, P, and K) and Ca and diseases in pistachios. Thus we investigated the effect of various nutrient elements and their levels on the susceptibility of pistachio to *Botryosphaeria panicle* and shoot blight and *Alternaria* late blight in greenhouse studies.

Objective:

Determine the effects of fertilization on pistachio diseases such as *Botryosphaeria* and *Alternaria* blights in greenhouse experiments.

Procedures:

Botryosphaeria panicle and shoot blight. The susceptible pistachio cultivar Kerman to *Botryosphaeria* blight was selected for greenhouse experiments. Potted, 2-year-old trees were obtained from a pistachio nursery for experiments in 1999 and experiment I in 2000. One-year-old trees were used in experiment II in 2000. Three levels of nitrogen (N), phosphorous (P), and potassium (K) elements were established by feeding 4-replicated potted trees with modified Hoagland solution (Hoagland, 1950) once per 2 weeks (1.0 liter per tree). Three levels of calcium were established by spraying 4-replicated trees with 0.1%, 0.2% and 0.4% CaCl_2 and $\text{Ca}(\text{NO}_3)_2$ (50ml per tree) for experiment I and II in 2000, respectively. After fertilizing the trees for 2 months, all trees were sprayed with 20,000 of spores /ml suspension of *B. dothidea*. To create conditions favorable for infection, the inoculated trees were covered with a plastic bag for 12 hours. The disease severity was assessed 15 days after inoculation. The following system was used for severity assessment: 0 = leaves without lesions, 1= lesion area less than one quarter of the leaf area, 2 = lesion area between one quarter and half of the leaf area, 3 = lesion area between half and three quarters of the leaf area, and 4 = lesion area greater than three quarters of the leaf area. The disease index (DI) for each tree was calculated using the formula:

$$DI = \frac{\sum_{i=0}^4 N_i * i}{\sum_{i=0}^4 N_i}$$

Where i is severity (0 to 4) and N_i is the number of leaves with the severity of i . Analysis of variance for DIs of pistachio trees affected by the different levels of fertilization was conducted using ANOVA of SAS.

Alternaria late blight. Similar to the *Botryosphaeria* blight experiments (1999/00 and 2000/01), the susceptible pistachio cultivar Kerman was selected for a greenhouse experiment to study the effect of fertilization on *Alternaria* late blight. Because *Alternaria* late blight requires senescing leaves in order to infect, this experiment was performed in August to October 2001 when leaves were fully mature and started senescing. Potted, 1-year-old Kerman pistachio trees were obtained from a nursery for the greenhouse experiments. Two levels of nitrogen (N) (25 and 100 mM), potassium (K) (25 and 100 mM), and Calcium (Ca) (12.5 and 50 mM) were established by spraying six replicated potted trees with NH_4NO_3 , KCl, KNO_3 , CaCl_2 , or $\text{Ca}(\text{NO}_3)_2$. After fertilizing the trees once a week for 2 months, all trees were sprayed with 20,000 of spores /ml suspension of *Alternaria alternata*. To create conditions of high humidity favorable for infection, the inoculated trees were covered with a plastic bag for 12 hours. Two weeks after inoculation, leaf samples were collected from each tree and analyzed for latent infections using the OverNight Freezing Incubation Technique (ONFIT). Analysis

of variance for latent infections (number of lesions per leaf) by *A. alternata* on pistachio leaves among various treatments was conducted using ANOVA of SAS.

Results and conclusions:

Botryosphaeria panicle and shoot blight. In 1999, there were no significant differences among the percentages of infected leaves among the various treatments. However, the 200 % K treatment significantly reduced severity of *Botryosphaeria* blight on pistachio leaves as compared with the normal fertilization (100% N, P, K) (Table 1). These results showed that nutritional stress did not increase the incidence of *Botryosphaeria* disease as compared with the normal nutrition level. This could be because of either sufficient amounts of N, P, and K were stored in the potted trees in the first year or probably because of not enough nutritional stress was established by applying these treatments.

For experiment I in 2000, although there were no significant differences ($F = 1.82$, $P = 0.1193$) (Table 2) in disease index (DI) among the various treatments, the DI of 200% K treatment was reduced by almost 30.0% as compared to that of the control treatment (100% each of N, P, and K). In this experiment, 2.0% and 4.0% CaCl_2 were phytotoxic to pistachio, thus, $\text{Ca}(\text{NO}_3)_2$ was used instead of CaCl_2 in experiment II in 2000. In experiment II, the disease index (DI) of 200% K treatment was reduced significantly ($P < 0.05$) by 27.3% as compared to that of the control treatment, and the DIs of the trees sprayed with 0.10%, 0.20%, and 0.40% $\text{Ca}(\text{NO}_3)_2$ were reduced significantly ($P < 0.05$) by 33%, 24%, and 19%, as compared to that of the control treatment, respectively (Table 2).

Alternaria late blight. The results from the greenhouse experiments showed that the severity of *Alternaria* late blight on pistachio was not affected by applying potassium nitrate or potassium chlorite. However, the disease was reduced significantly by eight sprays of 100 mM of nitrogen, applied either as NH_4NO_3 or $\text{Ca}(\text{NO}_3)_2$ (Fig. 1). Calcium chlorite at 50 mM or potassium nitrate at 100 mM rates showed trends towards reducing the number of latent infections of *A. alternata* per leaf of pistachio as compared to the control trees. But eight applications of CaCl_2 at 50 mM or KCl at 100 mM rates caused phytotoxicity to 1-year-old pistachio trees in these experiments.

The general conclusion from these experiments thus far on the effects of fertilization on *Botryosphaeria* blight is that fertilizing trees with high levels of potassium or spraying trees with calcium nitrate can reduce the severity of *Botryosphaeria* panicle and shoot blight. In addition, nitrogen (applied either as NH_4NO_3 or $\text{Ca}(\text{NO}_3)_2$) fertilization can reduce latent infections of *Alternaria* late blight and subsequently late blight disease of pistachio. This is in contrast to other studies on other crops where increased nitrogen fertilization increased disease. For instance, increasing nitrogen fertilization of nectarines increased brown rot disease caused by *Monilinia fructicola* (Daane et al. 1995).

A current objective of this study is to analyze plant tissues for disease resistance/susceptibility compounds. Thus frozen leaf samples from each replicated tree in each treatment are being analyzed for disease resistance/susceptibility compounds.

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Table 1. Effects of nutrition stress on *Botryosphaeria* panicle and shoot blight in a greenhouse experiment in 1999.

Treatment	Infected leaves %^x	Leaf disease index^x
75% N	64.4 a ^y	0.90 ab ^y
75% P	60.4 a	0.95 a
75% K	62.7 a	0.83 ab
100% N,P,K	58.8 a	0.87 ab
200% N	60.1 a	0.80 abc
200% P	57.3 a	0.71 bc
200% K	54.3 a	0.58 c

^x Data in columns presented are the average of two experiments since results from these experiments were similar.

^y Values with common letters are not significantly different at $P = 0.05$ level according to a LSD test.

Table 2. Effects of nutritional stress on *Botryosphaeria* panicle and shoot blight of pistachio caused by *Botryosphaeria dothidea* in a greenhouse study in 2000.

Treatment	Disease index (DI)
Experiment I	
CK (100% N, P, K)	0.75 ^x (±0.28) ^y a ^z
50% N	0.91 (±0.28) a
200% N	0.53 (±0.17) a
50% P	0.89 (±0.42) a
200% P	0.60 (±0.09) a
50% K	0.73 (±0.15) a
200% K	0.52 (±0.10) a
0.1% CaCl ₂	0.57 (±0.15) a
0.2% CaCl ₂	0.53 (±0.18) a
Experiment II	
CK (100% N, P, K)	0.47 (±0.11) abc
50% N	0.49 (±0.05) ab
200% N	0.44 (±0.10) abcd
50% P	0.53 (±0.10) a
200% P	0.40 (±0.06) bcde
50% K	0.48 (±0.09) abc
200% K	0.34 (±0.03) de
0.1% Ca(NO ₃) ₂	0.32 (±0.06) e
0.2% Ca(NO ₃) ₂	0.36 (±0.05) de
0.4% Ca(NO ₃) ₂	0.38 (±0.06) cde

^x The data presented are the average of four replicated trees.

^y Numbers in (±) denote standard errors.

^z Values in columns for each experiment followed by the same letter are not significantly different according to LSD of SAS test at $P = 0.05$.

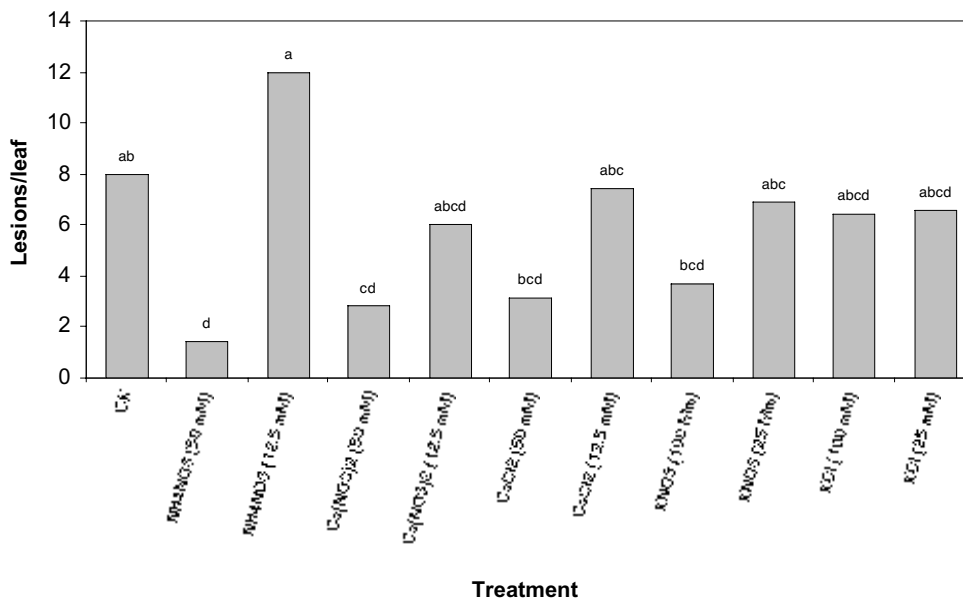


Figure 1. Effects of nutrition on *Alternaria* late blight of pistachio caused by *Alternaria alternata* in greenhouse experiments. Bars topped with different letters are significantly different at $P = 0.05$ level according to LSD test.

Leguminous Cover Crop Residues in Orchard Soils: Nitrogen Release and Tree Uptake

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Abstract

Almond production is dependent on nitrogen availability. Cover crops offer a potentially valuable source of nitrogen, especially if the cover crop plants are nitrogen fixers, such as clovers, vetches, and other legumes. Little is known about how much N derived from a cover crop is actually taken up by the almond trees, and over what period of time.

We grew six young 'Non-pareil' almond trees in lysimeters with intact columns of orchard soil for eight weeks. To the soil surface of three lysimeters we applied 180 g (DW) of 'Lana' woollypod vetch hay grown with a ¹⁵N labeled fertilizer (KNO₃). Leaf samples were collected bi-weekly and analyzed for %N and ¹⁵N content. After eight weeks all of the trees were destructively sampled and the soil, roots, stems, and leaves were analyzed for %N and ¹⁵N.

Almond leaf nitrogen derived from a vetch cover crop (%Ndfcc) increased rapidly over four weeks, stabilized at about 30% in existing leaves, and reached 43% in new leaves. Almond leaf nitrogen content increased from 1.6-2.3% over the first four weeks. Leaf biomass doubled in eight weeks compared with control plants grown without vetch hay. Leaf number increased 88% in treated trees and decreased 5% in controls. Soil nitrogen derived from vetch was >4% in the top 4 inches, although absolute soil nitrogen levels decreased in eight weeks. We could account for approximately 75% of nitrogen released from the vetch, about equally divided between soil and plant pools.

These results indicate that substantial nitrogen was released from the vetch residue applied to the soil surface in the treatment lysimeters. Thirty-five percent of the released nitrogen was taken up by the tree in eight weeks following application of the vetch residue. The first four weeks showed the fastest rate of uptake. Vetch nitrogen was partitioned into plant and soil pools approximately equally. On a per biomass basis, and as a total, new leaves represented the greatest uptake of vetch-derived nitrogen. Vetch as a source of nitrogen provided adequate nutrition for young almond trees.

Yield response of rice to N and K Fertilization Following Straw Removal and Incorporation.

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Summary

Due to legislation, the management practice of burning rice straw has been strongly limited during the past 10 years. Straw incorporating in combination with winter flooding has become the most common practice. The impact of straw removal on N and K fertilization responses on yield of rice was evaluated during three subsequent growing seasons at a site near Marysville, where some of the flooded soil is known to show K deficiency. Five rates of N and 6 rates of K were applied when straw had been removed or incorporated. Whereas there was no significant yield response to K fertilizer during the first two years of the experiment, in the third year K fertilization increased grain yield significantly when straw was removed and sufficient N was applied. When straw was incorporated, no K fertilizer responses were observed. This K response strongly suggests that straw incorporation led to higher plant available K levels. In the third year, K fertilization also decreased Aggregate Sheath Spot (AgSS) severity. However, N fertilizer decreased AgSS throughout the study.

A second study was conducted to determine how near infra red spectrometry analysis of soils can be used to predict the availability of nutrients, in particular Ca, Mg, N, and K, and how well the availability is correlated with rice yield. An unfertilized, 400 m long transect was used, sampled at 100 locations. Whereas soil test analysis for Ca, Mg, and P availability showed a very strong correlation with the near infra red spectra, soil N availability and the concentration of K in plant tissue did not correlate well with the spectra. Grain yield and total crop N uptake could not be predicted from the spectra. Whereas the near infrared spectra were very well suited to determine the availability of Ca, Mg, and P in the soil, its use to predict the availability of K and N appears to be limited.

Introduction

California legislation (AB 1378) leads to a phase down of rice straw burning over a ten-year period which will change the way farmers manage rice straw. Although various options are available, it is likely that the incorporation of rice straw (i.e. on-site disposal) will remain a major option for rice straw management. As the average concentration of K in rice straw is around 1.4% the amount of straw removed by baling for off-site use is approximately 6 tons per ha, the amount of K removed in the straw after harvest in California rice fields can exceed 100 kg ha⁻¹. When the straw is removed on a continued basis, this management practice could show a pronounced effect on the available K levels in the soil.

The rising appreciation for the strong controls on yield exercised by short-range spatial variability of natural resources in agricultural fields led to the developing field of site-specific farming or precision agriculture. Infrared (IR) spectrometry in the near- and mid-infrared range shows considerable promise for making fast, inexpensive and accurate predictions within a precision agriculture context. Within agriculture, IR spectrometry is already routinely used in predicting protein content, moisture levels and fat content of food products and forage crops. The mid-infrared (MIR) spectrum has been often used for qualitative analyses of organic substances. Due to relatively simple sample preparation procedures, diffuse reflectance Fourier transformed (DRIFT-MIR) approaches have been especially popular.

The main objectives of this study were, (1) to determine the impact of continuous straw removal on yield response following K and N fertilization and (2), to evaluate the potential of NIR and DRIFT-MIR spectrometry for predicting crop and soil parameters in a flooded California rice field.

Materials and Methods

The K and N fertilization experiment, conducted for three years, was carried in the Sacramento Valley of California. The soil is classified as a San Joaquin loam that has been historically K deficient. Two adjacent sites, each 3 ha large, were selected and at one site the straw was removed and at the other site straw was incorporated. At each site, a factorial experimental design was used, laid out as a split plot design with N as main plot treatment and K as subplot treatment, replicated 4 times. Five rates of N (0, 50, 100, 150 and 200 kg ha⁻¹) as ammonium sulfate and 6 rates of K (0, 25, 50, 75, 100, and 125 kg ha⁻¹) as KCl were applied. To avoid compounding effect of fertilization, the experiments in the second and third year were established directly adjacent to the first year's site. Midseason K concentrations during panicle initiation and Aggregate Sheath Spot severity (AgSS) as affected by N and K was determined.

The study site for the NIR and DRIFT-MIR was located in Butte County, on the northeast side of the Sacramento Valley, California. The alluvial soils can be classified as very fine, smectitic, thermic xeric duraquerts and fall within a Lofgren-Blavo series complex. The 36 ha field has been cropped with rice continuously for over 20 years. Within the field, two transects of 400 m length and 10 m width were established in the spring of 2000. No fertilization was applied to the transects. On both transects, 50 soil and crop samples were taken for analysis, totaling 100 sampling locations. Forty samples were evenly spaced at 10 m, with 10 additional samples randomly located within both transects. Soil samples were taken in spring of 2000, and crop and weed samples at harvest. IR spectra were linked to total soil C and N, mineralizable N, P Olsen, effective cation exchange capacity (eCEC) and exchangeable cations (Ca, Mg, Na and K), as well as yield, N uptake, biomass and weed biomass using partial least squares regression (PLSr). Subsamples of the dried, milled soils were ball-milled for 48 hours before IR analyses, in order to minimize the effect of aggregate sizes on reflectance spectra. DRIFT-MIR analyses were subsequently performed on the same subsamples. For this, 1.000 ± 0.05 mg of ball-milled soil was added with 30.0 ± 0.5 mg spectrometry grade KBr in a ball mill, and mixed overnight.

Results and Discussion

N and K fertilization

In the first two years, midseason K was significantly higher when straw was incorporated. However, the reverse occurred in the third year when the highest midseason K concentrations were found when straw was removed. Indirect evidence exist that there was a spatial pattern of available nutrients across the 3 ha large fields which would make a comparison between the straw incorporated and straw removed experiment less valid. Increased rates of K fertilizers lead to a significant increase in K concentrations, even when no increase in grain yield was observed. Potassium had no effect on AgSS for the first two years but the incidence declined in the third year from 2.8 to 2.5 (ranking between 0 and 5) following the application of K. Nitrogen fertilizer always reduced AgSS incidence.

For all three years, grain yield was strongly affected by N application, independent of straw management and, on average, yield increased by 50 % following an N application of 100 kgNha⁻¹. When straw was incorporated, grain yield was higher when no N fertilizer was applied compared to the zero N yield when the residue was removed (Fig. 1). Furthermore, the maximum yield was observed when 100 kgNha⁻¹ applied and

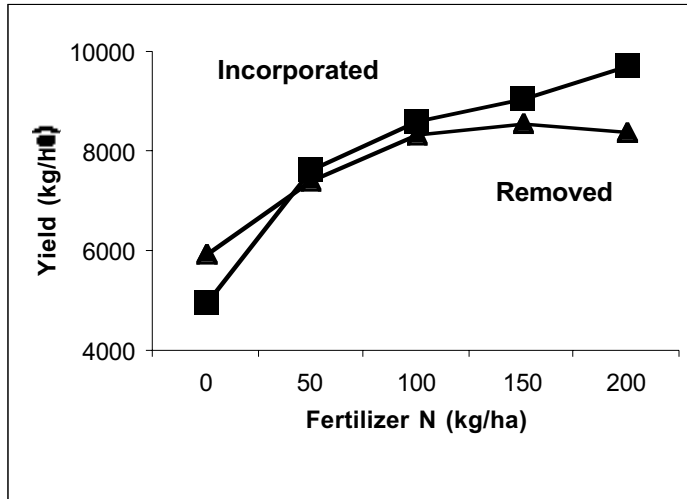


Fig. 1. Yield response of rice following N fertilizer following straw removal or incorporation.

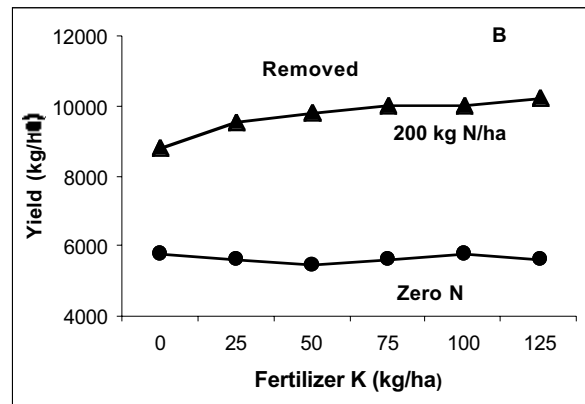
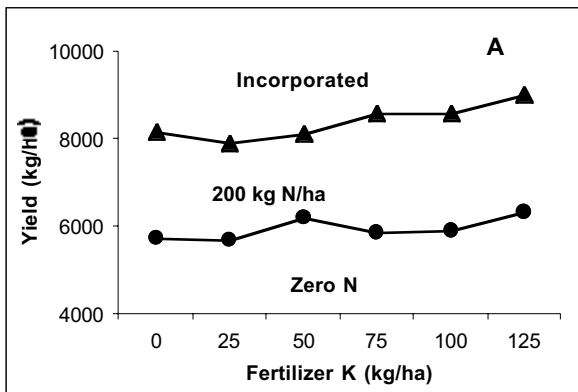


Fig. 2. Yield response of rice following K fertilization under two levels of N and straw removal or incorporation.

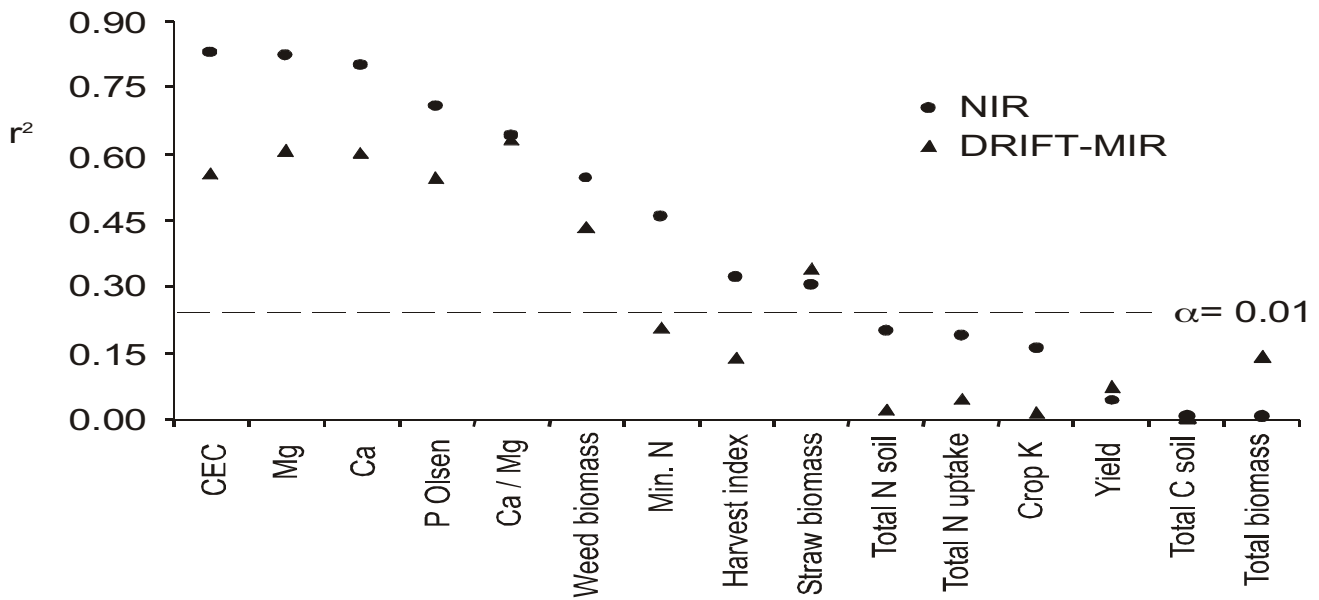


Fig. 3. Correlation between near infra red spectra and the availability of nutrients in the soil and crop performance.

straw was incorporated whereas the highest yield was observed when 200 kgNha⁻¹ was applied and straw was removed. Moreover, the maximum yield observed when straw was removed was higher than when straw was incorporated (Fig. 1). Apparently, a non-N effect occurred and its negative effect on yield was more pronounced when straw was incorporated. A similar yield response to straw management practices has been observed earlier in the Valley in the long term straw management study at Maxwell.

For the first two years no increase in grain yield was observed following the application of K. However, a significant increase in grain yield occurred following K fertilization in the third year but only under a high rate of N fertilizers. Straw yield increased significantly when straw was incorporated. As grain yield was unaffected by straw management, straw incorporation led to a reduction in the harvest index (grain yield/total aboveground yield). Nitrogen N requirement (kgNton⁻¹ha⁻¹) increased under higher rates of N and increased further when straw was removed. Fertilizer-N use efficiency, based on the N difference method, for the first two years of the experiment, was largely unaffected by straw management. Similarly, K fertilization did not increase N use efficiency. The N requirement in the second year of the experiment decreased significantly under higher rates of K fertilization but only when straw was removed. Available soil K (pre-fertilization available K by ammonium acetate extraction plus K applied) was highly correlated with grain yield, indicating that no measurable amounts of K fixation occurred. Moreover the ammonium acetate method appears to perform well to predict plant K availability in flooded rice soils.

Soil test analysis by near infra red

The coefficient of variation (CV) along the transect for the soil measured variables ranged between 8 (exchangeable Ca) and 28 % (P Olson). The CV for the crop variables ranged between 12 % (K concentration) and 46 % (weeds biomass). For soil, predictions for eCEC, Ca and Mg were the most accurate, with r² values of 0.83, 0.80 and 0.90 for NIR and 0.56, 0.60 and 0.61 for DRIFT-MIR. Correlations for P Olsen were 0.71 and 0.55, and for mineralizable N (one week anaerobic incubation) 0.46 and 0.21, respectively.

No significant correlations were found between the spectra and total soil C or N. For crop parameters, only weed pressure (r^2 of 0.55 and 0.44) and straw biomass (0.30 and 0.34) yielded significant correlations (Fig. 3). The correlation with weed pressure was an indirect effect due to better competition by weeds compared to rice under low soil fertility levels. For most parameters, standard errors of prediction were lower than reported in the literature. This indicates that the small range of variability within a field might be the limiting factor in predicting these parameters. It also illustrates the limited use of correlation coefficients in PLSr model validations.

We concluded that NIR spectrometry shows promise for SSM, although its predictive power for parameters may vary from site to site. Moreover, predictive models remain unique for specific agroecosystems, and therefore have to be calibrated for every area. The fast and accurate predictions for Ca and Mg concentrations in the soil could be especially important in diagnosing and combating grass tetany, which strongly depends upon Ca and Mg concentrations in the soil.

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Evaluating and Demonstrating the Effectiveness of In-Field Nitrate Testing in Drip and Sprinkler Irrigated Vegetables

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INTRODUCTION

Vegetable production, including lettuce, celery, baby greens, peppers, and onions, is an important sector of the agricultural economy in the Upper Pajaro River Watershed region which includes the Southern Santa Clara Valley. However, a 1996 study by the Santa Clara Valley Water District (SCVWD) found that over 56 percent of the wells in the region exceeded the Maximum Contaminant Level (MCL) of 45 parts per million. The principal source of nitrate was determined to be agricultural fertilization. Concurrently the Region 3 Water Quality Control Board is currently developing a Total Maximum Daily Load Plan (TMDL) for nutrients (including nitrate) for Llagas Creek within the next few years. At this time, both the SCVWD and the Santa Clara Farm Bureau are initiating outreach programs to address these water quality issues.

The high value of vegetable crops along with market demands for quality, make growers reluctant to increase economic risk by reducing nitrogen and/or irrigation inputs. To date recognition and adoption of in-field soil and plant monitoring as a simple and effective N management decision-making tool in this region has been limited due to the lack of a significant research and education effort in this region. This project has evaluated if improvements in nitrogen (N) fertilizer use efficiency are possible through the use of in-field monitoring and, specifically, if the use of a soil nitrate quick test is an effective and appropriate tool for these and other growers in the region.

OBJECTIVES

The primary objective of this project was to assist a few key Santa Clara County growers in evaluating and adopting the use of in-field nitrate testing and nitrogen management planning to improve fertilizer use efficiency and profitability. Routine field monitoring and comparative trials utilizing in-field soil and petiole testing is being used to:

- 1) confirm the utility of in-field soil nitrate testing in this region for pre-plant and sidedress N scheduling on cool season crops like lettuce whether on sprinkler or drip irrigation,
- 2) demonstrate how effectively in-field quick soil and petiole testing will work for crops on surface and buried drip systems for a long, warm season crop like peppers (green and colored bell types and chili types) which have not had as much attention as the cool season crops (e.g. lettuce).
- 3) evaluate and use the data, grower observations and comments to demonstrate to a larger group of growers in outreach events that these tools actually work and are cost-effective under their regional conditions e.g. climate, crop types, irrigation technologies.

This project is conducted in close partnership with the SCVWD's Nitrate Management Program, which has provided invaluable assistance by providing soil quick test kits to growers, laboratory analytical support, and organizing the public meeting series. Additionally the project has collaborated with the District's Mobile Irrigation Lab Program to provide cooperating growers with irrigation system evaluations. Outreach activities have included annual field reports to each cooperator, direct training in use of soil nitrate quick tests, and a total of five (5) presentations at public meetings.

PROJECT ACTIVITIES

Field Monitoring - During the 2000 and 2001 growing season have monitored a total of 21 fields and 28 crop sequences in the South Santa Clara Valley. Crops have included head lettuce, baby greens, celery, broccoli, onions, and peppers (bell, pimento and chili types). Project activities began in January 2000 with presentations at two of the Water district's grower workshops. Beginning in early March, weekly and bi-weekly monitoring of soil and/or petioles was used to document soil nitrate dynamics and identify potentially key decision times for cooperating growers. The fields that were monitored for soil nitrate-N were on very different soil types and were located between the Morgan Hill area and south almost to the Santa Clara County line. Table 1 summarizes the crops monitored in the 2000 and 2001 growing seasons.

In a number of these fields over both seasons, we used soil nitrate data to suggest if elimination or reduction of pre-plant or sidedress N might be practical. We also utilized small in-field plots or strips to assess the outcome of this change in N fertilization practice, monitoring soil and crop productivity. For selected fields we have developed a simple nitrogen budget for each grower's fields that includes estimates of nitrate input from all sources, including irrigation water as shown in Table 2. The water district provided invaluable assistance by providing a number of complete well water tests for participating growers.

This project has been enhanced by collaboration with the SCVWD's Mobile Irrigation Lab Program. Power Hydrodynamics has provided irrigation system evaluations for each grower and field that we have trials or monitoring programs in place. In addition Mobile Lab technicians have collected irrigation water samples for occasional confirmation of nitrate content as well as, tailwater/runoff estimates and samples for nitrate analysis where appropriate.

Outreach - We attempted to have regular communications (either directly or via faxed updates) with ranch managers concerning monitoring work and other observations. At the end of both seasons each cooperator has received a report package that includes plots for soil/petiole and soil moisture

monitoring, results of trials, if any, and other relevant observations and interpretations from each field. We also followed up each report with a meeting discussion to clarify or expand upon the reported results. In cooperation with the SCVWD, County UCCE, and Agricultural Commissioner, presentations of project objectives and results have been made in the winter and summer of both years. By request, we have provided direct training to two of the cooperators on in-field monitoring tools, and specifically the soil quick test. A final project report will be available through the SCVWD's Nitrate Management Program.

RESULTS AND CONCLUSIONS

As expected, grower irrigation and N fertilization scheduling varied significantly, particularly between crop years. As example, one bell pepper grower applied 380 lbs N per acre in 2000 and only 256 lbs for a similar crop program in 2001. The critical factors affecting soil nitrate dynamics and residual N in cooperator's fields appeared to be irrigation system type, irrigation/fertilization scheduling, (for drip systems the timing of N injection during any set), soil texture, and the growth stage and relative condition of the crop. Some of the well waters tested contain high levels of nitrate-N, which could be supply agronomically significant quantities of available N. Nitrogen applications to lettuce varied between growers and irrigation/fertilization systems. Large quantities of fertilizer N may be applied to peppers in the Santa Clara Valley. At the end of the 2000 (a cooler than normal season), we found very high residual soil nitrate-N in five of the six pepper fields, while in the 2001 season (a 'normal' year) we found that the same cooperators applied less N fertilizer. We have determined that these growers have historically increased N applications during unusually cool periods or seasons expecting to stimulate crop growth. Additionally, we have found that excessive N fertilization may also occur in fields with gravelly or coarser soil texture.

Collaboration with the SCVWD's Mobile Irrigation Lab to provide irrigation system evaluations has enhanced the scope of this project's fieldwork. Generally all of the irrigation systems tested had good to excellent distribution uniformity. However, we have found that irrigation scheduling by the cooperating growers is often erratic leading to both under- and over-irrigation. In particular for bell peppers, we have found that growers do not appear to adjust irrigation scheduling for different development stages of the crop. In the 2001 season we found that 4 of 5 fields were under-irrigated prior to fruit bulking stage, then over-irrigated prior to first harvest and for the rest of the season as the result of fixed scheduling. In-season leaching may often occur on coarse- and fine-textured soils with high gravel content, and it appears that some growers have typically 'over-corrected' with increased fertilization.

The results of field monitoring and the limited small field trials suggest that, in many cases, crop use efficiency of applied fertilizer may be less than optimal. We have noted that incorrect drip tape selection, field configuration, and excessive early season fertilization are common factors reducing the effectiveness on N fertilization. Soil sampling methods for the nitrate quick test must be adapted to differences in fertilizer placement and the wetted zone where roots are active. Integrating the use of tensiometers complements the soil and petiole nitrate monitoring and has identified both problems and successes of growers' irrigation systems and scheduling.

We have found that providing grower cooperators with a seasonal 'picture' of the outcome of their N fertilization programs and irrigation scheduling has great value. For most of the cooperators the results and report interpretations have raised important questions and validates that in-field monitoring can improve N fertilizer efficiency.

However, we have also found that there are critical barriers to the use of soil nitrate and/or petiole quick testing by these growers. First is the challenge of incorporating this activity into the routines of

grower, production foreman, or irrigator. Second is the lack of an established ‘action threshold’ or ‘critical level’ for the longer warm season crops, as has been established for some cool season crops in the Salinas Valley region. Finally, in this region with limited access to public-funded research, many of the cooperators feel that additional field experiments would provide them with more confidence and incentive to adopt in-field soil nitrate and moisture monitoring.

Table 1. Summary of crops and soils for each grower cooperator

Grower-crop	Irrigation Method	Field Size (acres)	Soil type
C&E Farms			
2000			
Spring lettuce	Surface Drip	12	sandy clay loam
Late Summer lettuce	Sprinkler-Surface Drip	10	sandy loam
Spring celery	Surface Drip	20	sandy clay loam
Fall celery	Surface Drip	15	gravelly s. loam
Pimento peppers	Surface Drip	30	gravelly s. loam
2001			
Spring lettuce	Surface Drip	11	sandy clay loam
Spring lettuce	Sprinkler-S. Drip-Furrow	12	sandy clay loam
Late summer lettuce	Furrow-Surface Drip	40	clay loam
Baby spinach [2 rotations]		Sprinkler	11 sandy clay loam
Mixed baby greens	Sprinkler	8	sandy loam
Spring celery	Sprinkler-SurfaceDrip	40	sandy loam
Late summer celery	Sprinkler-Surface Drip	12	gravelly sandy loam
El Camino Packing			
2000			
Spring lettuce	Sprinkler	25	silty clay loam
Summer broccoli	Sprinkler	25	silty clay loam
Bell peppers [seed]	Sprinkler-Surface Drip	30	gravelly clay loam
2001			
Winter cabbage	Sprinkler	10	gravelly clay loam
Spring lettuce	Sprinkler	3	gravelly clay loam
Bell peppers [seed]	Sprinkler-Surface Drip	20	fine sandy loam
Bell peppers [transplant]	Sprinkler-Buried Drip	30	clay loam
White globe onions	Sprinkler	15	loam
Uesugi Farms			
2000			
Colored bell peppers	Buried Drip	40	sandy clay loam
Bell peppers	Buried Drip	30	gravelly sandy loam
2001			
Jalapeno peppers	Buried Drip	3	sandy clay loam
Colored bell peppers	Buried Drip	48	sandy clay loam
Chiala Farms			
2000			
Anaheim peppers	Sprinkler/Buried Drip	10	gravelly sandy loam
2001			
Jalapeno peppers	Buried Drip	10	gravelly clay loam
LJB Farms			
2000			
Jalapeno Peppers	Buried Drip	15	sandy clay loam

Table 1. An example N budget for a double crop of head lettuce in 2000 season

Field: Block #12 - clay loam soil

Crop: Head lettuce - 65 day spring crop – 60 day late summer crop

Nitrogen Source	Crop 1 ----- lbs N per acre -----	Crop 2
Mineralized Soil N (<i>1-2 lbs per day</i>)	91	84
Crop Residue N (<i>Residue N</i>) X .5	--	30
Residual Soil N (<i>Test</i>)	20	80
Fertilizer N	198	143
Organic N (wastes, manure, compost) (<i>tons X lbs N per ton</i>) X (.1 to .25 per crop)	--	--
Irrigation N (<i>assumes 10 ppm N avg.</i>) (<i>NO₃-N X 2.71</i>) X <i>acre ft. applied</i>)	32	40
TOTAL N INPUT	349	377
Crop N (<i>Yield and literature data</i>)	100	90
Residue N (<i>Yield and literature data</i>)	60	50
TOTAL N REMOVED	160	140
Potentially Excess N (<i>N Input – N Removed</i>)	189	237

Pre-sidedress Soil Nitrate Testing Identifies Processing Tomato Fields Not Requiring Sidedress N Fertilizer

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Abstract

Overuse of chemical N fertilizers has been linked to nitrate contamination of both surface and ground water. Excessive use of fertilizer also is an economic loss to the farmer. Typical N application rates for processing tomato (*Lycopersicon esculentum* Mill.) production in California are 150 to 250 kg_{ha}⁻¹. The contributions of residual soil NO₃-N and in-season N mineralization to plant nutrient status are generally not included in fertilizer input calculations, often resulting in overuse of fertilizer. The primary goal of this research was to determine if the pre-sidedress soil nitrate test (PSNT) could identify fields not requiring sidedress N application to achieve maximum tomato yield; a secondary goal was to evaluate tissue N testing currently used for identifying post-sidedress plant N deficiencies. Field experiments were conducted during 1998 and 1999. Pre-sidedress soil nitrate concentrations were determined to a depth of 60 cm at ten field sites. N mineralization rate was estimated by aerobic incubation test. Sidedress fertilizer was applied at six incremental rates from 0 to 280 kg_{ha}⁻¹ N, with six replications per field. At harvest, only four fields showed a fruit yield response to fertilizer application. Within the responsive fields, fruit yields were not increased with sidedress N application above 112 kg_{ha}⁻¹. Yield response to sidedress N did not occur in fields with pre-sidedress soil NO₃-N levels >16 mg·kg⁻¹. Soil sample NO₃-N levels from 30 cm and 60 cm sampling depth were strongly correlated. Mineralization was estimated to contribute an average of 60 kg_{ha}⁻¹ N between sidedressing and harvest. Plant tissue NO₃-N concentration was found to be most strongly correlated to plant N deficiency at fruit set growth stage. Dry petiole NO₃-N was determined to be a more accurate indicator of plant N status than petiole sap NO₃-N measured by a nitrate-selective electrode. The results from this study suggested that N fertilizer inputs could be reduced substantially below current industry norms without reducing yields in fields identified by the PSNT as having residual pre-sidedress soil NO₃-N levels >16 mg·kg⁻¹ in the top 60 cm.

Introduction

A number of studies have documented a correlation between NO₃-N concentration in the top 30 cm of soil prior to sidedressing and crop yield response to sidedress N (Magdoff et al., 1984; Hartz et al., 2000). A pre-sidedress nitrate test (PSNT) can thus indicate a critical level of soil NO₃-N above which crop yield will not be increased by subsequent sidedress N application. The objective of our research was to determine if the PSNT technique is useful for predicting the necessity of sidedress N fertilizer on a field-by-field basis in commercial processing tomato production in California.

Materials and Methods

The project was carried out at 3 commercial farm sites and one research station site in 1998, and 5 farm sites and one research station site in 1999 (Table 1). At the two research station sites (fields 4 and 8), an unfertilized winter cover crop of wheat (*Triticum aestivum* L.) and a summer crop of Sudangrass (*Sorghum sudanense* [Piper] Stapf) were grown, mowed, and all above-ground residue removed prior to planting of tomatoes in order to reduce soil nitrate concentrations. Commercial tomato plantings followed standard crop rotations for the region and the individual grower's cultural practices including pre-plant and/or pre-sidedress N fertilization (Table 1). Common hybrid processing tomato varieties were grown at all locations (Table 1).

All fields received a single sidedress application of urea at rates between 0 to 280 kg ha⁻¹ N in six increments (0, 56, 112, 168, 224, 280 kg ha⁻¹ N) when plant height was approximately 10-15 cm. Fertilizer was banded using a standard applicator to a depth of 15 cm, and at a distance of 15 cm from the plant row. Experimental design in all fields was randomized, complete-block with all treatments represented in each field. All fields were furrow irrigated, and other cultural practices typical of the commercial tomato industry were followed.

Prior to sidedress N application, pre-sidedress soil nitrate testing was conducted at all sites to a depth of 60 cm in 30 cm increments. Soil cores (2.5 cm diameter) were taken from shoulders of beds approximately 60 cm away from bed centers to avoid pre-sidedress fertilizers applied by individual growers (Table 1) and analyzed for nitrate using standard procedures at the UC DANR Analytical Laboratory.

Table 1. Soil N concentration prior to sidedress fertilizer application, soil organic matter (SOM) and soil organic N as measured by depth, grower's fertilizer N inputs, and tomato cultivar.

Year	Field	<u>NO₃-N</u> (mg kg ⁻¹)		<u>SOM</u> (g kg ⁻¹)	<u>Organic</u> <u>N (g kg⁻¹)</u>	<u>Grower inputs</u> (kg ha ⁻¹ N)		Cultivar
		0 - 30 cm	0 - 60 cm	0 - 30 cm	0 - 30 cm	pre- sidedress	sidedress ^y	
1998	1	6.3	7.2	7.9	0.8	30	119	BOS 3155
	2	7.4	8.8	8.3	0.9	51	99	La Rossa
	3	22.3	28.5	8.3	0.8	30	119	BOS 3155
	4 ^z	8.5	6.1	7.3	0.7	28	-----	Heinz 8892
1999	5	7.2	10.9	6.8	0.7	127	146	Lipton 599
	6	23.7	20.7	6.8	0.9	64	198	Heinz 9557
	7	16.0	13.3	7.1	0.8	44	198	CXD 152
	8 ^z	4.7	3.5	8.0	0.8	13	-----	Heinz 8892
	9	15.7	15.8	22.5	1.8	7	134	BOS 3155
	10	10.1	12.2	15.2	1.1	16	134	RC 32

^y sidedress N inputs by growers in non-experimental rows within trial fields.

^z fields at University of California's Westside Research and Extension Center received only experimental sidedress N inputs.

Net mineralization of soil N was determined following eight-week aerobic incubations of the composite samples (procedures outlined in Krusekopf, 2001)

Approximately 30 petioles (third petiole from a growing point) were collected from plants in all field plots at three plant growth stages: early bloom, fruit set (earliest fruit approximately 2.5 cm diameter), and fruit bulking/early fruit color development and analyzed for NO₃-N using the method of Carlson et al. (1990).

Fruit yields were determined by mechanically harvesting plots into a scale-equipped GTO dumpster weigh wagon. Relative fruit yield for each treatment was calculated by dividing the mean yield for each treatment by the mean of the highest yielding treatment in that field. Fields, described by the terms N-limited or N-responsive, were defined as those showing significant yield response to fertilizer treatment.

Results

Concentrations of soil NO₃-N, organic matter (SOM), and total organic N as measured by pre-sidedress soil testing varied widely among fields (Table 1). Pre-sidedress soil NO₃-N levels across all fields ranged from 3.5 to 28.5 mg·kg⁻¹ N. However, there was little difference ($r^2=0.84$) in soil NO₃-N levels within individual fields between 0 to 30 cm and 0 to 60 cm soil depth. SOM (6.8 to 22.5 g·kg⁻¹) and total soil organic N content (0.7 to 1.7 g·kg⁻¹) were within typical ranges observed for Central Valley soils. Total N application (pre-sidedress plus sidedress N) by commercial growers in non-experimental rows at project sites ranged from 140 to 274 kg_ha⁻¹ N, consistent with typical input rates used by the industry.

Table 2. Effect of sidedress N rate on fruit yield in fields with significant N response.

Sidedress kg ha ⁻¹ N	Fruit yield (t ha ⁻¹)			
	Field 4	Field 8	Field 9	Field 10
0	97.2 ^z	88.9 ^z	112.0 ^z	77.5 ^z
56	118.5 ^z	115.6	119.4	88.5
112	129.5	123.0	121.4	90.3
168	138.0	120.7	118.5	91.2
224	137.8	121.0	124.1	89.4
280	141.6	95.4	116.3	87.8

^z indicates that mean yield of treatment level was significantly different ($P=0.05$) than the combined mean yield of all higher treatment rates, as determined by orthogonal contrast

Significant yield response to sidedress N application was found in only four of ten fields (Table 2). This overall lack of response to sidedress N, and the observation that even in responsive fields yield increase was limited to the lower treatment levels, suggested that linear and quadratic trend analysis was not the most appropriate analytical technique. Therefore, yield data were analyzed by orthogonal contrasts comparing each N treatment level against all higher N treatment rates. In fields 8, 9 and 10 the application of any sidedress N increased yield compared to unfertilized plots, but yields at 56 kg_ha⁻¹ N were not significantly different to those achieved with higher fertilization rates. In field 4, a significant yield increase was observed up to 112 kg_ha⁻¹ N. There were no fields with yield response to sidedress N application that had pre-sidedress soil NO₃-N concentrations above 15.7 mg·kg⁻¹ at 0 to 30 cm depth (Figure 1A) or 15.8 mg·kg⁻¹ at 0 to 60 cm depth (Figure 1B).

Fruit maturity and quality parameters (percent red or percent rotten fruit, blended fruit color, and SS) were unaffected by N treatment in most fields (data not shown).

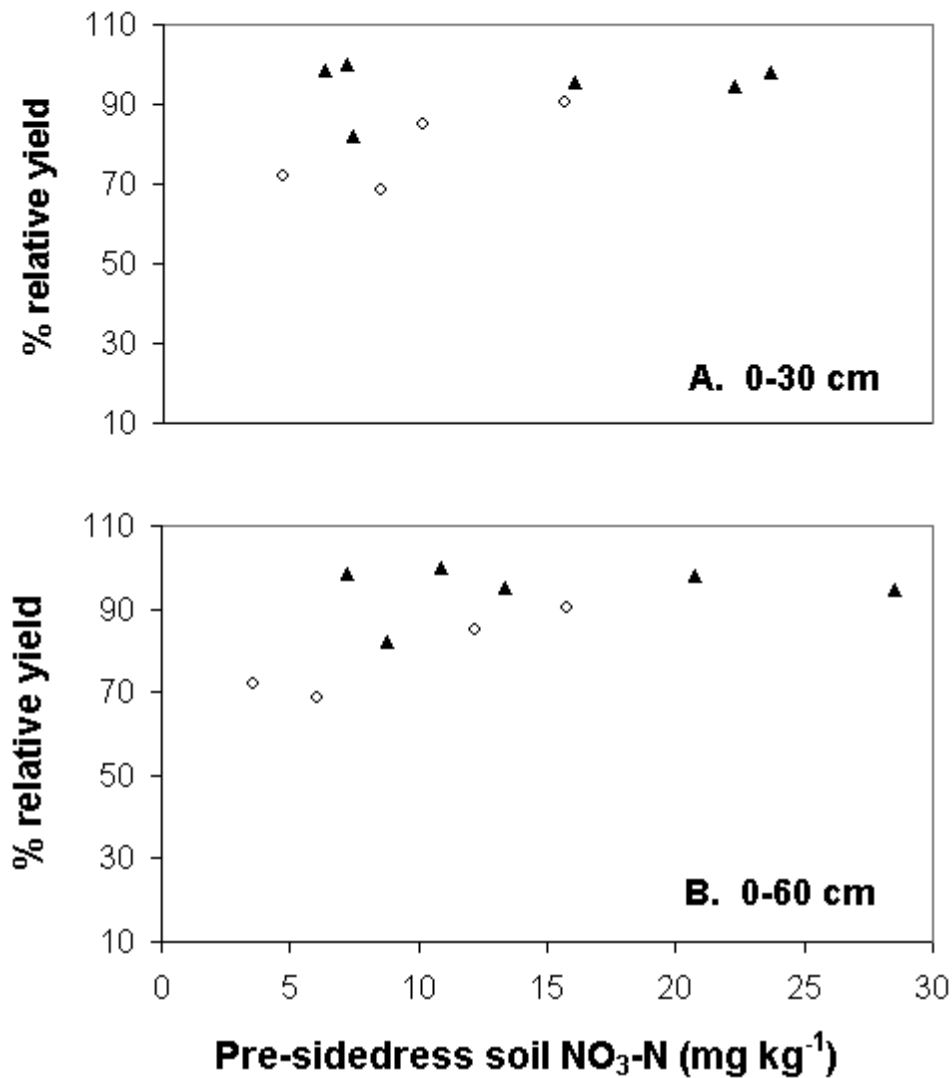


Figure 1. Relationship of pre-sidedress soil NO₃-N as measured at (A.) 0 to 30 cm and (B.) 0 to 60 cm depths and field mean of relative fruit yield by N treatment rate. Symbols indicate fields with (▲) or without (◊) significant yield response to sidedress N application, as determined by orthogonal contrast.

Discussion

This study showed that both university recommended and common industry sidedress N application rates for processing tomato production in California are excessive and could be substantially reduced without loss of yield or fruit quality. Of the ten fields utilized in this study, only four fields had any significant yield response to sidedress N, and none of these fields demonstrated yield response to sidedress N application above 112 kg_ha^{-1} N. Furthermore, fruit quality was virtually unaffected by sidedress N rate.

Pre-sidedress soil nitrate testing was a useful indicator of soil $\text{NO}_3\text{-N}$ availability. No fields used for this study that had $>16 \text{ mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$ in the top 60 cm of soil (approximately 140 kg_ha^{-1} $\text{NO}_3\text{-N}$, at a typical bulk density of $1.35 \text{ g}\cdot\text{cm}^{-3}$) prior to sidedress demonstrated any yield response to sidedress N application. This observation indicates the possibility of a critical level of residual soil $\text{NO}_3\text{-N}$ that will be sufficient to sustain proper plant growth and maximum yield without sidedress N application. The similarities between soil $\text{NO}_3\text{-N}$ levels at the 0 to 30 cm and 0 to 60 cm depths suggested that either sampling depth could be used to estimate $\text{NO}_3\text{-N}$ availability.

The lack of yield response to sidedress N application in fields with $>16 \text{ mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$ prior to sidedressing was not surprising, since these soil $\text{NO}_3\text{-N}$ levels represented more than 60% of seasonal total N uptake (200 kg_ha^{-1} N) for high-yield tomato production (Maynard and Hochmuth, 1997). Pre-sidedress residual soil N in project fields was augmented by in-season N mineralization of soil organic matter. Based on the incubation results, N mineralization could have provided an additional 40 to 80 kg_ha^{-1} N to plants during the growing season. Therefore, in-season mineralization of organic N, coupled with existing soil $\text{NO}_3\text{-N}$ estimated by PSNT, are likely factors in the overall weak crop response to sidedress N.

A PSNT level of $\approx 16 \text{ mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$ in the top 0 to 60 cm (or 0 to 30 cm) of soil could represent a conservative threshold level for determining whether sidedress fertilization is required. This suggested PSNT threshold level for processing tomatoes is slightly lower than those determined for corn (*Zea mays* L.) production in the Northeastern and Midwestern U.S. (Fox et al., 1989; Heckman et al., 1995; Magdoff, 1991; Schmitt and Randall, 1994; Spellman et al., 1996), and California coastal valley lettuce (*Lactuca sativa* L.) and celery (*Apium graveolens* L.) production (Hartz et al., 2000). These studies generally set PSNT thresholds between 20 to 25 $\text{mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$.

The results of this study support the use of a pre-sidedress soil nitrate test (PSNT) to identify California processing tomato fields that are unlikely to respond to sidedress N application. Fields with pre-sidedress soil nitrate concentrations of $>16 \text{ mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$ in the top 30 cm of soil would have a low probability of increased yields with sidedress N application. Furthermore, the limited response to sidedress N application, even in fields with minimal residual $\text{NO}_3\text{-N}$ levels, suggested that sidedress N rates currently used by the commercial tomato industry could be substantially reduced with no loss of yield or fruit quality. Dry petiole $\text{NO}_3\text{-N}$ sampling at the fruit set stage was determined to be the most effective indicator of post-sidedress plant N deficiency. Plants with dry petiole tissue nitrate-N levels of $<2500 \text{ mg}\cdot\text{kg}^{-1}$ $\text{NO}_3\text{-N}$ at fruit set are likely to be N-deficient and could benefit from late-season fertilizer applications.

Acknowledgement

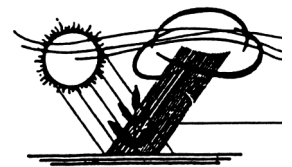
This summary presentation to the 2002 Annual Meeting of the California Chapter of the Agronomy Society of America has been excerpted from the MS Thesis by Henry Krusekopf submitted in partial fulfillment of his degree requirements at the University of California, Davis. An expanded version of this paper is in press in HortScience.

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**NEW REGULATORY
FRAMEWORK FOR
GROUNDWATER PROTECTION**



Detection and Mitigation of Pesticide Residues in California's Well Water Using Soil Characteristics and Depth to Ground Water

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In the late 1970's, residues of 1,2- dibromo-3-chloropropane (DBCP) were detected in California's ground water. This discovery demonstrated the potential impact that agricultural applications of pesticides could have on California's ground water supplies (Peoples et al., 1980). Prior to this time, movement of pesticide residues to ground water was considered unlikely because of dilution effects, low water solubility, high vapor pressure, rapid degradation, or binding to soil. After DBCP was detected, the Department of Pesticide Regulation (DPR, formerly the Division of Pest Management in the California Department of Food and Agriculture) conducted well sampling to determine the presence and geographical distribution of high use pesticides in California's ground water. Data from DPR's sampling programs and from other state, federal, and local agencies indicate that residues are not confined to a single area of California. A graph of the location of detected pesticides in the major ground water basins in California produces a similar list for all basins (Figure 1). An important aspect of this graphic is that the residues have been associated with a wide range of soil and climatic conditions.

In this report, I'll discuss our investigations on the pathways by which pesticide residues move to ground water and the subsequent studies that have been conducted to derive management practices aimed at maintaining pesticide use while minimizing off-site movement. These management practices have been incorporated into proposed changes in the current ground water regulations. Information on the regulatory changes and supporting documents is available on the internet at:

http://www.cdpr.ca.gov/docs/empm/gwp_prog/gwp_prog.htm

Why proceed with further regulation?

Pesticide substitution does not solve the problem

The DPR is conducting repeated sampling of approximately 70 domestic wells located in Fresno and Tulare Counties. Nearly all of the wells contain multiple residues of pre-emergence herbicides and their breakdown products. These herbicides are used either in combination with each other or as substitutes. For example, norflurazon (Soilcam) is a more recent substitute for simazine (Princep). Norflurazon residues have been found in 21 of the 70 monitored wells. Of these 21 wells, 20 wells also contained residues for parent simazine and two of its breakdown products. Furthermore, 10 of the wells in this subset also contained two additional residues for diuron (Karmex) and bromacil (Hyvar), resulting in at least 6 residues in each of these 10 wells. Physical-chemical properties of pesticides determine potential to move off-site. Each of these herbicides exhibits relatively long soil life and low soil sorption, a combination that assures efficacy but that also allows for mobility in percolation or runoff water.

Residues may reside in water for decades once they reach ground water

Figure 2 shows the concentration of DBCP in three wells located in three separate townships in Fresno County. Use of DBCP was suspended in 1979. A trend towards decreasing concentrations is observed for the well designated by the unfilled bars. In contrast, the solid bars indicate fairly stable concentrations across all years and the lighter, half-filled bars indicate an increase in concentration over years. Residues can be quite stable, lasting many years and can move with ground water flow to areas not previously impacted.

Base best management decisions on local soil and climatic conditions

Pesticide use statements on labels are broad and may not provide adequate directions to maximize efficiency. For example, practically all pre-emergence herbicide labels indicate that rainfall should be used to incorporate residues into soil. Residues of citrus herbicides have been measured in rain runoff (Braun et. al. 1991). Soils in the study area had low infiltration rates, which was due to soil compaction caused by a combination of soil properties and agricultural practices. Surface runoff water contaminates ground water when it is allowed to quickly recharge ground water, such as when it is injected deep into subsurface soil. Off-site movement in runoff water is minimized when residues are thoroughly incorporated into the soil matrix. Rainfall is not a reliable method on soils with low infiltration rates, so other methods of incorporation should be employed.

Uncertainty in health concerns

Issues with health concerns include:

- Breakdown products – Pesticide breakdown products have recently been added to chemical analyses and they are detected more frequently and at higher concentration than parent residues. If the breakdown products are toxicologically significant, are the residues measured in a single sampled additive? What then is the health guideline?
- Domestic wells are not routinely monitored - The California Department of Health Services (DHS) is tasked with monitoring and regulating drinking water and most programs deal with municipal wells, which serve multiple family connections. DPR's efforts complements DHS's activities by focusing on rural, single family, domestic drinking water wells. But DPR's regulatory authority extends to pesticide use practices and not specifically to regulation of well function.
- Numerous health guidelines - The U.S. EPA and the California Department of Health Services have developed various regulatory guidelines. Atrazine, for example, has a Maximum Contaminant Level of 3 ppb and a Public Health Goal of 0.1 ppb. It is unclear as to which one applies to our developing regulatory process.

Current regulatory system not effective

Agricultural use of pesticides detected in California's ground water is regulated through the issue of 'Advisories'. It was anticipated that this could be a method to adopt management practices that would prevent ground water contamination. This method has not been effective in adapting management practices to local soil conditions and in preventing further contamination of ground water.

Determining areas vulnerable to pesticide contamination

A process for identifying vulnerable areas has been developed for California conditions. It is denoted as the California Vulnerability Approach (CALVUL) (Troiano et. al. 1999). Prior to development of the CALVUL method, the main approach that was used to describe vulnerable areas of land was to develop a model of downward leaching as a function of specific land variables. The goal was to produce an index that would rank land areas from invulnerable to vulnerable conditions. Detections of residues over a broad range of soil and climatic conditions in California prompted development of a novel approach to describing vulnerable land areas. With detections covering such a wide range in conditions, as previously indicated in Figure 1, we had little confidence in declaring an area as invulnerable or in describing an “invulnerable condition”. Instead we focused our efforts on describing the geographic conditions that are associated with contamination and on conducting studies to understand the processes for movement to ground water. Cluster analysis was used to determine soil variables that grouped sections of land with detections of pesticide residues in ground water. In the most recent analysis, important soil clustering variables were shrink-swell potential, permeability, the presence of a hardpan soil layer, and the presence of an annual water table (Table 1). The combination of shrink-swell potential and permeability was indicative of soil texture, e.g. highly permeable soils with very little shrink-swell potential reflected coarse-textured soils and at the opposite end slowly permeable soils with high shrink-swell potential reflected fine-textured soils. The number of soil particles passing a number 200 sieve is included to further illustrate this relationship. Two other variables, the presence of a hardpan layer and the presence of an annual water table, produced further divisions of the clusters.

In addition to soil properties, depth-to-ground water has also been identified as a factor in determining vulnerability (Troiano et. al. 1997). The probability for detection of residues in domestic wells is greater in areas with shallow depth-to-ground. A cut-off of 70 feet has been determined from an analysis of the relationship between frequencies of pesticide detections and estimated sectional depth-to-ground water (Spurlock 200B).

We are proposing to identify vulnerable areas as the location of a vulnerable soil condition within an area of shallow depth-to-ground water. These areas will be designated as Ground Water Protection Areas (GWPA). The relationship of GWPAs to sections with detections of pesticide residues is illustrated in Figure 3. The outlined squares are sections with detections of pesticide residues. Many of these sections are currently designated as Pesticide Management Zones (PMZ) where pesticides listed in regulation on the 6800(a) list are subject to regulation. Designation of PMZs has grown as a consequence of well sampling and they are only identified after residues are detected in well water. Adoption of GWPAs would eliminate further designation of PMZs and further sampling in sections adjacent to PMZs.

Matching best management practices to soil conditions of GWPA's

An important aspect of the CALVUL approach was to generate an understanding of local conditions of ground water contamination. Since soil condition was one aspect of the description of GWPA's, it was possible to link specific processes of pesticide movement to ground water with best management practices. Movement of pesticide residues in coarse soils is caused by leaching of residues through the normal course of recharge of ground water. In low rainfall areas, percolation losses from irrigation applications are the major source of ground water recharge. Pesticide residues that contact percolating water generated from irrigation applications are susceptible to movement to ground water. The effectiveness of irrigation management in minimizing downward movement of pesticide residues was illustrated in a study of amount and method of irrigation water application on movement of atrazine in a sandy soil in Fresno (Troiano et.al. 1993). A target of 133% efficiency in irrigation applications for 6 months after pesticide application was determined through a Monte Carlo analysis of the potential movement of pesticides on coarse soils, using the data from the previous irrigation study as a benchmark (Spurlock 2000B). Thus, in coarse soils, **leaching** is identified as the primary process of movement of residues to ground water and irrigation management is the proposed best management practice when residues are subject to movement with percolating water.

In contrast, dissolution of pesticide residues in runoff water has been identified as the source of contamination for soils with a hardpan layer and where the surface layer has been compacted. Owing to greatly reduced rates of soil infiltration, elevated concentrations of herbicide residues have been measured in rain runoff water that was systematically drained from fields (Braun and Hawkins 1991). Methods to dispose surface runoff water rapidly to subsurface soil act as sources of ground water contamination. For pre-emergence herbicides, rainfall is indicated as the primary method of soil incorporation. Other methods, such as mechanical incorporation, have been shown to greatly reduce off-site movement and may eventually prove to be more effective in maximizing herbicide efficacy, especially in areas with low rainfall (Troiano et. al. 1998). Thus, in GWPA's with hardpan soils, **runoff** is identified as the primary process of movement to ground water and either elimination of injection of surface water to subsurface soil or full incorporation of residues into soil prior to rainfall are the proposed best management practices.

Summary

The thrust of proposed changes in ground water regulations is to provide a framework for adoption of best management practices that are tailored to local soil and climatic conditions. The suggested changes are intended as a further refinement of label instructions with the potential effect of maximizing the efficacy of pesticide applications.

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Table 1. Results of a cluster analysis for grouping sections of land with pesticide residues detected in ground water.

Cluster Description	Contaminated Sections	Soil Property					No 200 Sieve	Pathway
		Shrink/Swell Index	Permeability (in/hr)	Hardpan Index	Water Table Index	Water Table Index		
	#	(0-3)	(in/hr)	(0-1)	(0-1)	(%)		
Coarse (C) Texture	83	0.01±0.04	7.8±1.4	0.05±0.09	0.07±0.08	33±4	Leaching	
M-C + WT	15	0.06±0.13	5.1±1.1	0.04±0.08	0.43±0.12	41±8	N.D.	
Medium (M) + Pan	123	0.17±0.23	2.9±1.2	0.41±0.10	0.02±0.05	49±7	Runoff	
Medium Texture	71	0.24±0.28	3.1±1.3	0.06±0.09	0.04±0.08	49±9	N.D.	
Medium + Pan	58	0.02±0.08	1.7±0.1	0.84±0.15	0±0	53±6	Runoff	
M-F + Pan	15	0.65±0.16	1.3±0.9	0.80±0.16	0.03±0.08	62±7	Runoff	
M-F + Pan	18	1.08±0.19	0.8±0.3	0.45±0.14	0±0.02	66±5	Runoff	
Fine (F) + WT	11	0.71±0.24	1.2±0.6	0.01±0.03	0.89±0.11	76±10	N.D.	
Fine Texture	29	1.41±0.27	0.5±0.3	0±0.02	0.13±0.14	81±6	N.D.	
Fine + WT	12	1.16±0.24	0.6±0.2	0.05±0.12	0.54±0.09	79±7	N.D.	
Fine + WT + Pan	8	1.16±0.22	0.5±0.2	0.46±0.17	0.88±0.11	81±5	N.D.	
Very Fine	9	1.49±0.27	0.5±0.4	0±0	0.86±0.12	85±4	N.D.	
Total sections	452							

N.D. = Not Determined

Figure 1. Distribution of pesticide residues in major ground water basins in California and associated soil and climatic conditions.

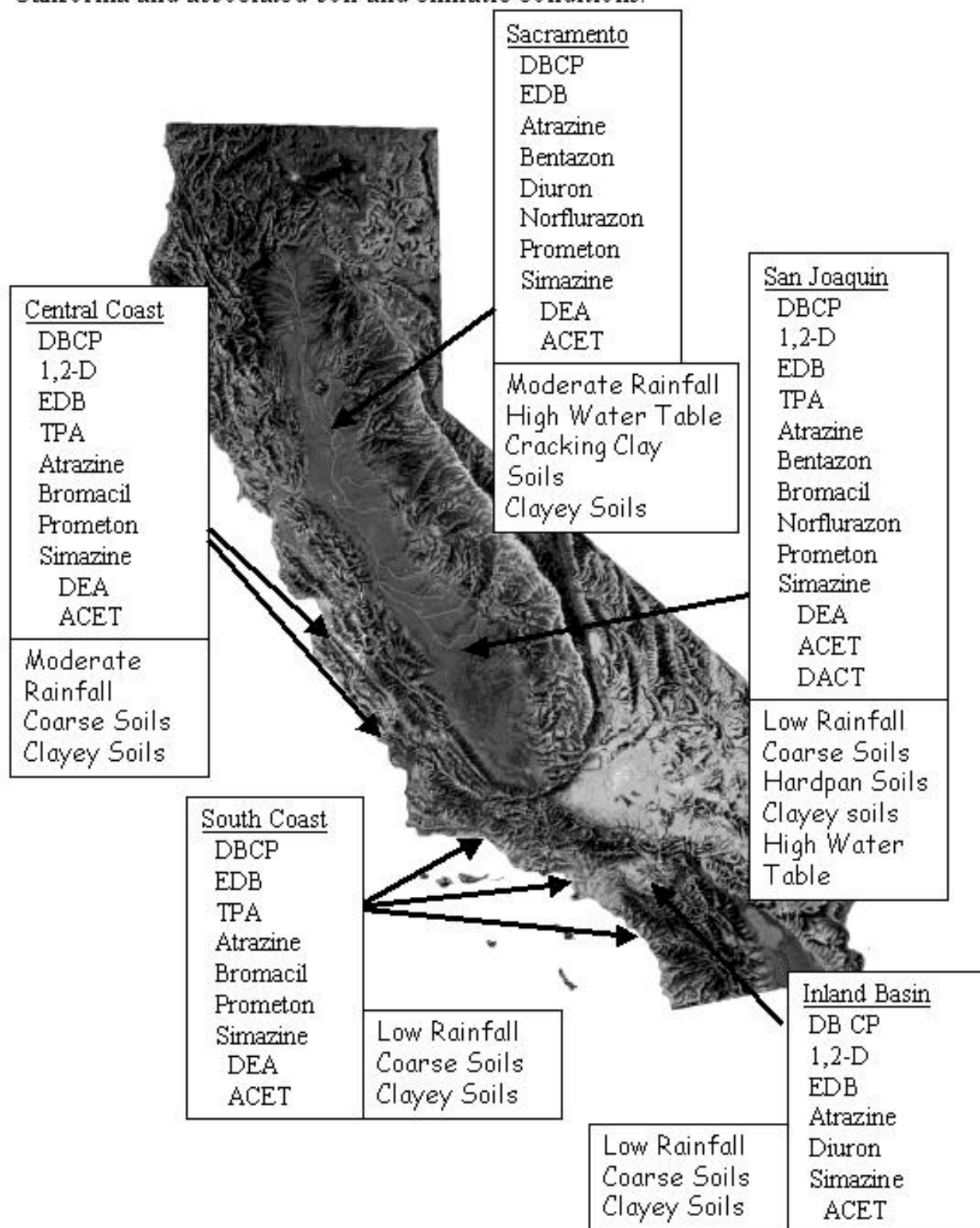


Figure 2. Concentration of DBCP in three wells sampled in three separate townships in Fresno County after suspension of use in 1979.

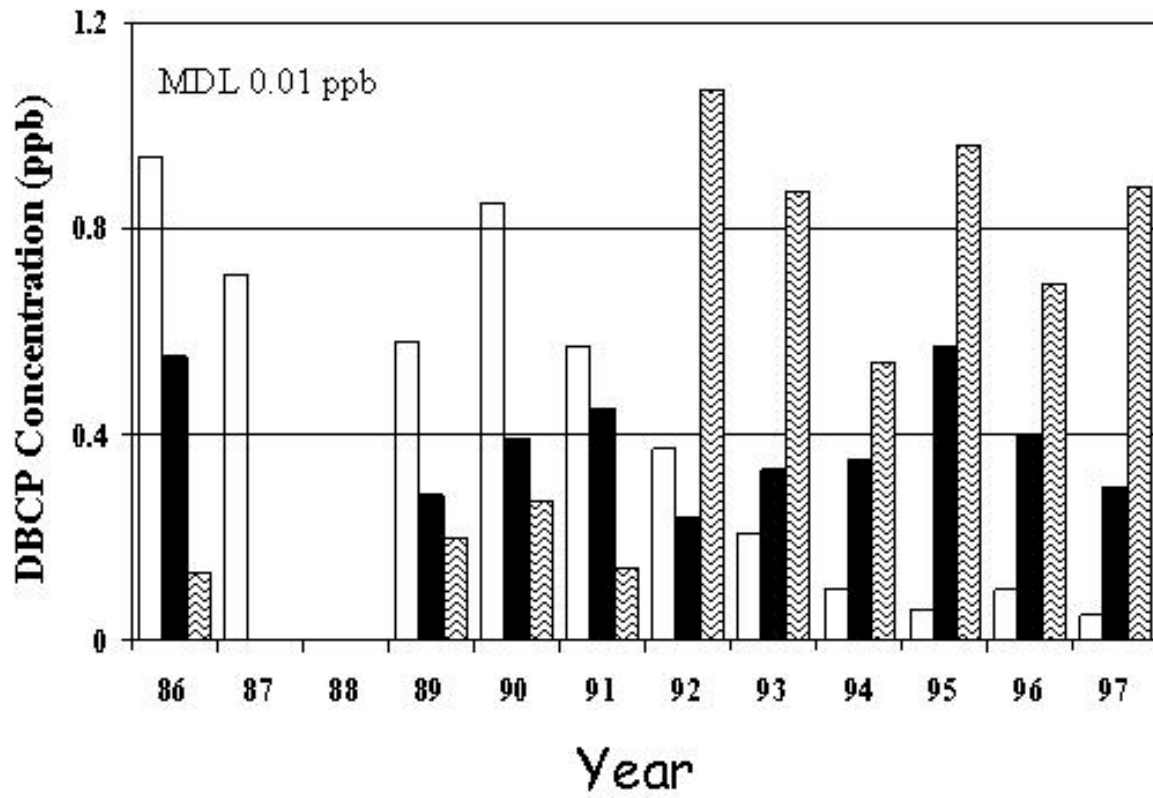
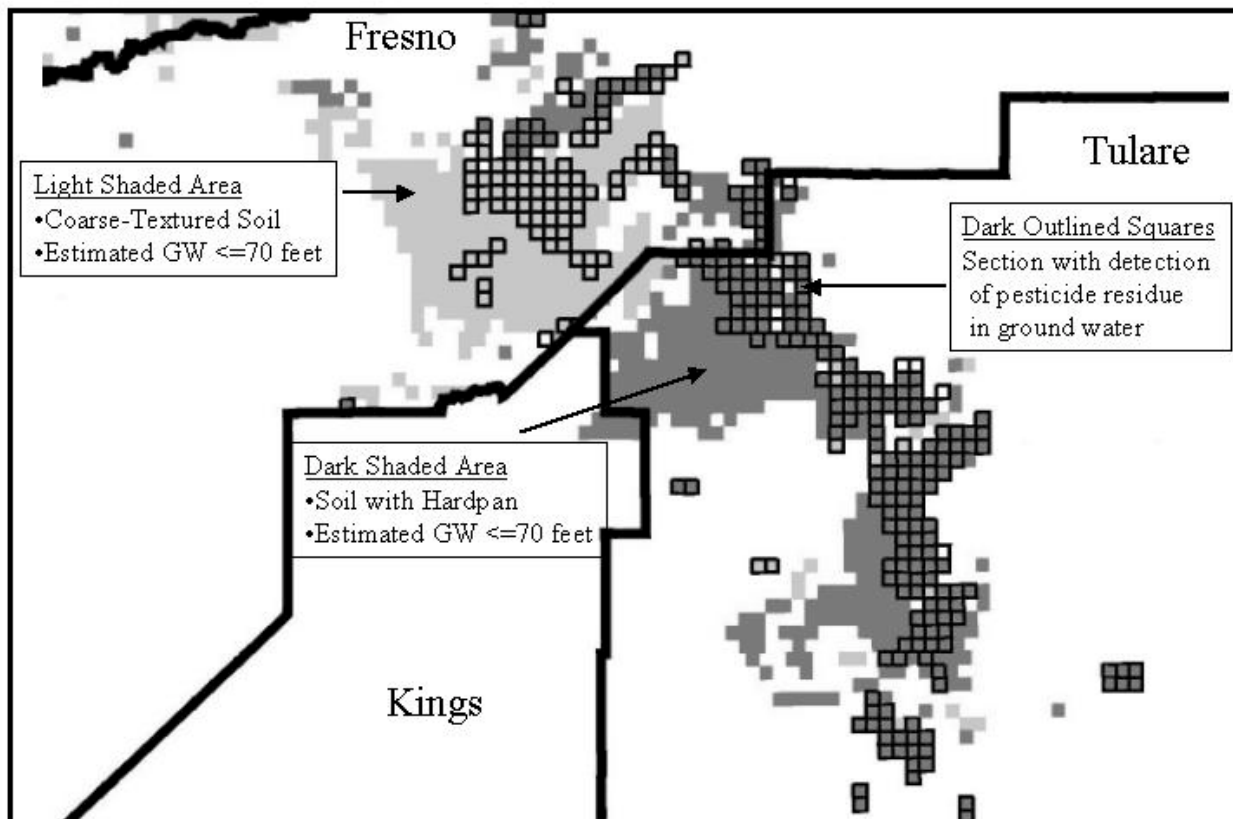


Figure 3. Relationship of proposed Ground Water Protection Areas to sections with pesticide residues detected in ground water in Fresno and Tulare Counties.



Wellhead Protection Program

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Protecting ground water from contamination is getting a lot of well-deserved attention today. Protecting wells is a critical step in protecting ground water from the direct introduction of chemicals into ground water. Well protection involves proper grading around the well, proper sanitary seals, and proper abandonment procedures along with the current topic: backflow prevention aspects of wellhead protection. The US EPA requires all pesticides approved for chemigation use to include a list of equipment that must be present on the label before chemigation can be used as a means of application. The approved language was adapted from the Nebraska wellhead protection program, which has been in place for more than 10 years.

Chemigation is defined as the application of chemicals with water through on-farm irrigation systems to land or crops. This all encompassing language applies to anything added to the irrigation water. Various regulatory agencies have altered the definition to fit their regulatory purview. For example, the California Department of Pesticide Regulation defines chemigation as the application of pesticides and leaves out other options.

Ground water contamination can occur anytime there is a failure or normal shutdown of the well pump in the irrigation system. The cause of the failure can be as common as a power failure but also could include any circumstance which would cause the pump to stop pumping water - from catastrophic pump failure to a blown fuse. Normally, chemigation would be terminated long enough before shutting off the well pump in order to allow enough time for the chemical to be flushed from the irrigation system. Any reversal of flow occurring after the irrigation system has been flushed will not introduce chemicals into the groundwater. It is only when the irrigation is terminated before proper flushing has occurred and/or while the chemigation injection pump is still operating, that a reversal of flow could cause ground water contamination problems.

Reverse flow of water down a well occurs each time a well pump is shut off. The column of water that the pump has been lifting from the water table to the surface reverses direction and heads back down to the water table due to the force which gravity exerts on it. Under the right circumstances, the water in the irrigation system can also move back down the well if a check valve is not present in the irrigation pipeline. If the irrigation system has been used to apply chemicals (chemigation) and the chemicals have not been properly flushed out of the system, those chemicals will follow the irrigation water back down the well. Traces of agricultural chemicals have been showing up in ground water in California for some time now and one source of the contamination may be contaminated water backflowing down the well.

As mentioned previously, the Federal EPA has mandated that all pesticides approved for chemigation must include a list of equipment designed to prevent backflow of contaminated water down the well. The labels include the following eight system features. A few labels require additional equipment.

1. A functional check valve appropriately located in the irrigation pipeline.
2. A vacuum relief valve located upstream of the check valve.
3. A low-pressure drain valve must be appropriately located on the irrigation pipeline to prevent backflow of water that leaks past the check valve from reaching the ground water.
4. The pesticide injection pipeline must contain a functional, automatic, quick closing check-valve to prevent the flow of irrigation water back toward the chemical supply tank or injection pump.
5. The pesticide injection pipeline must also contain a functional, normally closed, automatic valve located on the intake side of the injection pump and connected to the system electrical interlock to prevent fluid from being withdrawn from the supply tank when the system is either automatically or manually shut down.
6. The system must contain a functional inter-lock to automatically shut off the injection pump when the irrigation pump motor stops.
7. The irrigation line or water pump must include a functional pressure switch that will stop the water pump motor when the water pressure decreases to the point where pesticide distribution is adversely affected.
8. Injection systems must use a metering pump such as a positive displacement injection pump or diaphragm pump, venturi system or pressure-safe cylinder equipped with a metering valve and flow meter. This equipment must be constructed of chemical resistant material and be capable of being fitted with a system interlock.

The first three components can all be supplied in what is commonly known as a chemigation valve. Manufacturers make these valves in aluminum and steel, galvanized, epoxy or powder coated, flanged, plain end or ring lock. All have the same basic components - a spring loaded, rubber coated swing check with a vacuum relief valve and low-pressure drain located upstream of the check valve. These valves are designed to operate with a minimum of head loss, generally 2-3 psi, and are also designed with a 4-inch diameter port to allow for inspection of the swing check without the removal of the chemigation valve.

The swing check is spring loaded and rubber coated to insure positive sealing at very low pressure. If the pump and filter station is located above the level of the irrigation system in the field, the backflow pressure on the check valve, if any, will be much less than 1 psi.

The vacuum relief valve is usually a combination air/vacuum relief valve. These are a common sight in the valley and are quite reliable. These can be attached to the chemigation valve by means of a ring-lock clamp or a grooved coupler and, in addition to relieving vacuum developed by water in the column pipe returning to ground water level, the vacuum relief valve often serves to cover the port for inspecting the condition of the swing check.

The low-pressure drain will drain off any liquid that may leak past the swing check. It is meant to protect the well from leaks of up to a few gallons per minute, not to protect from catastrophic failure. It consists of a small, normally open, poppet valve on a light spring that can shut under very low flow conditions to minimize leak potential but will open under atmospheric pressure to direct any leak away from the irrigation pipeline.

The quick closing check valve in the pesticide injection pipeline is also a poppet valve but in this case it is normally closed. A light spring holds the valve, usually a stainless steel ball, against a metal seat. The pressure developed by the injection pump overcomes the spring pressure and opens the valve during the pesticide injection process. The valve keeps water from backing up into the injection pump and pesticide supply tank.

The normally closed valve in the pesticide pipeline between the injection pump and pesticide supply tank is usually a small diameter solenoid valve which is tied into the system interlocks. Its purpose is to isolate the pesticide supply tank from the irrigation system when the injection pump is not operating.

The system interlocks consist of relays and wiring which will not allow the injection pump to operate when the water pump is not operating. The interlocks will shut off the injection pump whenever the pump motor stops.

The pressure switch monitors system pressure and can be set to trip the system off when the system pressure is too far below normal operating pressure. Regulations state that the switch must stop the water pump motor whenever pressure drops to the point where pesticide distribution is adversely affected. The operator must have determined before hand what the minimum operating pressure for his system is. This will be much more challenging than the installation of the pressure switch. Very few irrigation system operators know how the distribution uniformity of their irrigation system varies with pressure. Very few know the distribution uniformity of their irrigation system at any pressure.

Finally, the injection pump must be a positive displacement type or, if another type is used, it must be used in conjunction with a metering valve and flow meter. The positive displacement pump has the ability to be calibrated with actually measuring the output volume. These injection pumps have a fixed bore through which a piston with an adjustable stroke passes. The variability in output of the pump is

achieved by adjustment of the stroke. The rate of injection is not affected by system pressure only by the stroke of the pump. The rate of injection of all of the other injection methods mentioned is not as predictable and therefore a flow meter and metering valve are required to monitor and adjust the flow.

These requirements have been listed on the labels of pesticides approved for chemigation since 1988 and a few counties have been inspecting pumping facilities to determine the extent of compliance with the label requirements. The State of California is currently involved in training the agricultural community in the concepts and equipment involved in wellhead protection. The thrust of this educational program is to encourage voluntary compliance with the pesticide label requirements statewide.

Alfalfa Herbicide Pollution Pathways and Mitigation Practices

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Introduction

Investigations on the pathway for movement of pesticide residues to ground water are needed to determine if mitigation measures can be developed that allow continued use, but that are also protective of underground aquifers. For example, on coarse-textured sandy soils, guidelines for irrigation management have been suggested to minimize movement of residues lost to deep percolation, whereas in hardpan soils with low infiltration rates, improved incorporation of pre-emergence herbicides is recommended to reduce concentrations in runoff water that eventually recharges ground water.

These two scenarios are not representative of all geographical settings where residues have been detected in California's ground water, so further investigations required on movement of pesticides to ground. This report describes an investigation on the pathway for movement of hexazinone and diuron residues to ground water in an area dominated by cracking clay soils. Residues of these pre-emergence herbicides were detected in wells sampled near the town of Tracy, California where the predominant cropping pattern was a rotation of alfalfa with corn and beans. Tracy is centrally located on the western side of the Central Valley of California. The residues were related to agricultural applications, especially since hexazinone could only have been used on alfalfa.

Movement through cracks in clay soils is a potential pathway for pesticide residue movement to ground water. Another potential pathway noted in this area was through the percolation of water collected in ponds at the edge of the fields. The ponds collected runoff water that was generated from rainfall or irrigation events. Pond water could have been lost to evaporation, percolation, or in some cases it was reused through an irrigation return system. Given that the ground water in this area was shallow at around 15 feet and that the ponds were generally 6 to 9 feet deep, they appeared to be potential candidates for recharging the shallow ground water with water containing pesticide residues.

Field Study

A field study was initiated in the winter of 1999 to determine the predominant pathway for movement of residues to ground water. The objectives were to:

1. Evaluate the fate of diuron and hexazinone applied to an alfalfa crop,
2. Determine potential for downward movement of water from the ponds,
3. Evaluate the effect of a surfactant on the offsite movement of hexazinone and diuron.
4. Investigate the effectiveness of trifluralin and paraquat as potential replacements.

Site and Study Description

This study was conducted within an alfalfa field located near Tracy, California. The field was approximately 34 acres in size entering the third season of alfalfa cultivation. The predominant soil-mapping unit was a Capay clay (fine, smectitic, thermic Typic Haploxerert). The ground water was shallow and located at around 15 feet.

Diuron and hexazinone are applied as pre-emergence herbicides to alfalfa during the dormant season in December and January to control existing winter weeds and to prevent subsequent weed germination.

The timing of application coincides with the rainy season to incorporate the herbicide residues into soil. The method of irrigation is border check using siphons to deliver water from an open ditch. Each irrigated check was 27 ft wide by 1100 ft in length, which was equivalent to 0.68 acres. The rate of water flow onto the check was constant for each irrigation, and it was measured at 202 gallons per minute for the first irrigation of the season and just slightly greater at 212 gallons per minute for the second irrigation. Runoff water was diverted from the tail end of the field to a small pond situated on the Northwest corner of the field.

A randomized complete block design with 4 replicate blocks was utilized to compare environmental fate and efficacy among the following three main treatment effects:

1. Grower standard pre-emergence herbicide treatment of hexazinone and diuron applied at 0.5 and 1.5 lbs/acre, respectively.
2. Effect of a surfactant added to Treatment 1 at a rate of 2 gal/acre.
3. Efficacy and fate of alternative herbicides using trifluralin and paraquat applied at 0.5 and 1.5 lbs/acre, respectively

Each treatment was applied to one check resulting in a total of 12 checks used for the study. In order to measure potential spatial differences due to water movement due to rainfall or irrigation, each check was equally subdivided into thirds, with each third approximately 15 feet wide by 366 feet in length. Samples were taken from each third to represent the head, middle, and tail portions of the check.

Treatment Applications

Pre-emergence treatments of diuron and hexazinone with and without surfactant were applied as a tank mix on December 23, 1999. Paraquat was also applied on December 23 followed by a sequential application of trifluralin in a granular application on January 19, 2000. Deposition was measured during application by placing 11.5 x 11.5 inch squares of Kimbie sheets on the soil surface. Three sheets were collected after being placed in each replicate check, one in each of the upper, middle, and lower sub-sampling areas.

Pond Water Sampling

It is important to note that the water entering the pond was the result of runoff from a larger area than the experimental area. Therefore, a pond sample did not directly represent the herbicide concentrations or mass as a result of runoff from the treatment areas. However, they were important as an indication of the potential fate of residues entering the pond.

A technique was developed to determine pond volume from water depth measurements. First, the volume of the pond was estimated using a 3-dimensional survey technique. Then a relationship was established between pond depth and estimated volume. This relationship was calibrated by relating measured inflow volume of runoff water to the concomitant increase in pond depth. Inflow was measured using a 200 mm throat broad crested RCB flume equipped with a stilling well and pressure transducer to measure head. An additional transducer was placed at the bottom of the pond to measure pond depth. There was good agreement between volume deduced from pond depth and direct measurement. Pond depth was then used to determine the volume of infiltrated water, the rate of infiltration as calculated through temporal changes in wetted area.

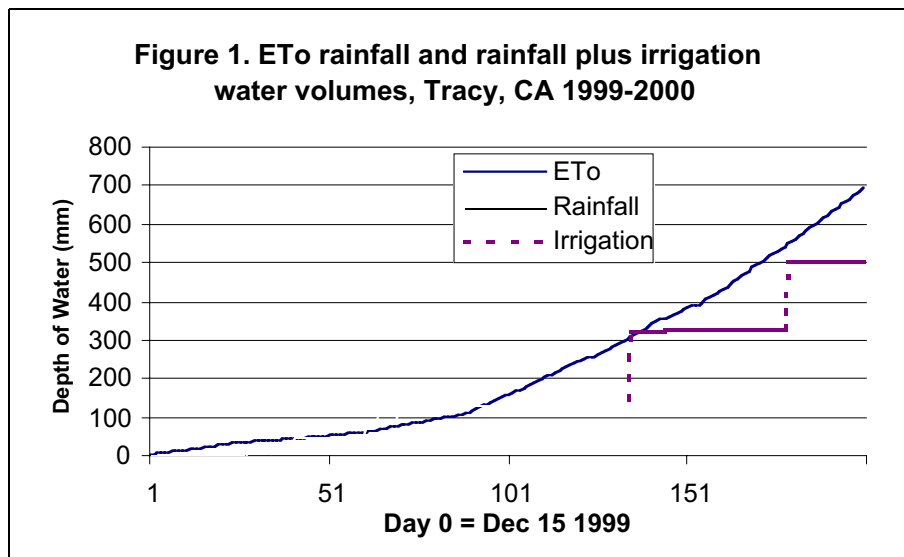
Chemical Analysis and Quality Control

The selected laboratories developed and validated a method for analyzing Kimbie sheet, soil, sediment, vegetation, and water samples for hexazinone and diuron. The analytical method was approved by DPR. This study was done in accordance with EHAP SOP QAQC001.001.

Results and Discussion

Water Distribution and Movement

A comparison of the cumulative amount of rainfall and irrigation to cumulative ETo provides reference for the potential runoff and percolated water produced during the study (Figure 1). Prior to the initial date of this study, which will be indicated as 15 Dec. 1999, very little rainfall was recorded in the fall.



The cumulative amount of rainfall eventually was greater than cumulative ETo and thus would have potentially produced some percolation or runoff water. During this period, however, runoff water was not observed from the treated sites, so the frequency and amount of rainfall was not sufficient to generate runoff water samples. Soil water content at the second soil coring date was consistently greater than background samples, indicating that rainfall did produce percolation that was measured down to the lowest depth sampled.

Rainfall after day 85 was minimal. The contributions of water from the two irrigations are visible as the two sharp upward spikes in the curve for accumulated rainfall plus irrigation. The irrigations supplied enough water to cover the cumulative deficit in ETo.

Both irrigation events were similar in terms of total run time and onflow volumes, averaging 6.88 in depth (Table 1). Runoff depth varied between irrigations from 0.17 to 0.49 acre inch/acre. Differences between irrigations were caused by small differences in on flow volumes, run times and antecedent soil moisture content. The proportion of tail water caused by runoff was 2.5% of the first and 7.1% of the second irrigation applied volumes. Runoff from the second irrigation was considered more reflective of typical conditions.

The moisture profiles of the soil cores were reflective of a potential distribution caused by the dynamics of border check irrigation. Moisture at the head end of the check was greater than at the tail end, which is caused by greater opportunity time of water that contacts the head end of the check. Increases in water content at the lowest depth indicated that the irrigation treatments caused drainage past this depth and provided a potential leaching environment.

Soil and Vegetation Sampling

Background sampling: Diuron residues were detected in all surface samples at the 0-3 inch depth and only sporadically in the next lower depth at 6 inches (Figure 2). Upon summation of residues from all depths, the detections indicated an average recovery of 0.12 kg/ha, which corresponded to approximately 8% carry-over from the previous years application.

Hexazinone residues were essentially undetected, which was likely due to its lower application rate (Figure 3). Paraquat and trifluralin had not been previously applied and they were not detected in background samples.

Prior to First Irrigation: The amount of rainwater received by the plots between pesticide application and commencement of soil sampling on April 3 was 5.1 inches. A test for the effect of surfactant indicated greater concentration of diuron in treatments with added surfactant whether or not the deposition data were used as a covariate in the ANOVA. Although location effects were not significant in the split-plot ANOVA, regression within treatments indicated residues increased from the head to tail end of the standard treatment. The distribution pattern for hexazinone appeared similar to diuron, in that there were no significant effects in the statistical analysis, a result that may have been due to the lower application rate (Figure3).

The distribution of residues throughout the soil profile was different between diuron and hexazinone. Very little diuron was detected beneath the first 0-3 inch depth, whereas, concentrations of hexazinone in the deeper segment were equal to those measured in the first segment (Figures 2 and 3). Little to no residues were measured for either herbicide in the third segment, which represented the 12-inch depth. Based on a comparison of their physical-chemical properties, greater movement through soil would be expected for hexazinone, caused primarily by its lower soil adsorption value (Koc).

The mass of residues recovered from the total soil core length averaged 0.58 kg/ha for diuron and 0.09 kg/ha for hexazinone. These values represented a decrease from the application day values of 66% for diuron and 79% for hexazinone. Diuron was only sporadically detected in vegetation samples. But residues were consistently detected at the surface and next lower depth in soil sampled from the drain and pond. Samples were sporadically measured at the depth 3.

After Second Irrigation: The alfalfa field received two surface irrigations prior to this soil coring. The average depth of water received by the plots between pesticide application and commencement of soil sampling on June 26 was 19.7 inches. The magnitude of the residues for both pesticides was reduced to levels that were similar to those measured in the background samples. Statistical tests for effects of treatment and location were not significant. However, the observed patterns were similar to the previous soil coring date (Figures 2 and 3).

Figure 2. Distribution of diuron in soil at three sampling dates and compared between minus and plus surfactant treatments.

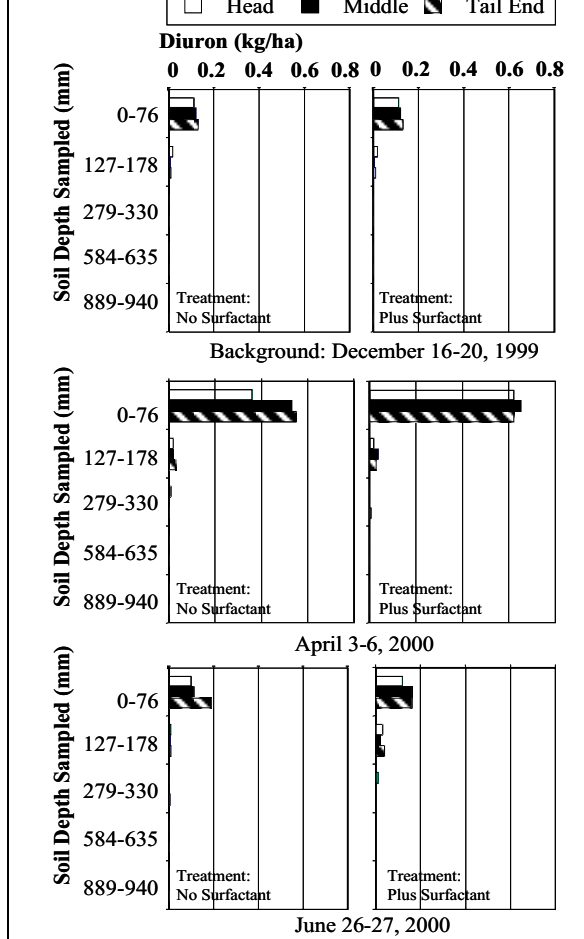
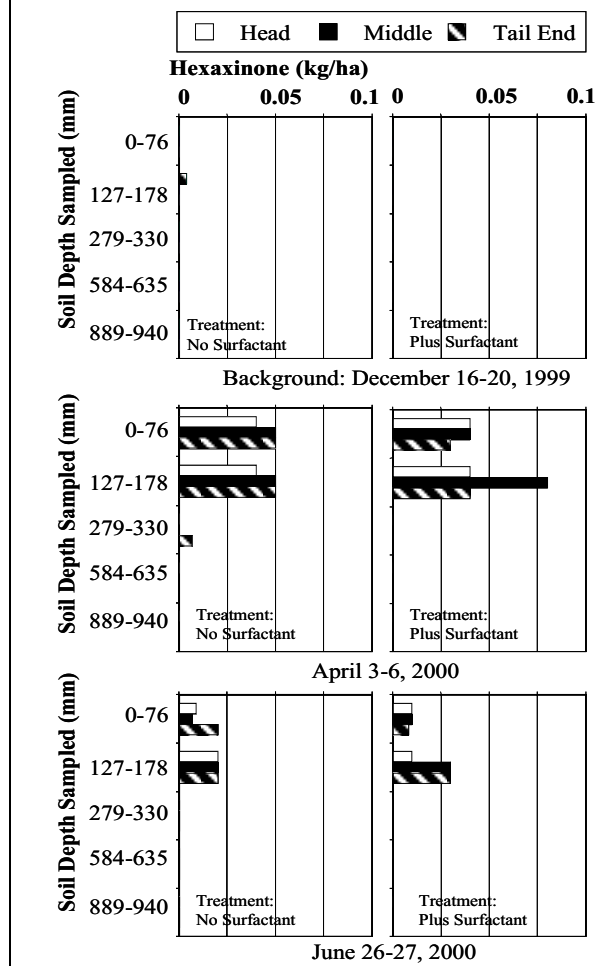


Figure 3. Distribution of hexazinone in soil at three sampling dates and compared between minus and plus surfactant treatments.



Runoff Water Measurement and Sampling

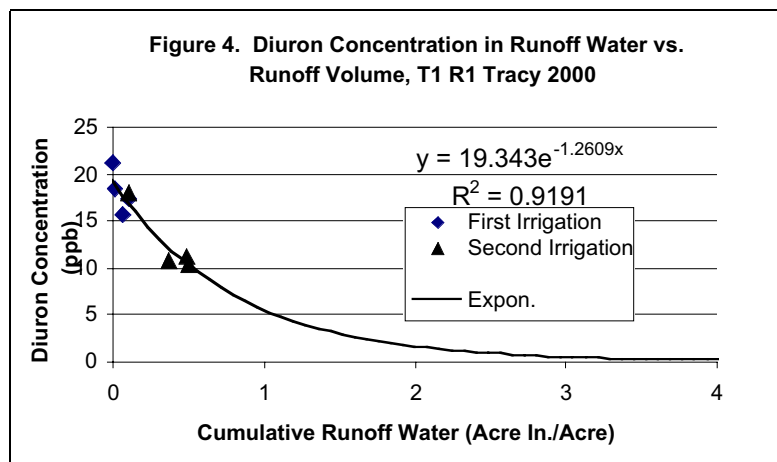
Herbicide Concentration and Mass in Runoff Water: Significant differences in diuron concentration were measured between irrigations with the concentrations for the first irrigation runoff approximately twice the concentration of the second (Table 1). Hexazinone concentrations also appeared greater at the first irrigation; however, the level of probability indicated only a trend ($P= 0.0726$). The addition of the surfactant did not significantly affect the concentration of herbicides in runoff water. The mass of both diuron and hexazinone in the runoff waters was calculated as the product of the concentration and volume of runoff water (Table 1). No significant differences in mass of herbicide leaving the field were found between treatments or irrigations. Although the concentration of diuron herbicide was reduced in half from the first irrigation, the runoff volume had tripled in the second irrigation resulting in no significant differences in the mass leaving the field. The results for hexazinone were similar. No triflurilan or paraquat was detected in runoff waters.

Table 1. Average concentration and mass of residuals with treatments across irrigations and irrigations across treatments

Treatment	Diuron (ppb)	Hexazinone (ppb)	Diuron (g/Acre)	Hexazinone (g/Acre)
1	13.27	0.423	0.4285	0.0134
2	17.37	0.7	0.3691	0.0115
P =	0.2024	0.2773	0.6082	0.627
Irrigation				
1	20.53 A	0.945	0.3135	0.0123
2	10.08 B	0.258	0.4841	0.0127
P =	0.0174	0.0726	0.1857	0.9039

Decline in concentration as a function of runoff volumes: The concentration of herbicide in the runoff water declines as cumulative runoff water volume increased both in a single and multiple irrigations. The initial 5-gallon sample collected at each irrigation had a higher concentration than samples collected later in each irrigation. The concentration of diuron in the initial sample collected in the second irrigation was more similar to those of the pervious irrigation however all subsequent samples were lower. Hexazinone followed a similar pattern.

Using data collected from both irrigations, a relationship between concentration in the runoff water and cumulative runoff was constructed (Figure 4). Using an exponential fit, a significant relationship was found in both herbicides. The model predicts less than 0.5 ppb Diuron in the runoff water at a cumulative runoff of 3.0 inches per acre. The model constructed for Hexazinone predicts less than 0.02 ppb at a cumulative runoff of 1.5 inches per acre.



Holding Pond

The holding pond captured the unmeasured runoff from the entire field. Although runoff from the experimental area did not occur from rainfall, some water was collected in the holding pond from the drain check/field road area at the tail end of the field (pond volume vs. time). During the irrigations, runoff was collected from the experimental area and the rest of the field. The non-experimental area was treated with both diuron and hexazinone as in Treatment 1. Seven individual irrigation sets totaling 50 checks contributed variable runoff volumes. An attempt was made by the irrigator to minimize runoff from the field as a whole so as not to exceed the capacity of the pond. There was no

pond water-recycling pump. Therefore, the concentration of the pond water was not strictly reflective of the concentration of herbicides in the runoff of a specific treatment; however, they were similar.

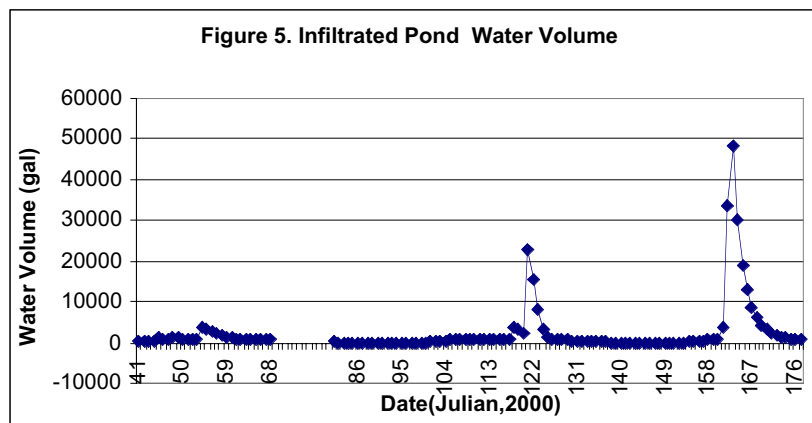
Pond Volume

At full capacity, the pond holds 105,000 gallons. Full capacity occurs water no longer drains from the field. The pond was empty prior to each irrigation event. The pond capacity provides for near 3000 gallons per acre irrigated. The first irrigation resulted in less runoff than the second. The maximum pond capacity was reached the second irrigation. Runoff volume from the experimental area averaged over both irrigations 4.8 percent on the inflow, or 0.33-acre inch/acre. If the entire 34-acre field were irrigated in a fashion like the experimental area, 11.2 acre-inches of runoff would result. Only 4.5-acre inch of runoff was captured on average between the two irrigations indicating current operations resulted in considerably less runoff volume.

Pond Infiltrated Water

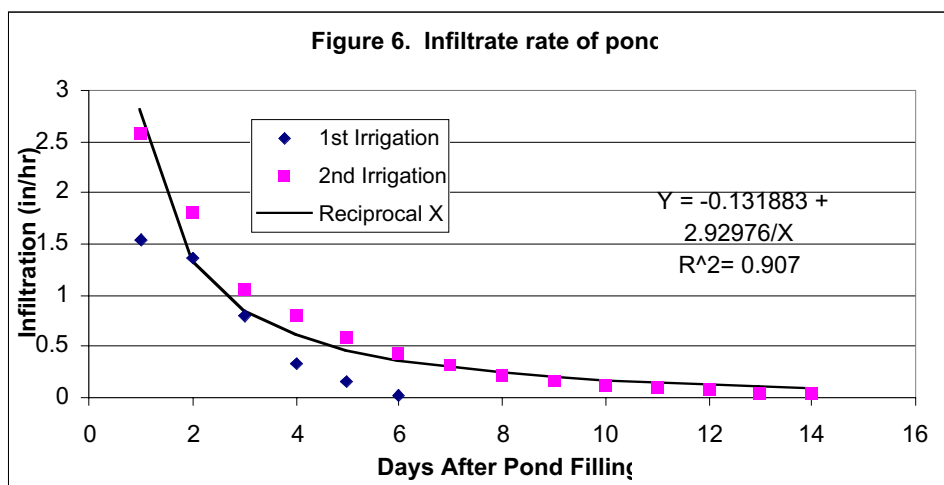
Due to infiltration occurring during the 4 days of runoff, collection the infiltrated volumes were greater than the difference between maximum depths and empty. Pressure transducers were used to make continuous measurements of pond depth and depth of water inflow through a flume. The volume of water infiltrating via the pond was calculated using a relationship developed between the infiltrated water and pond depth.

By applying this relationship to the known pond depth over the season, it was possible to estimate the infiltration both during and after pond filling (Figure 5). The first irrigation resulted in near 65,000 gallons while the second infiltrated 179,000 gallons. The majority of the water was infiltrated in just a few days. The total volume of runoff water infiltrated by the pond as a result of both irrigations was 244,000 gallons.



Pond Infiltration Rate

The rate of water infiltration is dependent upon the area wetted by the pond at any given time. The relationship between pond depth and wetted area is shown in Figure 6. Using this relationship, infiltrated water was calculated during the infiltration period each irrigation. Infiltration rate (inches/hour) was highest at 2.5 in/hr when the pond was deepest declining to less than 0.03 in/hr in 6 to 14 days (depending on the irrigation). The infiltration rate drops rapidly indicating the lower reaches of the pond are less permeable. This is probably due to cracking in the upper area of the pond and a residual organic muck in the bottom.



Holding Pond Concentration

The initial pond sampling of water (filtered) found a level of 2.16 ppb of diuron and 0.583 ppb hexazinone. At sampling the pond volume was low. The source of the water was thought to be field runoff. At this time rainfall, did not exceed ETo minimizing the dilution effect of rainfall. Samples were again collected after the inflow to the pond has ceased from the first irrigation. Diuron was found at 12.35 ppb and hexazinone at 1.02 ppb. After the second irrigation, pond concentrations were 11.76 and 0.894 ppb for diuron and hexazinone, respectively. The pond concentrations of both diuron and hexazinone were similar to those found in the Treatment 1 runoff waters. The holding pond concentrations are not the same as the concentrations in the treatment runoff due primarily to the irrigation system operation causing less runoff. Runoff volume from the entire field was 2.5 times less than the average runoff of the treatments. The concentration of diuron in the pond in the first irrigation was about twice that of the average treatment runoff. Hexazinone concentrations however were similar.

Using the seasonal irrigation requirement of 48 inches per acre and the average runoff measured in the two irrigations results in a 2.3-inches/acre volume for each acre. Under such a scenario, combined with the relationship between developed the diuron concentration and cumulative water runoff shows that little herbicide would be exiting the field with runoff waters by the end of the season. After the last irrigation in late September pond samples were collected October 4th, finding concentrations of 2.33ppb diuron and 0.36 ppb hexazinone.

Holding Pond Residue Mass

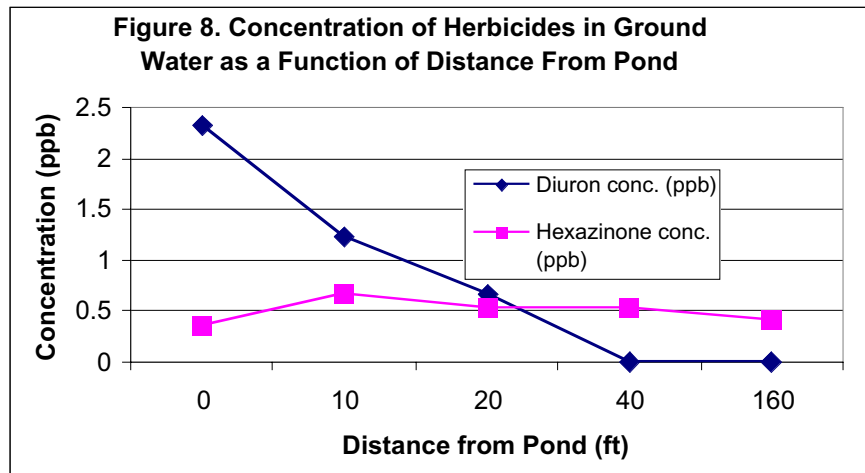
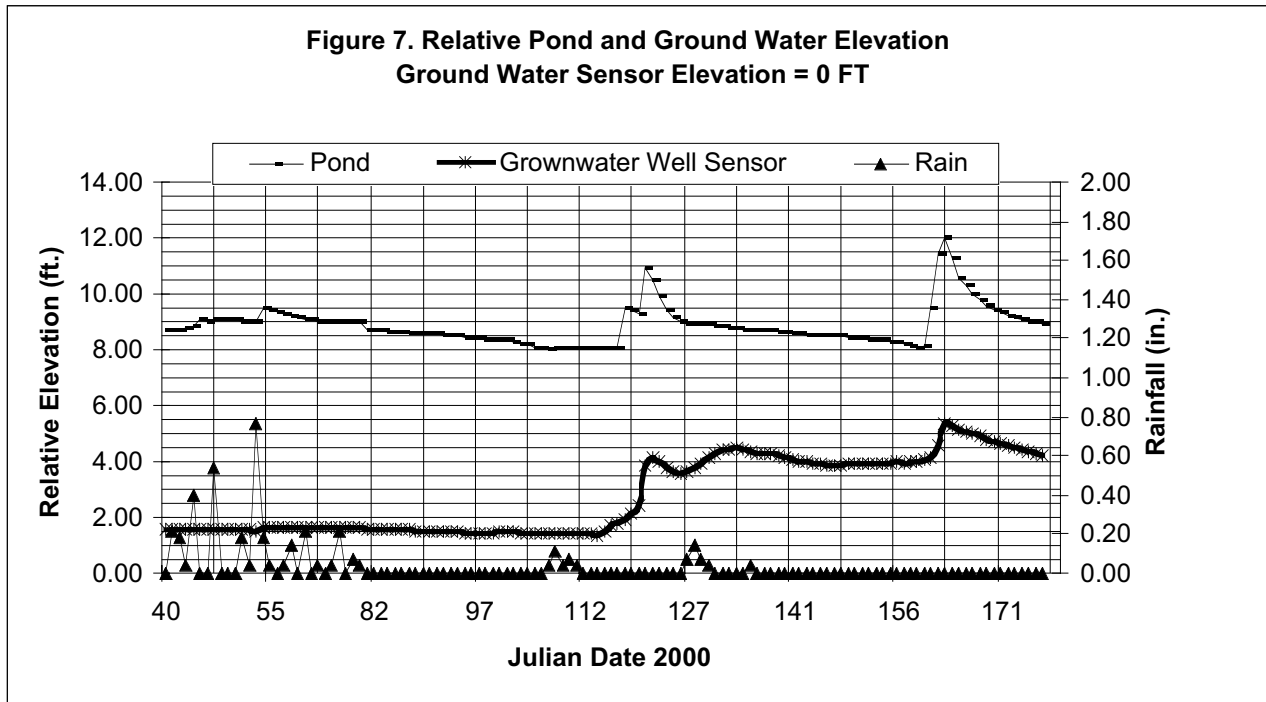
The mass of both diuron and hexazinone in the infiltrated pond water was calculated as the product of the average concentration of the pond waters and the calculated infiltrated volume as a result of both irrigation runoff events.

Table 2.

Irrigation	Volume (gal)	Conc. Diuron (ppb)	Mass Diuron (g)	Conc. Hex (ppb)	Mass Hex (g)
1	65000	12.35	3.04	1.019	0.25
2	175000	11.76	7.79	0.894	0.59
	240000		10.83		0.84

Holding Pond Relation to Ground Water

Simultaneous measurements were made of pond water depth and ground water depth through the measurement period. The shallow ground water appears to be strongly influenced by the infiltrating water volume (Figure 7.)



October 24th sampling of borehole water at distances 10, 20, 40 and 160 ft indicate a little hydraulic gradient. The last irrigation had been over 40 days prior to this measurement; therefore the pond would have been empty for near 25 days. The concentration of diuron in the water declined with distance from the pond water at near 2.5 ppb and non-detectable at 40 feet and further (Figure 8.) The hexazinone concentrations were similar in the pond and all sampling distances at about 0.5 ppb.

Yield and Efficacy

The three harvest sub-samples were needed due to variable alfalfa size and stunted growth occurring from a high stem nematode population. Vole feeding also contributed to variable growth. These

factors resulted in a high coefficient of variability. There were no significant yield differences between treatments.

Herbicide Efficacy

The hexazinone plus diuron treatments provided improved season long control of most winter weeds compared to paraquat and trifluralin treatments with an improvement of 50%. Paraquat was initially effective in burn down of emerged weeds. However, paraquat binds rapidly to soil so soil residual herbicide is not available in soil solution to suppress new weed germination and subsequent growth. The later application of trifluralin was ineffective in preventing germination of the winter annual broadleaf weeds. Later germinating summer broadleaves were controlled effectively with the hexazinone and diuron. The trifluralin treatment provided the best control only on the grass species of Yellow Foxtail.

Initially the addition of soil adjuvant accelerated vegetative burn down caused by hexazinone and diuron. However, by the April evaluation, both hexazinone-diuron treatments had measurably equal results.

Conclusion

Background sampling found about 8% of the application rate of diuron as a residual from the previous year's application. Movement of diuron and hexazinone in this cracking clay soil was confined to the upper reaches of the soil profile even though water percolated past the deepest depths sampled (three feet). The mass of residues recovered from the total soil core length prior to the first irrigation represented a decrease from the application day values of 66% for diuron and 79% for hexazinone, however no measurable runoff occurred. The distribution of residues throughout the soil profile was different between diuron and hexazinone. Very little diuron was detected beneath the first 0-3 inch depth, whereas, concentrations of hexazinone in the deeper segment were equal to those measured in the first segment. Little to no residues were measured for either herbicide in the third segment, which represented the 12-inch depth. Based on a comparison of their physical-chemical properties, greater movement through soil would be expected for hexazinone, caused primarily by its lower soil adsorption value (Koc). After the second irrigation (June), the magnitude of the residues for both pesticides was reduced to levels that were similar to those measured in the background samples. Statistical tests for effects of treatment and location were not significant. Trifluralin or paraquat was detected in soil samples.

Significant differences in diuron concentration were measured between irrigations with the concentrations for the first irrigation runoff approximately twice the concentration of the second (Table 1). Hexazinone concentrations also appeared greater at the first irrigation; however, the level of probability indicated only a trend ($P= 0.0726$). The addition of the surfactant did not significantly affect the concentration of herbicides in runoff water. No significant differences in the mass of herbicide leaving the field as runoff were found between treatments or irrigations. Although the concentration of diuron herbicide was reduced in half from the first irrigation, the runoff volume had tripled in the second irrigation resulting in no significant differences in the mass leaving the field. The results for hexazinone were similar. The mass of diuron and as mean of treatments was 0.7976 g/acre for the two irrigation events. Hexazinone was lower at 0.249g/acre. The mass was carried in 0.66-acre inch/acre of runoff water.

Concentrations of both diuron and hexazinone decline with increasing runoff volumes. No trifluralin or paraquat was detected in runoff waters. A model constructed from collected data predicts less than 0.5 ppb diuron in the runoff water at a cumulative runoff of 3.0 inches per acre. The model

constructed for hexazinone predicts less than 0.02 ppb at a cumulative runoff of 1.5 inches per acre. It is suspected under the constraint of management, the runoff of the entire field was similar to the first irrigation since the pond was never full for the rest of the season's irrigations. Based on this conjecture, a total of 1.6-acre inch/acre would have been available as runoff. The model predicts a concentration near 2.88 ppb for diuron by season's end. After the irrigation season (October 24), pond concentration was similar at 2.4 ppb. However agreement is not as good with hexazinone at a predicted 0.16 ppb and sampled of near 0.5 ppb.

The holding pond captured the unmeasured runoff from the entire field. The non-experimental area was treated with both diuron and hexazinone as in Treatment 1; however, runoff volume per acre was managed to be smaller than the experimental area. Given these differences, the runoff concentrations from the experimental area were similar to those measured in the pond. The mass of residues infiltrated for diuron was 10.83 grams while hexazinone was 0.84 grams as a result of the two irrigations. These values could have been larger or smaller depending on the runoff management. However even with a controlled runoff the model predicts the concentration to be relatively low by season's end. The rate of infiltration is rapid at near 2.5 inches per hour at maximum capacity dropping to a low of 0.1 inches per hour near empty. It is suspected cracking of the pond wall during the drying cycle enhances the infiltration rate. The pond-infiltrated water has a direct effect of raising localized groundwater levels measured twenty feet south into the field. Each irrigation event increased the groundwater level as a direct response to pond filling and infiltrating stages. Concentration of diuron measured in the groundwater at season's end declined with distance from the pond starting at 2.5 ppb with a linear decline with distance to non-detectable at 40 feet. Hexazinone, by virtue of its lower soil adsorption value (K_{oc}), was constant from the pond water to the farthest distance measured (160 ft).

Mitigation

The surfactant treatment was similar to the non-surfactant in terms of field distribution and runoff concentrations and volume.

Alternative herbicide materials that do not move as easily in soil and in runoff waters are an option, however they (in the case paraquat and trifluralin) did not provide the weed control of diuron and hexazinone combination. Since alfalfa hay price is established on high quality and weed free forage, significant impact can be expected with out adequate weed control.

The species of broadleaf and grass weeds in alfalfa vary as the season progresses from winter to summer. This trial demonstrates the importance of having soil residual herbicides that are applied in winter and effective on the winter spectrum of weeds. It is also apparent that no single herbicide treatment used in this experiment can effectively control the wide range of species that germinate throughout the year. Managing weeds in alfalfa will have to rely on different chemistry's of herbicides with post emergence activity and soil residual properties that are efficient in controlling the numerous mix of weeds.

Management of the residue containing runoff water seems the most likely mitigation practice in this and similar cases. Pumping the runoff from the pond to reuse in the same or adjacent field as soon as sufficient volumes are available will reduce the volume available for infiltration, reduce the high infiltration fuller pond conditions and the time for infiltration to take place.

Minimizing Off-site Herbicide Movement in Permanent Crops

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Minimizing off-site movement of herbicides in tree and vine crops is important to provide cost-effective weed control and prevent contamination of surface and groundwater supplies. The potential for groundwater contamination from herbicides is of concern, because approximately 90% of the rural population in the United States rely on groundwater for domestic use. According to state water quality surveys by the EPA in 1990, contaminated water accumulates from the transport of pollutants (including herbicides) in runoff water, leaching, irrigation water, and seepage or hydrologic modification. It is estimated that agriculture is responsible for 65% of Non-Point Source pollution in groundwater. The primary factors affecting Non-Point Source include rainfall intensity and duration, vegetation cover, soil structure and texture, topography, and geology. For the most part, surface water runoff will move pollutants to streams, rivers, and lakes, while groundwater will collect chemicals leaching downward through the soil. Since it is very expensive to purify contaminated water, certain preventative measures should be employed to minimize off-site movement and maintain a high quality water supply.

Maintaining effective weed control, while minimizing off-site movement of herbicides in tree and vine crops, can be accomplished by incorporating several strategies when selecting and using herbicides. Some of the more important strategies include: herbicide selection based on how they behave in the soil, tillage and rainfall management, and herbicide management. Other factors should be employed where deemed appropriate.

Numerous factors influence the activation, efficacy, and residual properties of herbicides. Adsorption, leaching, and volatilization are physical processes that occur to herbicides in the soil. These physical processes are different for each herbicide. Adsorption to the soil is beneficial by helping retain herbicides within the surface layers of soil where they are needed for weed control and out of deeper layers where they might cause crop injury or enter groundwater. If adsorption is very strong, herbicide activity may be reduced, requiring higher application rates. If adsorption is weak, activity may increase to cause crop injury. Leaching can aid in the distribution of herbicides in the surface layers. If too much leaching occurs, the herbicide can injure the crop, be wasted, or enter groundwater. Volatility can help distribute herbicides that do not move by other means within the surface layers of soil. It can also result in loss to the atmosphere and poor weed control. Since there are several physical properties for each herbicide, the combination of these properties often dictate how they will act in the soil. Selecting soil-residual herbicides based on physical properties of leaching, volatilization, and degradation are important to maintain efficacy and reduce possible off-site movement. These herbicide properties are discussed below and are given for various soil-residual herbicides in table 1.

Leaching is the physical process of movement of herbicides in soil water flow and is influenced by several factors, including solubility and soil adsorption. The amount of movement is influenced by the amount of herbicide in the soil, soil texture, and the extent of water movement. The amount of herbicide in the soil solution is a function of the solubility of the herbicide and strength of soil binding (adsorption). Herbicide solubility is a measure of how much it ionizes in water. In most cases, as solubility declines, adsorption increases and soil mobility declines. Herbicides low in solubility are

excluded from the soil water and become associated with soil colloids and organic matter. While certain herbicides may have low solubility, under certain conditions (like sandy soils or clay soils with large cracks) they may tend to leach in free-flowing water rather than adsorb to soil particles. Soil adsorption is a measure of the affinity of an herbicide to soil organic matter. Herbicides that are low in solubility and have a high affinity to soil particles will be less likely to leach. Since organic matter is the most influential soil factor governing adsorption, the K_{oc} (mL/g) of an herbicide is a very useful measure of its tendency to move with water in soil. Herbicides that are soluble with low soil sorption are prone to leaching, including diuron, napropamide, and norflurazon. Herbicides that are low in solubility and not prone to leaching, include thiazopyr, trifluralin, and pendimethalin.

Volatilization of an herbicide is determined by vapor pressure (the pressure of the gas phase of an herbicide in equilibrium with the solid or liquid phase at any given temperature). Vapor pressure affects how volatile an herbicide is. Volatility is the tendency of an herbicide to escape as a gas. Typical vapor pressures for herbicides range from very volatile (3.4×10^{-2} for EPTC or Eptam) to non-volatile (2.8×10^{-12} for alsulfuron or Permit). Highly volatile herbicides, like Eptam, can escape into the air within hours if not incorporated into the soil promptly after application.

Herbicide degradation is not a fixed property, but is influenced by soil and environmental conditions. Degradation or the breakdown of herbicides can occur by microbial decomposition, chemical decomposition, photodecomposition, soil adsorption, volatilization, leaching, surface runoff, and plant metabolism. The half-life of an herbicide is often used to express the length of time required to reduce the amount of active ingredient by one-half. Herbicides that tend to degrade rapidly are generally not prone to leaching, unless they move in runoff water or enter deeper soil layers through cracks.

Table 1. Physical properties of selected soil-residual herbicides used in trees and vines

Herbicide	Vapor Pressure (mm Hg)	Volatility	Soil Sorption K_{oc} (mL/g)	Solubility (mg/L)	Soil mobility	Half-Life (days)	Primary degradation
diuron	6.9×10^{-8}	Low	42	480	Med	90	Microbial
isoxaben	3.9×10^{-7}	Low	1	190-570	Low	50-120	UV light
napropamide	4.0×10^{-6}	Low	73	700	Low	70	UV light
norflurazon	2.9×10^{-8}	High	28	700	High	70-180	UV light
oryzalin	$< 10^{-8}$	Low	2.6	600	Low	20	Microbial
oxyfluorfen	2.0×10^{-6}	Low	.1	100,000	Low	35	UV light
pendimethalin	9.4×10^{-6}	Med	.275	17,200	Low	45	UV light
pronamide	8.5×10^{-5}	Med	15	800	Med	60	Chemical
simazine	2.2×10^{-8}	Low	6.2	130	Low	91	UV light
thiazopyr	2.0×10^{-6}	Low	2.5	---	Low	64	Microbial
trifluralin	1.1×10^{-4}	Med	3	7,000	Low	45	UV light

Tillage and rainfall management can be used to prevent herbicide movement downward through the soil profile and in runoff water. Some management options include treatment prior to mild rainfall, using cover crops or other vegetative cover, use of conventional tillage, and maintaining soil organic matter.

Most soil-residual herbicides in tree and vine crops require rainfall or irrigation water for incorporation and activation. Since irrigation water is expensive, growers rely on winter rainfall for incorporation. To avoid potential runoff, spray herbicides on non-saturated soil preceding a mild rainfall event.

Rainfall amounts less than _” do not generally result in runoff and are useful for moving herbicides into the top inches of the soil. Making applications ahead of large amounts of rains or prolonged periods of rain can result in surface runoff from the treatment site, especially under bare soil conditions on sloping soils. Herbicides that are highly soluble should be applied toward the end of the rainy season.

Cover crops or resident vegetation can be planted or maintained between tree and vine rows, at the ends of fields, in border strips, and at the base of irrigation ditches or canals to help reduce surface water movement. Soil erosion and runoff can be significantly reduced where vegetation is maintained on sloping soils with heavy soil textures. Most soil-residual herbicides have a high affinity to soil organic matter. It is desirable to maintain soil organic matter where possible. Incorporating resident vegetation (weeds) or cover crop materials can help to maintain organic levels. Soils low in organic matter favor leaching of herbicides, especially those with low soil adsorption.

Conventional tillage practices (including disking) can help to disrupt soil macropores, so there is less likely to be water movement downward. Reduced tillage or non-tillage on sloping soils tends to favor surface runoff. Herbicides in runoff water can accumulate and move downward through the soil profile when large soil cracks are encountered following runoff.

Herbicide management practices are also important in reducing the risk of groundwater contamination, including consulting herbicide labels, implementing IPM strategies, and sprayer maintenance and calibration.

People involved in selecting and using herbicides should consult labels and technical bulletins to determine proper use rates, application procedures, timing, and other factors to maintain efficacy and reduce the risk of off-site movement. Factors affecting herbicide efficacy and movement in soil and water have been used to help develop labels for herbicide use. Consult other written sources to determine specific herbicide characteristics, including solubility, leaching potential, volatility, adsorption potential, and persistence. The more familiar you are with specific herbicide properties, the more likely you will be to select the most appropriate herbicide(s) for the task. Where possible, use the lowest rate allowable to maintain the desired degree of weed control.

One should implement IPM strategies to help reduce the amount of herbicide needed to control weeds. Mechanical control, cover crops, weed monitoring and mapping, low toxicity and low mobility materials, and reduced rates or spray patterns can each help to maintain weed control while reduce the risk of groundwater contamination. Treating with post-emergence herbicides may also be desirable on soils high in runoff or leaching potential.

Herbicide sprayers should undergo routine maintenance and calibration to insure proper herbicide placement and delivery. Leaky tanks, hoses, and other parts should be replaced or repaired before herbicides are applied. This reduces the risk of crop injury, contamination, and saves money. Accurately calibrating sprayer equipment is essential to insure proper herbicide amounts are applied uniformly to the soil surface. There is no set number of times a sprayer should be calibrated. However, as a general rule of thumb, it is desirable to calibrate a sprayer at least twice a season.

Many factors influence the potential off-site movement of herbicides in tree and vine crops. Being familiar with the physical properties of herbicides and implementing strategies based on maintaining herbicides at the site of placement can reduce the risk of crop injury, off-site movement, and groundwater contamination.

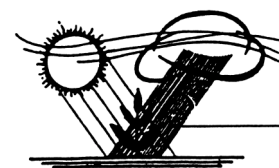
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**NEW TECHNOLOGIES
FOR CROP AND
SOIL MANAGEMENT**



Status of Agricultural Biotechnology: Current and Future Products

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Agricultural biotechnology has been rapidly adopted by producers. Biotech plantings constituted 68% of US soybean acres in 2001. The main biotech crops in California are Roundup Ready cotton (40% of 2001 CA cotton plantings) followed by Roundup Ready corn (9.8% of 2001 CA corn plantings). The biotech products currently being grown are crops that exhibit increased resistance to pests (e.g. corn, canola, cotton and potatoes with *Bacillus thuringiensis* (Bt) genes for insecticidal proteins); tolerance to more environmentally benign herbicides (e.g. corn, cotton, soybeans, canola, sugarbeets); and virus resistance (e.g. squash, cucumbers and papaya). In general, farmers who use these new varieties have realized significant savings in production costs, as well as increased yields (USDA/ERS. 2000. Genetically engineered crops for pest management in U.S. agriculture. Report No. AER-786)

Research is now being conducted to generate plants with altered nutrient compositions. Researchers are working to produce oils that have better nutritional quality and stability, to enhance nutritional components that may be useful in reducing the incidence of several cancers, and to decrease the allergenic proteins that occur naturally in specific foods. The nutritional composition of plants is the result of the interaction of a number of complex metabolic pathways. Biotech modification of plant nutrients requires a comprehensive understanding of these pathways and may entail the production of plants carrying more than one transgene to achieve the desired compositional modification.

Adopting Cover Crops in California Agriculture

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The adoption of cover crops in California has been slow. There are many reasons for the lack of adoption. Foremost is the intensive use of tillage and chemical inputs that have made California agriculture one of the most productive agricultural breadbaskets of the world. With the use of these practices, the condition of the soil became less important since crop nutrient demands could be met through fertilizers. Ground water pollution problems, salinity, fugitive dust emissions, and higher cost of production and transportation of fertilizers now necessitates a reassessment of past conventional agricultural practices.

Prior to the use of these intensive practices, cover cropping was often used to enhance soil fertility and soil tilth. We now recognize that the maintenance of soil quality is required to sustain the long-term fertility of soil. In addition, soil quality or health directly impacts society through influencing water and air quality as well as the quality of the food supply. One of the key indicators of soil quality is the soil's organic matter content. Soil organic matter has qualities that contribute directly to crop growth through its effect on physical, chemical and biological soil properties. The physical aspects of SOM serve to enhance infiltration and aeration of soil and the various organic components play an important role in stabilizing and supplying nutrients for plant uptake. The use of cover crops is an excellent way to increase the quality of soils through the addition of organic matter, introduction of nitrogen through leguminous cover crops and reduction of nutrient transport from agricultural fields. In addition, removing carbon dioxide from the atmosphere and storing it as soil organic matter is viewed as a means to mitigate the "greenhouse effect" caused by the burning of fossil fuels. Growers may some day benefit from storing carbon in their soils through payments or through trading of credits to offset emissions of carbon dioxide from transportation and industrial sources.

The benefits from accumulating organic matter in soil through the use of cover crops are realized within one to three years. Changes in soil tilth are often immediately realized while the effect on nutrient availability often takes more than a few years. As soil organic matter builds up, an equilibrium between carbon inputs and nutrient availability occurs leading to sustained plant nutrient availability. This often translates into reducing the amount of fertilizer additions leading increased nutrient use efficiency. In addition, the use of cover crops often breaks pest cycles leading to less pesticide input. However, improper cover crop management can lead to weed problems. The following is an example of the influence of cover crops on soil organic matter accumulation in soil conducted at the Sustainable Agriculture Farming System project at the University of California Davis.

A. Site description.

The Sustainable Agriculture Farming Systems (SAFS) Project was established in 1988 at the Agronomy Farm of the University of California at Davis. The 11.3 ha site is dedicated to the study of agronomic, economic and biological aspects of conventional and alternative farming systems in California's Sacramento Valley. The soils are classified as Reiff loam (coarse-loamy, mixed, non-acid, thermic Mollic Xerofluvents) and Yolo silt loam (fine-silty, mixed, non-acid, thermic Mollic Xerofluvents).

B. Description of the Farming System.

The study consists of two conventional and two alternative systems that differ primarily in crop rotation and use of external inputs. These include 4-year rotations under conventional (Conv-4), low-input (LI), and organic (ORG) management and a conventionally managed 2-year (Conv-2) rotation. The three systems in the 4-year rotations include processing tomatoes, safflower, bean and corn. In the conventional-4-year treatment, beans are double-cropped with winter wheat. In the low-input and organic treatments, beans typically follow a biculture of oats and vetch that serves as either a cover crop or cash crop. The conventional-2-year treatment is a tomato and wheat rotation typical of farming systems of the region. Table 1 shows details on the farming system treatments.

Table 1. Description of treatments, crop rotations and agronomic management.

Treatment	Crop Rotation	Agronomic Management
Organic (ORG)	Tomato; safflower; corn; oats/vetch; bean.	Four-year, five-crop rotation using composted manure, legume and grass cover crops, and organic supplements; no synthetic pesticides or fertilizers.
Low-input (LI)	Tomato; safflower; corn; oats/vetch; bean.	Four-year, five-crop rotation relying on legume and grass cover crops and one-half synthetic fertilizer applied.
Conventional 4-year (Conv-4)	Tomato; safflower; corn; wheat; bean.	Four year, five crop rotation using synthetic fertilizer and pesticides .
Conventional 2-year (Conv-2)	Tomato; wheat.	Two-year, two-crop rotation relying on synthetic fertilizer and pesticides .

The organic system is managed according to practices recommended by California Certified Organic Farmers that do not allow synthetic chemicals. Fertilizer N sources include legume and grass cover crops, composted animal manures, and occasional organic supplements. The low-input system has legume cover crops to reduce the amount of synthetic fertilizers required. The conventional systems are managed with standard chemical inputs of pesticides, and various N fertilizers. Each cropping system has four replications for each of the possible crop rotation entry points, resulting in a total of 56 plots, each measuring 68 m x 18 m. Treatments are arranged in a split-plot design, with cropping systems as the main plot treatments, and crop point of entry as sub-plot treatments. Total carbon and nitrogen inputs to the various farming systems over a ten-year period from 1988 to 1998 are summarized in Table 2.

Results and Discussion

The analysis of the soils from the cropping system treatments showed that the ORG and LI treatments have experienced significant increases in soil carbon and nitrogen compared to the conventional treatments (Table 2). Soil carbon levels increased by 29%, 17% and 5% in the ORG, LI and CONV-4 respectively compared to the CONV-2 treatments in the 0 to 15 cm soil depth. Similar increases were noted for soil nitrogen. The increase in soil carbon and nitrogen in the ORG and LI treatments can be attributable to the use of manure and cover crops. The difference in soil carbon between the ORG and LI treatment is the addition of manure. The increase in soil carbon in the LI treatment compared to the CONV-4 is the use of winter cover crops. The increase in total soil carbon in the CONV-4 compared to the CONV-2 treatment is most likely attributable to the crop rotation effect. The increase in soil carbon and nitrogen was a result of input rather than changes in tillage. The ORG and LI actually received more tillage because of the extra operations associated with incorporating the cover crops and manure. These results show the value of carbon inputs to soil to sequester carbon. The increase in soil nitrogen in the LI treatment over the conventional treatments is solely due to the use of cover crops since the LI treatment received the least nitrogen input of all treatments.

Table 2. Amount of C and N inputs over a 10 y period to the various farming systems.

<i>Farming system</i>	Carbon input		Nitrogen input	
	----- Mg ha ⁻¹ -----			
<u>Organic</u>	42.9 (d)		1.96 (c)	
Low-Input	39.4 (c)		1.65 (a)	
Conventional-4	36.1 (b)		1.92 (c)	
Conventional-2	29.3 (a)		1.74 (b)	

Table 3. Soil carbon and nitrogen in SAFS systems under different management since 1988. All plots in each system had the same initial measured soil organic matter content in Fall 1988, from which soil C at this time is estimated.

System	<i>Soil % carbon</i>			<i>Soil % nitrogen</i>	
	Fall 1988	Fall 1996	Fall 2000	Fall 1996	Fall 2000
Organic	0.83	1.08	1.13	0.117	0.116
Low-input	0.83	1.03	1.04	0.111	0.107
Conv-4	0.83	0.90	0.92	0.094	0.095
Conv-2	0.83	0.84	0.88	0.092	0.094

The results show the significant value of cover crops in California row crops in increasing soil carbon and nitrogen. In addition, the results show the significant increase of soil nitrogen in the LI treatment is attributable to cover crops. For these reasons, cover cropping will become an effective practice to both sequester soil carbon and enhance long-term soil fertility in California.

Expansion of Conservation Tillage Initiatives in California

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Introduction

Although the term “conservation tillage” (CT) technically denotes a range of crop production alternatives that typically leave a minimum of 30% of the soil surface covered by residues from previous crops (Reeder, 2000), the development and adoption of CT systems for California’s very diverse cropping systems is likely to spawn many tillage system variants that do not fully reflect the classic model systems that have been developed in other regions. Through a wide range of university and public agency research and demonstration activities, as well as private sector trials, there has been a well-documented, and rather dramatic increase in interest and innovation related to reduced tillage crop production alternatives during the last five years in California’s Central Valley (CT2001 Proceedings, 2001). This interest has resulted from a number of interrelated factors.

Recent escalating diesel fuel costs (CEC, 2000) have, first of all, resulted in sharp declines in net farm income and threaten long-term economic viability in many Central Valley crop production regions (USDA Economic Research Service, 2000). A medium-sized row crop farm of 4,000 acres in this region may have weekly diesel fuel costs of upwards of \$12,000 (Personal communication, Anonymous). Cutting diesel fuel use from 75 to 35 gallons / acre has been identified as a 2001 production target in the northern San Joaquin Valley (Personal communication, Anonymous). Reducing production costs has thus become a compelling and critical goal of growers throughout this region of California which has historically been an area of phenomenal productivity (Calif. Dep’t. Food and Agriculture, 1990).

There is also a body of research evidence from other regions of the United States (largely untested yet in California, however) suggesting that 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 (Karlen, 1990) and subsurface compaction (Personal communication, Taylor) over the long-term. Finally, because intensive tillage typically leads to decreased soil carbon (C) via gaseous CO₂ emissions (reviewed by Reicosky et al., 1995), and because there is concern that this C source has been a significant component in the historic increase in

atmospheric CO₂ (Wilson, 1978; Post et al., 1990) and the potentially associated greenhouse effect (Lal et al., 1998), there is increased interest in investigating cropping systems opportunities for mitigating these emissions. While these factors have gained greater “currency” in recent years, the fundamental motivation for reducing tillage remains economic; California growers are investigating a range of minimum tillage options primarily for reducing production costs.

CT Research and Information Development Initiatives

To respond to the needs for information on reduced tillage production alternatives, the University of California’s Division of Agriculture and Natural Resources established the Conservation Tillage Workgroup in 1998 to develop knowledge and exchange information on CT production systems and to coordinate related research and extension education programs. Current Workgroup membership includes over 80 University of California researchers, USDA Agricultural Research Service and Natural Resource Conservation Service scientists, farmers, private industry affiliates and other public agency representatives. The Workgroup’s 1998, 2000, and 2001 conferences, which were held as two back-to-back daylong sessions in Five Points and Davis in each year and which focused on successful conservation tillage systems in other parts of the US, have been attended by over 850 participants. Workgroup member research and demonstration sites have expanded from one in 1996 to over twenty in 2001.

Conservation Tillage and Herbicide Resistant Crops

Running parallel to these CT research and extension education efforts has been the use of transgenic herbicide tolerant crops throughout a number of production valleys in California. Production of herbicide tolerant cotton in the San Joaquin Valley, for instance, began with about 500 experimental acres planted in 1997, and has increased steadily to upwards of 250,000 acres in 2001 (Vargas et al., 2001), with adoption expected to increase in the future. Acreage shifts within the herbicide tolerant lines have favored those varieties that are closely related to existing successful Acala parentage. Potential benefits of transgenic cotton result from reduced hand weeding costs, elimination of one or more in-season weed cultivations for standard bed planting systems, as well as irrigation levee establishment costs for ultra narrow row cotton which can be flood irrigated (Personal communication, H.Wu). To date, however, transgenic seed technologies have not been coupled with production practices that reduce intercrop tillage, at least at any wide scale, primarily because of current postharvest cotton plowdown regulations for pink bollworm management. Other issues related to these transgenics, including weed resistance and crop yield and quality concerns, are the focus of considerable ongoing study (Vargas et al., 2001).

Tillage Reduction Opportunities in San Joaquin Valley Cotton and Processing Tomato Rotations

In the fall of 1999, we began a four year comparison study of conservation tillage and conventional tillage practices with and without winter cover crops in cotton and tomato rotations in Five Points, CA at the University of California’s West Side Research and Extension Center. The study consists of a 3.23 hectare field experiment with four replications of these tillage / cover crop systems and both crops in each year.

To date, this study has demonstrated that planting and harvesting crops with conservation tillage systems is possible given some equipment modifications and that yields can be maintained relatively close to those of standard tillage in CT crop residue environments. Data from our 2001 tomato harvest indicate that yields in the CT \pm cover crop systems were similar to those in the standard till plots with an elimination of six tillage operations following last year’s cotton crop in the CT plots relative to the standard till systems (Table 1).

Table 1. 2001 Processing tomato (tons/ac) and cotton (bales/ac) yields

	Processing Tomatoes	Cotton
Standard Tillage		
<i>No cover crop</i>	60.1	3.6
<i>Cover crop</i>	63.4	2.8
Conservation Tillage		
<i>No cover crop</i>	64.4	3.2
<i>Cover crop</i>	60.5	3.0

2001 cotton yields were reduced 11 and 18% in the CT – cover crop and CT + cover crop systems, respectively, relative to the standard tillage control system, however, there was an elimination of 8 or 9 tillage operations in the CT systems relative to the ST approach (Table 2). Estimated resource use per acre (hours of labor and gallons of fuel) indicate the possibility of the CT systems to reduce these inputs relative to standard till systems, however, these data are quite preliminary and are subject to further analysis. Longer-term implications of these reduced till regimes in terms of soil compaction, water use, profitability, soil carbon sequestration, insects and diseases are being evaluated as the study progresses through a four-year cycle.

Other Conservation Tillage Initiatives in California

During the last two years, there have been a number of other CT evaluation projects that have been initiated in California. These range from a large-scale UC Davis campus-based comparison of reduced and standard till systems for crops common to the Southern Sacramento Valley that is being conducted by a large group of UCD researchers, UC Cooperative Extension Farm Advisors, and farmers, to smaller-scale farm demonstrations of reduced till planting and postharvest cotton management systems in Riverdale, CA in the Central San Joaquin Valley.

Table 2. Comparison of Standard and Conservation Tillage Systems

Preplant and Plant Operations for Cotton - 2001

	Standard Tillage		Conservation Tillage	
	No Cover Crop	With Cover Crop	No Cover Crop	With Cover Crop
Cost per Acre				
Fertilizer				
Seed	21	47	21	47
Herbicide	10		5	5
Water		8		
Labor (machine)	144	98	23	38
Labor (irrigation)		15		
Labor (hand weeding)				
Fuel	59	39	8	13
Lube and repair	63	54	11	23
Interest	28	29	6	12
total operating costs	324	290	73	137
Resource Use per Acre				
Times over the field	11	8	2	3
Hours of labor	15	12	2	4
Gallons of fuel	54	35	7	12

Preplant and Plant Operations for Processing Tomatoes - 2001

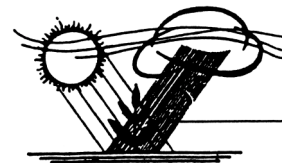
	Standard Tillage		Conservation Tillage	
	No Cover Crop	With Cover Crop	No Cover Crop	With Cover Crop
Cost per Acre				
Herbicide	5		5	5
Seed/Transplants	145	171	145	171
Water				
Fertilizer				
Labor (machine)	227	113	76	83
Labor (irrigation)				
Labor (hand weeding)				
Fuel	80	62	42	46
Lube and repair	100	80	57	65
Interest	31	27	17	21
total operating costs	599	461	341	391
Resource Use per Acre				
Times over the field	8	9	5	6
Hours of labor	23	12	8	8
Gallons of fuel	73	57	39	42

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**2002 CALIFORNIA
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POSTER SESSION ABSTRACTS**



Dynamics of Organic Matter Fractions in Two California Soils through Three Cotton Cycles

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Abstract

This study represents the first analysis of organic matter fractions as influenced by time, depth, N input and soil texture. A long-term cotton nitrogen (N) study provided the opportunity to follow the fate of soil-applied ^{15}N -fertilizer through three cropping cycles. The objective of this effort was to quantify the different soil organic matter (SOM) fractions and changes that occurred during the course of three cotton crops. The study was conducted in the San Joaquin Valley, CA on two different soil types. The soils were a Panoche clay loam (fine-loamy, mixed (calcareous), thermic Typic Torriorthent) and a Wasco sandy loam (course-loamy, mixed, nonacid, thermic Typic Torriorthent). Acala cotton (cv. Maxxa) was planted in each year of this three-year study. Designated ^{15}N -microplots were established in the low and medium N rates (56 and 168 kg N ha⁻¹, respectively) of the replicated field trials. After establishment in 1998, each season's cotton biomass remaining after harvest was shredded and incorporated in to the soil (approx. 20 cm). Post harvest soil samples were collected from each ^{15}N -microplot in two depth increments (0 - 30 cm and 30 - 60 cm). Humic and fulvic acids were obtained by the acid/alkali extraction method described by Stevenson (1994). Light fractions were determined from a sodium iodide solution extraction. Standard analysis of SOM was performed by the UC DANR Analytical Laboratory using the Walkely-Black and the Loss on Ignition (LOI) methods.

The total SOM found in the surface 30 cm of the Panoche (cl) increased slightly from the 1998 sampling to 1999 then remained constant through the 2000 season. The Wasco (sl) showed a relatively minor change in total SOM over the three years. The total SOM of the 30-60 cm depth tended to increase slightly for the clay loam soil while decreasing in the sandy loam soil. Nitrogen treatments had no significant effect on the amount of SOM over the three-year period of this study. There were specific differences in the amounts of humic and fulvic acids found in the two soils. The humic acid fraction represented more than 50% of the total organic matter of the Panoche (cl) while for the Wasco (sl) most of the total was recovered in the fulvic acid fraction. Similar differences were observed for the unextractable (R1) fraction. The clay loam soil had nearly twice the amount of total organic matter in the R1 fraction as the sandy loam soil. Surprisingly, the total organic matter determined by Loss on Ignition (LOI) was significantly higher than determinations using the Walkley-Black method. Values of total organic matter (%) determined by LOI were similar to values derived by the acid/alkali extraction method.

The two soil types have distinctly different amounts of soil organic matter fractions. Our next step will be to determine the % fertilizer ^{15}N applied in 1998 found in these organic matter pools. This information will be used to compare the mineralization/immobilization of applied N for these soils. This will provide a greater understanding of the nutrient cycling of different soil types. Knowing the general makeup of soil organic matter may provide better information on how to manage nutrient inputs to optimize crop utilization and prevent nutrient losses.

Acknowledgement: This work was supported by Cotton Incorporated and CDFA, Fertilizer Research & Education Program.

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Vegetable Production Grown under Conventional, Organic, and Natural Agriculture Systems

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Ten vegetable cultivars were grown under three production systems: conventional (C), organic (O), and natural/control (N). Each system was treated as a whole farm ecosystem receiving appropriate cultural practices for fertilizer, insecticide, and herbicide treatments according to current farming or certification standards. Over five years, the project will track trends in soil chemical, physical, and biological changes. Growth parameters for five summer crops (tomatoes, eggplant, corn, green beans, edible soybean) and five winter crops (onions, potatoes, broccoli, Chinese cabbage, spinach) will be measured. Assessment will also be conducted on insect diversity and population densities, and plant tissue nutritional changes over time.

After three years of production in 1999 through 2001, yields varied between systems depending on the crop and season. For example, 1999 conventional tomatoes yielded significantly higher than the organic. This was reversed in 2000 with the organic system significantly higher in production than the conventional. The natural agricultural system was comparable to the conventional in 2000. Cumulative yield for the three years in tomatoes showed similar total production with the conventional production at 121,863 Kg/ha compared to 118,790 Kg/ha for the organic. Vegetable biomass production followed the same pattern as yield. Total system production during the three years showed yield and biomass had increased over time for all systems.

Soil parameters varied between crops and between systems over time. Organic matter levels and available nitrogen have declined slightly in the conventional and natural agriculture systems. The organic system increased after the first year and has remained stable in these parameters in subsequent years. Nitrate nitrogen has increased slightly for all systems over time. The Fall sampling date nitrogen levels are significantly higher than the Spring sampling date.

Insect levels also varied depending on the specific crop grown. Some vegetable crops are more conducive to being grown under a given set of cultural practices. Insect populations in the summer 2000 plots showed that the conventional system had the least diversity and the least amount of beneficials with the natural agricultural system having the highest diversity. The organic system had the highest number of beneficials overall and lower incidence of pest populations.

NITROGEN RECOVERY FROM INCORPORATED COTTON RESIDUE

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Abstract

This study was conducted in the San Joaquin Valley, CA, in two fields differing in soil type to determine the recovery of residue N in plants and soil. Acala (cv. Maxxa) was grown in 1998, 1999, and 2000 on a Panoche clay loam (fine-loamy, mixed (calcareous), thermic Typic Torriorthent) and on a Wasco sandy loam (coarse-loamy, mixed, nonacid, thermic Typic Torriorthent). Four main N treatments were established in four replications at each site and in each year: 56, 112, 168, and 224 kg N ha⁻¹. Microplots within the N-56 and N-168 treatments, were fertilized with ¹⁵N-urea in 1998. In these microplots leaves that had fallen to the ground were collected prior to machine harvest. After harvest aboveground residue was coarsely chopped using standard field operations and then removed from the microplots. A new series of microplots was established by applying the ¹⁵N-labeled residues, collected from the original microplots, onto areas cleared of aboveground residues in the same N treatment. Thus, the new series of microplots received labeled aboveground residue but was not labeled in its belowground component. Residues were incorporated into the soil when the field was disked. Cotton was planted in 1999 and 2000 and aerial plant portions were collected and separated into different fractions several times throughout each growing season. Plant samples were dried, ground, and analyzed for N and ¹⁵N content. After harvest in 2000, soil samples were collected in 0.3-m or 0.6-m increments to a depth of 2.4 m, air dried, ground, and analyzed for N and ¹⁵N content.

On both soil types, uptake of residue N was considerably greater in the first year than in the second year after application. The majority of the residue N was recovered between early square and peak bloom, coinciding with the time of greatest total plant N uptake. At the time of defoliation in the first year after residue application, an average of 3.1% of the residue N was recovered by the plants on the Panoche clay loam and 5.9% by those on the Wasco sandy loam ($P = 0.053$). These recoveries correspond to about 1.8 and 2.8% of the total plant N taken up at these two sites, respectively. In the first season after application, N recovery from residue tended to be greater for the N-168 than the N-56 treatment at both locations, however, the difference was not statistically significant at either location when analyzed across all sampling dates. In the second year after application, the differences between treatments were not significant although they separated on the Wasco sandy loam.

In 1999, approximately 60% of the residue N recovered by cotton plants was removed from the field in seed and lint. In the second year after residue N application, partitioning of recovered residue N into the harvested plant portion was again about 60% on the Panoche clay loam but only about 44% on the Wasco sandy loam. Combined over the two growing seasons, only 2.7% to 5.2% of the initially applied cotton residue was removed from the field as harvest. At the end of the 2000 season, 48% to 86% of the N applied in form of cotton residue in 1998 was recovered in the soil, and between 12.9 % and 50.9 % of residue N was not accounted for.

Precision Agriculture: Use and Application of Site-Specific Management Tools to Analyze Soil Type and Salinity

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Of the many factors that affect the productivity of agricultural lands, one of the most significant is soil salinity. When accurately measured, soil salinity levels can provide landowners with invaluable data that may be used to better manage fields such as applying variable rates of fertilizer and irrigation water to the saline soils. Rather than treating the field as a whole and ignoring the problem areas, the landowner can concentrate on the more saline portion of the field in an effort to reclaim it. Our poster addresses the spatial variability of salinity in a quarter section of farmland located in the Broadview Water District, Firebaugh, CA.

Through the use of the EM38, an electro magnetic tool used to measure bulk electrical conductivity in the top three meters of the soil, combined with a global positioning system (GPS) we were able to identify more saline areas that we further evaluated using soil sampling. The EM38 data was compared to data obtained from a cotton seed yield monitor. Seed yield measurements were combined with GPS measurements to obtain spatial variability of the cotton yield. The cotton crop yield correlated well with the salinity distribution in the field. Visual observations were made throughout the growing season as well. It appeared that the EM38 data corresponded to the growing patterns observed.

The visual observations showed an area of cotton that was water stressed during most of the season. This resulted in early maturation of the cotton, a lighter leaf color, and stunted growth. Soil samples were taken and analyzed where the visual differences were observed. Texture and salinity analysis showed that the crop response was affected more by soil type than salinity. The EM38 data showed lower salinity levels in the sandy area due to basic soil properties. The large pore size characteristic of sandy soils allows water to infiltrate more easily and results in more salt leaching out of the root zone than in Panoche clay loam, which is the main soil type of the quarter section of this study.

The sandy area was delineated using a portable GPS unit based on the visual observations of the crop response. The measurements were imported into ARC Map. An aerial photo, clearly showing the lighter portion of the field (the sandy area), was georeferenced and used as a base for the GPS data. The field measurements were then layered over the base map and we found that the outline matched with the aerial photo. Soil salinity as well as the soil type stressed the cotton crop. Since the quarter section is managed as a single unit, the plants in the sandy area suffer. That area needs special attention that precision agriculture can provide. The site-specific tools that we used provided us with helpful data that can be used to optimize yields in this quarter section.

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Conservation Tillage Cotton and Processing Tomato Research in California's San Joaquin Valley

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Less than 1% of row crop acreage in California is currently farmed using conservation tillage (CT) practices. Adoption of CT systems in California has, however, recently been seen as a potential means for improving profitability and reducing energy use and a number of research, demonstration and evaluation initiatives are currently underway to explore a variety of cropping system options for reducing tillage. In the fall of 1999, we established a 3.2 hectare field experiment comparing conservation and standard tillage cotton and tomato productions with and without winter cover crops at the University of California West Side Research and Extension Center in Five Points, CA. To date, this study has demonstrated that planting and harvesting crops with conservation tillage systems is possible given some equipment modifications and that yields can be maintained relatively close to those of standard tillage in CT crop residue environments. Data from the second year of this study indicate that yields in the CT \pm cover crop systems were similar to those in the standard till plots, with an elimination of six tillage operations following last year's cotton crop in the CT plots relative to the standard till systems. 2001 cotton yields were reduced 11 and 18% in the CT – cover crop and CT + cover crop systems, respectively, relative to the standard tillage control system, however, there was an elimination of 8 or 9 tillage operations in the CT systems relative to the ST approach. Estimated resource use per acre (hours of labor and gallons of fuel) indicate the possibility of the CT systems to reduce these inputs relative to the standard till systems. This study is the first of its kind in California to systematically compare tillage system alternatives through a crop rotation. Longer-term implications of these reduced till regimes in terms of soil compaction, water use, profitability, soil carbon sequestration, insects and diseases are being evaluated as the study progresses through a four-year cycle.

Use of Sudan Grass and Early Soil Testing as a means to Optimize Nitrogen Management for Processing Tomatoes

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Processing tomatoes have been an important and profitable vegetable crop in California's Sacramento and San Joaquin Valleys for many years. In 2000, statewide harvested acreage was close to 271,000 acres. High profitability lead many farmers to apply insurance rates of nitrogen fertilizer thereby creating the potential for negative impacts on groundwater quality and on growers' earnings. Although new commercial varieties were released, relatively few fertilizer response trials have been conducted on these varieties. Re-evaluation of N fertilizer recommendations could therefore reduce environmental damage and increase profitability.

Organic matter can be a source of 90%-95% of the nitrogen in unfertilized soils and it should be factored into the N budget of a cropping system. In addition to nutrients, soil organic matter provides additional benefits through its effects on physical, chemical and biological properties of soil. If long-term organic matter additions improve overall soil quality, this may include a reduction in nitrogen leaching potential.

Currently, studies are underway to determine best way to integrate organic amendments into conventional agricultural practices. For example, the use of a cover crop following a cash crop provides a means of scavenging residual soil nitrogen and reducing leaching potential; and if incorporated, the cover crop N can be available to a subsequent crop via mineralization.

In the current project, Sudangrass (*Sorghum sudanense*) was chosen as a source of organic matter because it is widely-grown throughout California, with over 100,000 acres planted in 1997. Furthermore, there are no published studies on the effects of sudangrass utilized as an organic matter source on the yield and quality of processing tomatoes, as well as its interaction with nitrogen rates.

The objectives of this project were to: (1) develop and extend information on pre-sidedress soil testing as a means for optimizing nitrogen management for processing tomatoes, and (2) to evaluate the effect of sudangrass as a winter cover crop on nitrogen availability in soil and processing tomato production. Information presented in this poster will address the second objective.

Methods

The experiment was conducted at the UC Westside Research & Extension Center in Five Points in the San Joaquin Valley. No nitrogen was applied prior to or during the sudangrass crop. Three main plots were established for sudangrass (no sudangrass, sudangrass/incorporated, and sudangrass/removed) and five subplots for nitrogen fertilizer rates applied to tomato (0, 50, 100, 150, and 200 kg ha⁻¹ N). Each treatment combination was replicated four times. The main plot treatments (sudangrass) were applied for three years prior to the experiment, as well as during the two years of data collection (2000 & 2001). Pre-plant and post-harvest soil samples (0-30 and 30-60 cm) were taken in each plot to determine nitrate and ammonium concentrations. Leaf petiole samples were collected at three growth periods: first bloom, early fruit set and fruit bulking for the determination of dry petiole nitrate levels.

Leaf sampling for nitrate determination was also conducted in each subplot of the sudangrass/incorporated and sudangrass/removed main plots.

Processing tomato yields were determined using machine harvesting and electronic scales mounted on gondola weighing wagons. A 5-gallon subsample of unsorted fruit was taken from the harvester to determine fruit maturity and % defects. Fifty red fruit were taken from the harvester and sent to the State Grading Station of California for determination of % soluble solids and color

Results

Nitrogen fertilizer application rate accounted for 99% of the variation in processing tomato yields (Fig. 1). In both years (2000 and 2001), yield was highest when 150 lbs N/Acre were applied and 200 lbs. N/Acre led to a yield reduction.

N fertilizer application rate did not significantly affect quality factors such as color or pH. Although differences in total solids were found among treatments, there were no significant differences in solids between the 150 and 200 Lbs N/Acre application rates.

In 2000, tomato plots in which sudangrass had been incorporated had significantly higher yield than did those without sudangrass or where sudangrass was cut and removed. However, during the second season, this yield increase was not observed.

Soil and tissue nitrate are still under analysis. Their relationship to tomato yields will be examined when data are available.

Conclusion

Although growers commonly apply 200–250 lbs. N/acre (*personal communication, Don May*), our data indicate that under conditions of relatively low residual soil nitrogen, 150 lbs N/acre is sufficient to maintain maximum tomato yields. The inclusion of sudangrass in the cropping cycle of processing tomato for five years resulted in a yield increase in only one of the two years when yield was measured (2000). It is possible that more long-term use of the organic matter source is required to provide sufficient soil quality improvement to result in a yield increase for processing tomatoes.

Relationship between N rates and Yield

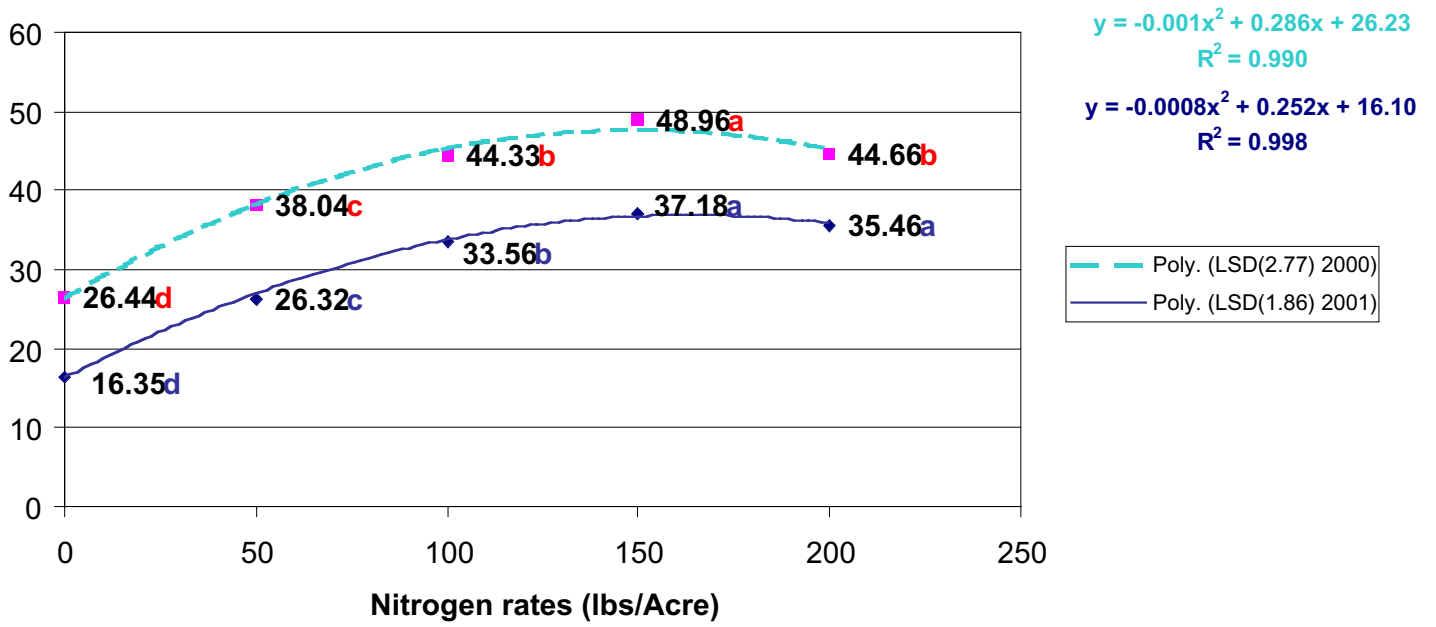


Figure 1. Relationship between N rates and yield during 2000 and 2001

Pima Cotton Responses to Planting Date and Density

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Pima cotton, *Gossypium barbadense*, has become an increasingly important component of cotton culture in the San Joaquin Valley with approximately 240,000 acres planted in 2001. But since its recent introduction to the Valley and approval by the San Joaquin Valley Cotton Board in 1991, little research has been conducted on agronomic factors that influence its performance and productivity. Pima varieties tend to have more indeterminate growth habit and have leaf characteristics and canopy architecture that differ in comparison with most widely grown Acala types, *Gossypium hirsutum*. It is thus reasonable to expect that some crop performance differences may exist between the two plant types when factors such as date of planting and plant spacing are manipulated. Evaluating the response of commonly grown Pima varieties to manipulations of spacing and planting date will also provide vital information used to evaluate the costly replant decision that many growers face each year.

This study was conducted in the 1998-2000 seasons using the industry standard and publicly available Pima S7 variety grown on a Panoche Clay loam at the West Side Research and Extension Center in Five Points, CA. This well-drained, high yield potential site offered a range of production performances particularly in light of the cool 1998 production season that resulted in large declines in SJV-wide production. Plant spacing ranged from 10,000 to 60,000 plants per acre and planting dates ranged from March 15 through May 29. Cotton was planted at initially high densities and stands were hand thinned to evenly spaced populations. Planting dates were spaced at 15-day intervals beginning on March 15 most years. Evaluations of in-season plant vigor and fruiting characteristics, final season plant mapping, crop maturity evaluation, lint quality and yield were conducted. A summary of these data findings is presented in this poster.

Both plant spacing and date of planting had significant effects on crop growth and development. Early and midseason vegetative canopy development changes were most notable between planting dates that were separated later in the planting season however these differences were reduced as the season progressed beyond last effective flower. An increased likelihood for yield reduction existed when planting dates followed April 15 in most years with yield declining in a linear manner for later planting dates within the same year but at a different rate from season to season. The manipulation of plant density also appears to partially compensate for delayed plantings. Examination of plant density appears to be optimized over a much narrower window than previously thought and should be considered more carefully at planting time. The 60,000 and 10,000 plant per acre populations consistently demonstrated significant yield reductions when compared to the 20,000 and 40,000 plant per acre treatments. The exception was found in planting dates exceeded the optimum early season planting. These low optimum populations are measurably lower than what is currently recommended for Acala cotton plantings.

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Changes in Soil Chemistry due to Continuous Irrigation with Effluent Water on Golf Courses

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The quality and quantity of irrigation water is becoming a limiting factor in maintaining high quality turf for golf courses all across the United States. A lot of them are blending water from different sources and a few of them have been forced to use reclaimed water. Since, irrigation water quality has a huge impact on the health of turf, golf course superintendents have to monitor their water and soil chemistry closely. High salt content in water prevents the turfgrasses from absorbing water through osmosis. Salinity problems are observed mainly during periods of high temperature and drought stress. High salt content in soils mainly sodium, disperses soil colloids leading to low infiltration rates. The permeability of soils has been shown to be a function of both the total salinity and the exchangeable sodium percentage (ESP). Experiments were conducted on a practice putting green in southern California. The treatments were laid out in a completely randomized design with three replications. An untreated check plot was used to compare all the treatments. The integrated treatment included three bacterial strains (*Bacillus subtilis*, *Bacillus licheniformis*, and *Bacillus megaterium*) applied at a rate of 500 gram/acre, a microbial stimulant applied at 1.25 gallons/acre, calcium acetate and calcium nitrate (8% Ca) applied at a rate of 3 gallons/acre and a weak organic acid/base combination at 24 oz/acre rate. The other treatments were a modification of the above treatment. In the modified treatments the rate of one of the components was doubled, while the rest of the components were kept constant. Three rates of the calcium source (0, 3 and 6 gal/acre), three rates of acid/base combination (0, 24 and 48 oz/acre) and three rates of *Bacillus sp.* (0, 500 and 1000 grams/acre) were used in the experiments. The treatments were applied with a compressed air sprayer with a carrier volume of 100 gallons/acre. All applications were made at an interval of two weeks. Soil samples were taken from the top 6 inches of the soil profile. The soil was sampled prior to the experiment, after two and four applications. Reduction in Sodium Adsorption Ratio (SAR) and Electrical Conductivity (EC) was observed due to the application of the various treatments. After four applications of the treatments there was a further reduction in SAR and EC. So, the application frequency seemed to be the key in managing salt related issues. The SAR decreased from 6.12 in the untreated plots to 5.08 after two applications and finally to 4.41 after four applications of the integrated treatment. The EC decreased from 3.26 dS/m to 2.33 dS/m after two applications and to 1.97 dS/m after four applications of the integrated treatment.

Impact of Rice Straw Incorporation on Soil Redox Status and Sulfide Toxicity to Plants

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Summary

Traditional rice straw burning after harvest has been restricted due to its contribution to poor air quality and subsequent California Air Quality Legislation. Straw incorporation into the soil has become an alternative to straw burning for rice growers in Sacramento Valley. However, among several potential problems, straw addition to rice paddies may enhance more reducing condition development and potentially adverse effects on succeeding rice plantings such as sulfide toxicity. Sulfide toxicity to rice plants had been observed in randomly localized sites in the Sacramento Valley, mostly in areas close to the drain outlets in rice fields and experimental plots. Plants suffering from sulfide toxicity show signs of retarded growth and reduced yields with characteristic blackened roots to death in the most severe cases.

To investigate the impact of straw incorporation on soil redox status and sulfide toxicity to rice, a greenhouse pot study was conducted. The treatments were straw incorporation at rates of 0, 0.6, and 2.3% straw (equivalent to 0, 6.0, and 23 tons ac⁻¹) and sulfate additions at 0, 160 and 800 mg kg⁻¹ (equivalent to 0, 350 and 1,820 lbs ac⁻¹). In addition to redox potential (Eh), changes in redox status were evaluated by identifying dominant TEAPs (terminal electron-accepting processes) and geochemical redox classes based on OXC (oxidative capacity) throughout the growing season. Results showed that more reducing conditions were developed much earlier with straw incorporated as compared to that with no straw incorporation. The most reducing methanic conditions were developed within three weeks for the 23 tons ac⁻¹ straw incorporated soil and in about six weeks for the 6 tons ac⁻¹ straw treatment. In contrast, methanic conditions were not identified throughout most of the rice-growing season for the no straw treatment until the end of the season.

Rice plants responded strongly to the straw treatments in early growing stages. Plant height at about four weeks, the average number of tillers at about six weeks and grain yield were all reduced significantly from straw incorporation compared to that with no straw incorporation. The sulfate addition only reduced the number of tillers significantly but did not have impact on the plant height and grain yield.

The adverse impact of straw incorporation on rice and subsequent symptoms of sulfide toxicity to rice were observed. Soluble sulfide concentrations, however, were very low in most of the water samples during the rice-growing season due to precipitation with mainly ferrous iron and thus not a good indicator in sulfide toxicity. Formation of FeS was confirmed by positive saturation indices (SI) using WATEQ (Ball et al., 1987).

The greenhouse study confirmed strong reducing condition development from straw incorporation and the adverse impact on rice plant within the range of 6 to 23 tons ac⁻¹ straw incorporated. Plant response, chemical analysis data and speciation modeling all support that sulfide toxicity to rice plants occurred from the straw incorporation. It was expected that sulfide toxicity observed in the field were related to high salinity in localized sites and where high amount of straw might not be unevenly incorporated. The reduction of Mn and Fe was enhanced and the high source of sulfate form sufficient

amount of sulfide resulted in depletion of bioavailable Mn and Fe oxides in precipitating sulfide minerals. As a result, sulfide accumulation and toxicity could occur. This could explain why sulfide toxicity was mostly observed in randomly localized sites close to drain outlets. Under the current practice of straw incorporation, sulfide toxicity due to straw incorporation was not observed on large scale. Water management towards reuse of irrigation water tends to increase soil salinity and long term straw return may result in soil organic matter increase. Thus, monitoring on the potential of sulfide toxicity due to long term of straw return still requires attention.

Effects of Side-Dress Nitrogen Source and Amount on Lettuce Yield and Quality In the San Joaquin Valley

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Head lettuce (*Lactuca sativa L.*) production in the California in 1999 was 147,500 acres with a value 768 million dollars. Head lettuce production in California represents 70-75% of the lettuce grown in the United States with the major production regions being the Salinas Valley, the Oxnard Plain, the Santa Maria Valley, the San Joaquin Valley and the Imperial and Palo Verde Valleys in the southern part of the state.

Managing fertilizer amount and timing in head lettuce can greatly enhance growth, yield and quality. The overall goal of this experiment is to establish best management practices for lettuce grown in the San Joaquin Valley. Nitrogen (N) requirements for lettuce change as the season progresses. Proper timing and amount of fertilizer applications decrease the possibility of nitrate leaching or undesirable effects due to excess N uptake. Currently, most nitrogen applications are applied as a split side-dress after thinning and mid-growth totaling between 60 and 200 lbs of N per acre. Since over 80% of all nitrogen is absorbed in the final three to four weeks prior to harvest, much of this early applied N is moved beyond the rootzone. In many instances, an N application through the irrigation is required to maintain desired petiole nitrate levels. This allows for inefficient use of nitrogen. In the San Joaquin Valley, the most popular nitrogen source is AN-20 or CAN-17 due to its low cost and readily available nitrate. Many growers tend to apply excess amounts early in the season when N absorption is low with the idea that early application is critical for establishing a proper frame for head production.

This experiment compared different N side-dress rates and frequencies using AN-20 and CAN-17 as sources for lettuce grown in the central San Joaquin Valley. Rates ranged from 80 to 160lb of N per acre divided into two side-dress events. It is anticipated that low first side-dress N applications will lower leaching potential and still provide the plant with adequate nitrogen later when N demand is high. Proper timing and frequency of applied N should lower the overall amount of nitrogen being applied without compromising lettuce quality and yield.

This project began in the fall of 2001 and will conclude in the spring of 2002. The project site is located on Dresick Farms near Huron, Ca. Tests were conducted on a 25-acre block consisting of Panoche clay loam, previously planted to tomato. Iceberg lettuce was planted on 1-meter beds with two seed rows. Plots were four beds wide, 10 meters long and were arranged in a split-block design replicated 4 times. No pre-plant nitrogen was applied. Prior to thinning and harvest, all blocks were evaluated for soil nitrate in the top two feet. Tissue samples were taken at thinning and then 5-7 days after each irrigation until harvest. Dried tissue analysis was conducted on the mid rib of the most recently mature leaf with analysis of N03-N.

Preliminary results for soil, tissue and yield will be presented.

Spring Nitrogen Application Timings as They Influence Yield and Protein in Wheat

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High yielding wheat varieties often have lower protein content unless the timing of nitrogen applications is carefully managed. Nitrogen (N) was topdressed on wheat (*Triticum aestivum* L. cv “Anza”) at up to four rates 34, 67, 101 and 134 kg ha⁻¹ on six dates at 15 day intervals beginning Feb 1 to April 15. A combination treatment of 101 kg ha⁻¹ on Feb 1 plus 34 kg ha⁻¹ on April 15 along with a control made 16 treatments. Significantly higher yields and protein resulted with higher N rates applied earlier in the season during high rainfall years. The 34 kg ha⁻¹ rate had progressively higher protein with later applications but a marked reduction in yield. The combination treatment of 101 kg ha⁻¹ on Feb 1 plus 34 kg ha⁻¹ on April 15 maximized yield and protein.

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Potential for Utilizing Blended Drainage Water for Irrigating Westside, San Joaquin Valley Pistachios: II -- Determining ET and Water Stress in Long-Term Field Trials

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Abstract

In many areas of Iran pistachios have been grown for decades using saline irrigation water. Research there and a 1 year sand tank study at the USDA Salinity Lab in Riverside, California have shown that most pistachio rootstocks can tolerate as much as 12 dS/m EC in the irrigation water without significant decline in growth and production.

Starting in 1994 five different salinity treatments of 0.5, 2, 4, 6, and 8 dS/m were applied to 4 different pistachio rootstocks budded to a Kerman scion in a six year old orchard on the westside of the San Joaquin Valley. Trees are irrigated with one, 55 lph (14.5 gph) micro sprinkler and planted to a 5.2 m by 6.1 m (17 x 20 foot) spacing. Saline irrigation treatments were formulated to simulate the quality of local drainage water, with a Na:Ca ratio of 3:1 and B at 10 ppm. After two years, there were no significant decreases in marketable yield among rootstocks or treatments. In 1997, the 2 dS/m treatment was changed to 12 dS/m and treatments continued @ 0.5, 4, 8 and 12 dS/m.

Soil water content depletion between irrigations has been determined by neutron backscatter. Due to the large number of trees in the trial (64) only 1 neutron probe access tube per tree, sited in an identical location relative to each tree and microsprinkler, has been used to develop an estimate of “comparative cumulative seasonal transpiration”. For 1999 and 2000, this comparative soil water content depletion (to 1.4 m) in the salinized wetting pattern, was 34, 47 and 54% less than for control trees for the 4, 8 and 12 dS/m treatments, respectively. Despite this significant difference in soil water uptake, all plant-based measurements of leaf water potential, photosynthesis, stomatal conductance and transpiration showed no significant difference. Visual assessment of tree vigor likewise showed no difference. Far-reaching roots from the salinized trees are most likely extracting fresh water from adjacent trees receiving fresh water. Seasonal water content depletion for non-saline plots was 5.1% at the 1.4 m depth and 12.8% for the 12 dS/m. With about 90% of the water extraction occurring above 1.4 m we have attempted to eliminate the water obtained from adjacent fresh water areas by severing these roots to a depth of 1.5 m and installing a 6 mil plastic barrier for 2001. The number of monitored trees has been reduced to 32 with 4 access tubes per tree.

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A New Approach To Plant Mapping Cotton In The San Joaquin Valley

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Final plant mapping in both Pima cotton, *Gossypium barbadense*, and Upland types, *Gossypium hirsutum*, is an important tool that is commonly used by researchers, crop consultants, and growers to evaluate late season plant development characteristics and ultimately plant performance. Selection of the plants to be sampled in a given field is very important, as a very limited number of plants are selected to represent a whole field or plot within a field. One of the obvious selection criteria would be that of overall plant size and vigor, often times relying solely on plant height as a relative comparison between plants to be evaluated and the rest of the plot or field. Typically plants are “randomly” selected using quick visual observations to identify a “representative” of the population. Other methods have used the random selection of one plant followed by the consecutive sampling of several adjacent plants which has the advantage of reducing sampling error caused by unintentional or otherwise visual plant selection biases. One often over-looked variable in plant selection is plant spacing or density. Plant density has been demonstrated to have a very profound influence on the development of basic plant structure and vigor as well as the location of fruiting bodies distributed on the plant. When compared to more standard stands of 35,000 to 45,000 plants per acres (PPA), plant densities of 20,000 PPA can have a significant effect on overall plant size as well as development of fruiting branches, fruit size, and distribution while having little or no impact on yield. Our objective here is to identify the relative importance of plant population to plant map populations and to propose an alternative method for plant selection for plant mapping purposes.

The data for this poster is developed from Pima and Acala density and irrigation trials that have been evaluated during the past five years at the University of California’s West Side Research and Extension Center in Five Points, CA. Plant spacing for these studies ranged from 2.4 in. to 16 inches between plants with a resulting plant populations of 10,000 to 60,000 plants per acre on 40 inch beds. Several years of final plant mapping measurements were collected consisting of plant height, number of vegetative and fruiting nodes, height to node ratio, and fruit distribution characteristics. A summary of these findings is presented in this poster. The effects of plant density on plant structure and fruit distribution are most notably seen in the size and development of the vegetative branches and also the fruiting branches that are lowest on the plant. As the plant canopy expands throughout the early to mid growing season, light required for photosynthesis is significantly reduced thereby lowering the available photosynthetic products needed for further leaf expansion, branch development, and fruit production. The monitoring results of plant density studies are evaluated, as well as studies in which minimal plant population control was experienced are presented. Our work clearly indicates that a difference of several inches between plants can have a profound influence on the results of final plant mapping.

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Diurnal and Seasonal Ammonia Emissions from Dairy Effluent

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Abstract

California is the number one dairy state, producing 26 billion pounds of milk and cheese in 1999. While the growth of this industry results in significant economic returns for the region, there is the issue of effective manure management. In dairy operations, manure is commonly handled as an effluent stream of liquid or slurry manure by means of a hydraulic flushing - lagoon storage - irrigation system. Major problems associated with the manure management are high solids and nutrient contents of the effluent stream, and gas production during the decomposition of manure in storage. As a result the health, environmental and economic concerns, there is a need to quantify the ammonia (NH₃) emissions at dairies. In this study, temporal ammonia emissions from a dairy lagoon and a pasture fertilized with liquid dairy manure were investigated using an active sampling technique. At 1m above the lagoon, NH₃ fluxes decreased from 160 ugNH₃m⁻²s⁻¹ when the pH of the effluent was 7.5 to 85 ugNH₃m⁻²s⁻¹ when the pH was lowered to 6.3. Diurnal and nocturnal changes in NH₃ fluxes were due to primarily to differences in wind speeds. In August NH₃ fluxes ranged from 120 to 70 ugNH₃m⁻²s⁻¹, and from 40 to 32 ugNH₃m⁻²s⁻¹ in December, for dairy effluent applied to a sheep pasture. The applicability of the sampling technique for quantifying NH₃ emissions at dairies is also discussed in the poster.

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Ammonia Emission Factors from Monitoring of Fertilizer Applications to Various California Crops

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Abstract

This study, supported by the California Air Resources Board, was commissioned to develop a statewide emissions inventory of ammonia volatilization from applied fertilizers. A series of 19 fertilizer applications to commercial crops were sampled continuously for 7 to 10 days using an active denuder method similar to that utilized in urban air quality studies. Denuders and anemometers were co-located 1, 2, 5, 10 and 20 meters above the soil surface on a portable tower. Volatile NH₃ losses from fertilizer applications ranged from 0.1 to 0.7 g NH₃-Nm⁻² (approximately 1 to 6 lb. NH₃-N per acre). Estimated emission factors ranged from less than 0.1% to 6.6%. Higher emission factors occurred on soils with pH values greater than 8.0, and for application methods that left the fertilizer at the soil surface. Emission factors from the field-sampling phase of the study were used to develop a database for the entire state. Crop acreages from overhead images were combined with fertilizer application rates and methods estimated for various regions of the state. Volatile NH₃ emissions from fertilizer applications were 12 X 10⁶ kg NH₃ annually in an estimated statewide emission of nearly 37 x 10⁶ kg NH₃.

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Use of Electromagnetic Survey to Assess Potential Canal Seepage

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Abstract

Seepage from irrigation canals is a serious water management problem in California's San Joaquin Valley. Seepage reduces irrigation efficiency and its water may contain toxic substances harmful to soils and groundwaters. Therefore, it is necessary to identify tools that can detect potential leakages. While the electromagnetic induction technique (EM) has been commonly utilized for salinity assessment, its use for seepage investigations is just developing. Recently, researchers in Australia found that EM was useful in detecting canal seepages. The goal of this study was to apply the EM technology to detect potential seepage along a canal of central California.

The research was conducted at the Lost Hills Water District in Kern County, CA. An unlined section of the canal was selected for the study. Surveys were conducted in 2001 when the canal was open (August) and then closed (October). A Mobile Conductivity Assessment (MCA) System was developed that comprised four components mounted on a truck: (1) an electromagnetic induction sensor EM-31, (2) a global positioning system (GPS) receiver, (3) a computer, and (4) a hydraulic soil sampler. The EM sensor was placed in a plastic carrier-sledge attached to the rear of the truck and measured the depth-weighted apparent soil electrical conductivity (EC) down to 10 ft. The EM and GPS instruments were connected via digital interfaces to the on-board laptop computer that simultaneously recorded the EM readings and their corresponding GPS locations. For both surveys, EM and GPS measurements were taken on each side of the canal. Data calibration and analyses were performed with the ESAP-95 statistical package following ground-truthing soil sampling (0-9 ft). Soils were analyzed for electrical conductivity, water content, bulk density, and texture. Contour maps of moisture, salinity, and texture distributions at different depths were generated using the ArcView GIS software.

For both surveys, the maps indicated that soil water content was lowest near the surface (0-3 ft) with values ranging from 20 to 30%. Moisture percentages were comparable in August and October, suggesting the possibility of no seepage at the surface. The 6-9 ft profile had the highest water content due to the presence of water table. The water content percentages at 3-9 ft were lower in October than in August. Greater soil water content could be indicative of potential seepage. Soil EC was lowest at 6-9 ft depth (< 4 dS/m). In August, throughout the profile, the highest EC values were always observed on the eastern side of the canal. Average soil EC increased after closing the canal. For all depths, soil water content and EC were greater in the mid-section of the canal. Results also indicated that percent clay content in the soil increased with depth and ranged from 10 to 50%. The overall results of such study and the contour maps can be useful in improving water management and conservation strategies along the irrigation canals.

Ammonia Emissions from Cotton during Fertilizer Application and Defoliation

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Abstract

In 1999, cotton production was ranked third among California's top 20 agricultural exports and accounted for an export value of \$439 million. Despite a forty one percent decline in export value from 1998 due mainly to production declines and unstable foreign exchange rates, cotton continues to be a leading export commodity and there is ongoing effort to improve nitrogen (N) use efficiency in cotton production. In addition to the economic losses represented by the amount of applied N that is not available for plant uptake, ammonia (NH₃) emissions from crop production are major health and environmental concerns. In this poster, we present some of our ongoing research aimed at defining an annual N budget for cotton. The major objective was to quantify NH₃ emissions from two cotton crops before, during and after N application and irrigation, as well as to determine any NH₃ emissions during defoliation of another cotton crop. Active denuder samplers, with citric acid traps, were used to monitor NH₃ concentrations both within and above the crop canopies. Standard mass balance micrometeorological techniques were used to estimate the integrated NH₃ flux by combining measurements of wind speed and NH₃ air sample concentrations from height-dependent sampling locations mounted on the portable mast towers. For cotton grown on an Oxalis silty clay with pH of 8.5, to which N was applied as anhydrous NH₃ injected into soil to a depth of approximately 15 cm followed by flood irrigation, there was a 5.6 kg N ha⁻¹ loss for every 100 kg N ha⁻¹ applied. For cotton grown on a Lethent silty clay with a lower pH of 7.8, subjected to similar N fertilization and irrigation, the NH₃ emission factor was only 3.9%. In the case of the cotton defoliation measurements, on Panoche loam with pH of 7.9, NH₃ emissions reduced from 26 kg N ha⁻¹ day⁻¹ after defoliant application to 6.3 kg N ha⁻¹ day⁻¹ by the time there was 65% crop defoliation. Our findings indicate that N losses through volatilization during both crop growth and defoliation are significant and should not be ignored in calculating annual N budgets for cotton.

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