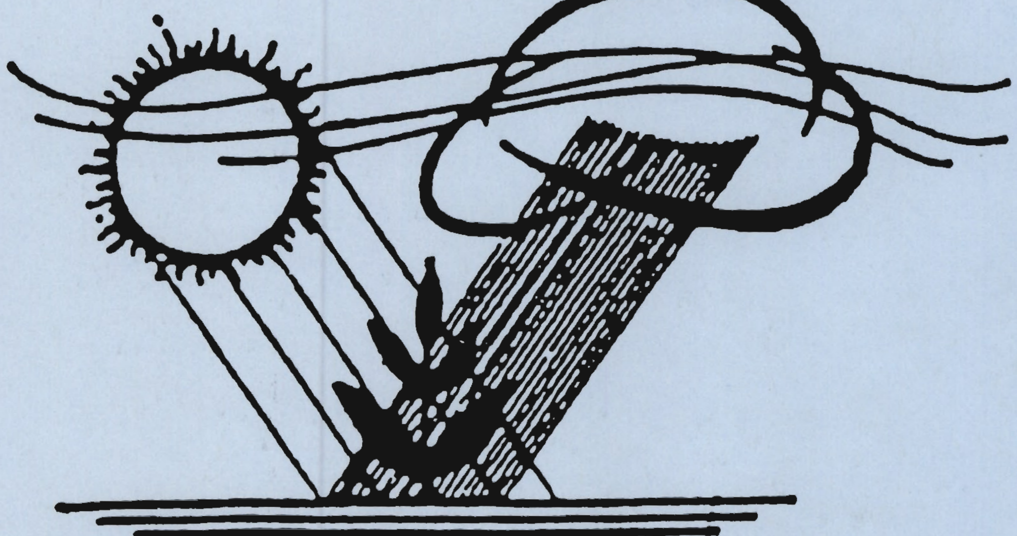
PROCEEDINGS

2000

CALIFORNIA PLANT AND SOIL CONFERENCE

FARMING IN CRISIS - SUSTAINING AGRICULTURE IN CALIFORNIA



CALIFORNIA CHAPTER OF AMERICAN SOCIETY OF AGRONOMY

AND

CALIFORNIA FERTILIZER ASSOCIATION

JANUARY 19 & 20, 2000

Radisson Hotel
2323 Grand Canal Blvd.
Stockton, CA 95207

WEDNESDAY, JANUARY 19, 2000

GENERAL SESSION

Session Chair: **Bill Rains**
Dept. Agronomy and Range Science, UC Davis

10:00 Introduction - Session Chair

10:10 **California Agriculture - Impact Of 8 Billion People; What Does It Mean?** - Bill Rains, Department of Agronomy and Range Science, UC Davis

10:40 **Agricultural Water Management Issues For 2000 and Beyond** - Gerald E. Johns, Assistant Chief, Division of Water Rights, State Water Resources Control Board, Sacramento, CA

11:10 **FQPA, The Tip Of The Iceberg** - James Wells, Vice President JSC California, Sacramento, CA

11:40 Discussion

12:00 UNIVERSITY-INDUSTRY LUNCHEON

CONCURRENT SESSIONS

I. PRECISION AG - GIS, GPS

Session Chairs: **Steve Kaffka,** Agronomy and Range Science, UC Davis and **Ron Brase,** Calif. AgQuest Consulting, Inc., Fresno, CA

1:30 Introduction - Session Chairs

1:40 **Assessment Of Salinity In Agricultural Soils** - D. Corwin, US Salinity Lab, Riverside, CA

2:00 **Field-Scale Soil Salinity Assessment And Sugarbeet Management In The Imperial And San Joaquin Valleys** - Stephen Kaffka*, Agronomy and Range Science, UC Davis, D. Corwin, G. Fitzgerald, and S. Lesch (* Presenter)

2:20 **Comparison Of Yield Maps Across A Four Row Crop Rotation** - Stuart Pettygrove*, Extension Soils Specialist, LAWR, UC Davis, R. Plant, J. Young, M. Cahn, R. Miller, L. Jackson, and F. Dennison (* Presenter).

2:40 Discussion

3:00 BREAK

3:20 **An Overview Of Precision Agriculture Technologies** - Michael Spiess, Department of Plant Science, Cal State Univ., Fresno

3:40 **Using Geo-Referenced Aerial Imagery In Precision Agriculture** - Richard Mead, mPower³ & United Agri Products, Fresno

4:00 **The Power Of Integrating GPS Technologies** - Ronald J. Brase, California AgQuest Consulting, Inc., Fresno

4:20 Discussion

4:30 ADJOURN

II. RESOURCE LIMITATIONS

Session Chairs: **Dave Zoldoske**, CIT, Cal State Univ., Fresno and **Jerome Pier**, Agronomist, J. R. Simplot Co., Lathrop, CA

1:30 Introduction - Session Chair

1:40 **Cal-Fed Water Use Efficiency Program and Policy Implications** - Tom Gohring, PE, US Bureau of Reclamation

2:00 **Mechanical-Move Irrigation Systems** - Wendell Dorsett, Sr. Application Engineer, Valmont Industries, Valley, Nebraska.

2:20 **Subsurface Drip Irrigation** - Claude Phene, Ph.D., SDI Consulting

2:40 Discussion

3:00 BREAK

3:20 **Irrigation Management For Grapevines** - Ronald. J. Brase, California AgQuest Consulting, Inc., Fresno, CA

3:40 **Water Management Using Continuous Soil Moisture Monitoring** - Dale Handley, Handley Irrigation Consulting

4:00 **Parital Rootzone Drying (PRD) To Improve Fruit Quality And Water Use Efficiency** - Sanliang Gu, Ph.D., Viticulture & Enology Research Center, CSU-Fresno

4:20 Discussion

4:30 ADJOURN

THURSDAY, JANUARY 20, 2000

III. **ADVANCES IN NUTRIENT MANAGEMENT**
Session Chairs: **Walt Bunter**, USDA/NRCS and **Casey Walsh Cady**, CDFA/FREP

8:30 Introduction - Session Chairs

8:40 **Uses Of N-15 In Rice Cropping Systems To Determine The Fate Of Fertilizer Nitrogen** - William Horwath, LAWR, UC Davis

9:00 **Nitrogen Management in Cotton Cropping Systems** - Felix Fritschi, UC Davis

9:20 **Plant And Microbial Utilization Of Cover Crop Nitrogen In A Vegetable Field** - Louise Jackson, UC Davis

9:40 Discussion

10:00 BREAK

10:20 **Development Of A Nitrogen Fertilizer Recommendation Model For California Almond Orchards** - Patrick Brown, UC Davis

10:40 **Water And Fertilizer Management For Garlic** - Ron Voss, UC Davis

11:00 **Winter Cover Crops Before Late-Season Processing Tomatoes For Soil Quality** - Gene Miyao, UCCE Yolo County

11:20 Discussion

12:00 CONFERENCE LUNCHEON

IV. **PRODUCING HIGH QUALITY AND SPECIALITY CROPS OF CALIFORNIA.**
Session Chairs: **Daniel Hostetler**, Cal Poly Pomona, **John Palmer**, Phytogen, Corcoran

8:30 **Introduction** - Session Chairs

8:40 **Phytochemicals: Creating Value Added Specialty Crops From Naturally Occuring Agents** - Wayne Bidlack, Cal Poly Pomona

9:00 **Quality Indicators In Lettuce Seed** - David Still, Cal Poly Pomona

9:20 **Future Traits In Value-Added Oilseeds And Grains** - Dave Dzisiak, Dow AgroSciences, Canada

9:40 Discussion

10:00 BREAK

10:20 **Producing Quality Cotton For Tomorrow's Markets** - Dick Bassett, Shafter CA

10:40 **Producing High Quality Rice For The Export Market** - Cass Mutters, UCCE Butte County

11:00 **Factors That Influence Alfalfa Forage Quality** - Dan Putnam, UC Davis

11:20 Discussion

12:00 CONFERENCE LUNCHEON

V. **ISSUES IN BIOTECH RESEARCH: PUBLIC vs. PUBLIC SECTOR FUNDING**
Session Chairs: **Bill Rains**, UC Davis, and **John Palmer**, Phytogen, Corcoran

1:30 **Introduction** - Session Chairs

1:40 **Effects Of Broadscale Use Of Pest-Killing Plants** - Brian Federici, UC Riverside

2:00 **Public Germplasm And Intellectual Property** - Brian Wright, UC Berkeley

2:20 **Genetic Resources From The Third World; Who Owns It?** - Pamela Ronald, UC Davis

2:40 **Making Sense Of The Plant Patent Puzzle** - John Sanders, Dow AgroSciences, San Diego

3:00 Discussion

3:20 ADJOURN

VI. **NUTRIENT REGULATION IN AGRICULTURE**
Session Chairs: **Warren Bendixen**, UCCE, Santa Maria, CA, and **Jerome Pier**, Agronomist, J. R. Simplot Co., Lathrop, CA

1:30 **Introduction** - Session Chairs

1:40 **Regulations For Non-Nutritive Elements In Fertilizer** - Renee Pinel, CFA, Sacramento

2:00 **Dairy Water Quality Compliance Program** - Jack Hodges

2:20 **Regulation Of Biosolids As A Fertilizing Material In California** - Stephen Mauch , CDFA, Sacramento, CA

2:40 **The UCCE Rangeland Watershed Programs Role In The Garcia River TMDL Process** - Kenneth Tate

3:00 Discussion

3:20 AJDOURN

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CALIFORNIA CHAPTER
AMERICAN SOCIETY OF AGRONOMY
PAST PRESIDENTS

1972	Duane S. Mikkelsen
1973	Iver Johnson
1974	Parker F. Pratt
1975	Malcolm H. McVickar
	Oscar A. Lorenz
1976	Donald L. Smith
1977	R. Merton Love
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1979	Roy L. Branson
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1981	Harry P. Karle
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1985	Burl Meek
1986	Stuart Pettygrove
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1989	Nat B. Dellavalle
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1998	Shannon Mueller
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CALIFORNIA CHAPTER
AMERICAN SOCIETY OF AGRONOMY
HONOREES

1973	J. Earl Coke
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	Audy Bell
	Frank Parsons
1997	Jolly Batcheller
	Hubert B. Cooper, Jr.
	Joseph Ronstadt Smith
1998	William H. Isom
	George A. Johannessen
	Ichiro "Ike" Kawaguchi
1999	Bill Fisher
	Bob Ball
	Owen Rice
2000	Donald W. Grimes
	Albert E. Ludwick
	Claude Phene

2000 Honorees of the California Chapter of the American Society of Agronomy

Donald W. Grimes

Albert E. Ludwick

Claude Phene

Donald (Don) W. Grimes

Don grew up on a family operated farm in Central Oklahoma that focused on livestock, corn, grain sorghum, cotton, and alfalfa production. He attended rural schools through High School while working on the farm with his parents and two brothers. This background cultivated an early interest in production agriculture that persisted through his career with the University of California.

Don completed his undergraduate degree in Agronomy (1954) at Oklahoma State University. He continued graduate studies at OSU and received an M.S. degree in Soil Chemistry the following year. He then began an agricultural research career that was to continue for the next 37 years.

He served as Irrigation Agronomist with Kansas State University until 1963 when he returned to graduate studies at Iowa State University. While attending ISU, he worked in the Cooperative Extension group as a liaison between the campus located soil testing laboratory and County Extension Agents. He was awarded a Ph.D. degree in 1966 with studies focusing on soil science with significant interest directed to production economics and plant physiology.

With this background of training and work experience, Don joined the Water Science and Engineering (now Land, Air and Water Resources) faculty at U.C., Davis and was initially located at the U.S. Cotton Research Station in Shafter. In 1969, he relocated to the U.C. Kearney Agricultural Center that served as a base for research studies conducted throughout the Central San Joaquin Valley region.

Don's research interests were directed to water-soil-plant relations with irrigation scheduling studies frequently using plant based water status indicators. His research was often done cooperatively with both Experiment Station and Cooperative Extension personnel in ways that hastened technology transfer to production systems. This characteristic was recognized in 1990 when he received a Distinguished Service Award in Creative Teamwork for service rendered to the people of California.

His research developed thresholds of water deficit tolerance for optimum growth and production of cotton, alfalfa (both for forage and seed production), and grape vines. The cotton work formed major components of the irrigation management section of a cotton management model used extensively in California and elsewhere. He developed water-yield production functions for several major crops that are useful in an economic analysis for maximum farm profitability. Working with colleagues in Cooperative Extension and graduate students, he was the first in California to quantify the contribution of shallow water tables to meeting the water requirements of cotton and alfalfa with limitations imposed by shallow water table salt load and depth. His research findings are contained in approximately 90 peer review publications and 100^+ reports and popular articles. Don's activities include consulting work performed in the Sudan and in the Dominican Republic.

After retiring in late 1992, Don has completed two short-term U.S. Agency for International Development projects in Mexico through Winrock International and taught introductory irrigation and soil science classes at the local Community College. He and wife Julia are continuing their residence in Reedley where they remain active in local church and civic groups. Visits with their three daughters and their families (five grand children) and activity with the California Flying Farmers provide frequent travel opportunities in their Mooney that Don still likes to fly.

ALBERT (AL) E. LUDWICK

Al has been a leader in developing programs for the environmentally and agronomically sound use of fertilizer in California and other western states. In his position as Western Director, Potash & Phosphate Institute he has been active in the California Fertilizer Association, Far West Fertilizer & Agrichemical Association and other state associations.

He graduated with a B.S. in Soil Science from Cal Poly, San Luis Obispo, and received both a M.S. and Ph. D in Soil Fertility from the University of Wisconsin.

He spent 1966 - 1970 in Brazil on an International Agricultural Development Program with the University of Wisconsin. Al taught soil chemistry (in Portuguese) in the graduate program of the Federal University of Rio Grande do Sul, advised graduate students, and conducted extension activities in southern Brazil. Following his stint in Brazil, he joined the Department of Agronomy at Colorado State University advancing from Assistant Professor to Professor in his ten-year tenure at CSU. During this period Al was involved in research, extension and teaching in the areas of soil fertility, fertilizer management and soil testing.

Al joined his current employer the Potash & Phosphate Institute in 1980 as Western Director. He is presently responsible for coordinating research programs and conducting educational activities in 9 western states with overall objective of market development for phosphate and potash fertilizers. Additionally he also served as Coordinator for Latin American programs from 1986-89 and for Mexico from 1990-94.

His involvement as a leader in industry activities has been extremely important to the California fertilizer industry. He has served as board member of the California Certified Crop Advisor Program helping establish this program in California. As an original and continuing member of the California Department of Food and Agriculture's Fertilizer Inspection Advisory Board's Technical Advisory Subcommittee he has been a leader in ensuring the success of the Fertilizer Research and Education Program.

Al serves as Editorial Chairman of the California Fertilizer Association's Handbook Committee. He has been responsible for the first and second editions of the *Western Fertilizer Handbook - Horticulture Edition* and *Western Fertilizer Handbook – 8th Edition.* His committee is currently working on the 9th edition of the handbook. Also he has been active in many other CFA committees and has served as a valuable resource on agronomic issues to the association.

He was been recognized by the American Society of Agronomy as a fellow in 1991 and also received the California Fertilizer Association's Distinguished Service Award in 1991. Al was given the Exemplary Service Award by the Western Nutrient Management Conference in 1999.

Al and his wife Helen live in Bodega Bay, California where he practices his hobby of golf.

Claude Phene

Dr. Claude Phene has worked more than 30 years in the area of soil and water management. Born in Bordeaux, France, Dr. Phene spent six years of active duty in the United States Air Force. Later, he earned a BA degree in Physics and a Ph.D. in Soil Physics from the University of California, Riverside.

Most of his professional career was spent with the United States Department of Agriculture, were Dr. Phene worked as a Physicist and Soil Scientist, Supervisor of Research and finally as Director of the USDA Water Management Laboratory in Fresno. Dr. Phene retired from the USDA in 1994.

Upon retirement, Dr. Phene immediately started his own consulting business, SDI Plus, in which he is still active today. He consults worldwide on irrigation and fertility requirements in agriculture. During his long and distinguished career, Dr. Phene's research results have been published in 283 scientific and technical publications, conference proceedings and annual reports authored and/co-authored by the incumbent since 1967.

Dr. Phene has been a member of the American Society of Agronomy since 1969, is a fellow in the Soil Science Society of America, and a life member in the Irrigation Association, among others. Additionally, he has served as an adjunct professor in the both the California State University and University of California systems. Dr. Claude Phene was instrumental in the formation of the Center for Irrigation Technology, CSU-Fresno.

Dr. Phene should be recognized as one of the first and most adamant supporters of subsurface drip irrigation. From the beginning, when few, if any considered the then new technology to be little more than a research tool, Dr. Phene persisted in promoting the practice with growers until the concept took hold. Today, many successful growers recognize Phene's research and tireless efforts in promoting subsurface drip irrigation as critical to bringing it to a commercial reality. To that end Dr. Claude Phene has changed our industry forever.

Finally, Claude resides with his wife Becky and their two children Marcelle and Daniel in Clovis, California. Becky is very much involved in irrigation with her company BCP Electronics. The company manufacturers and sells sophisticated irrigation scheduling control systems and soil moisture measuring equipment. For the Phene family, irrigation is not a job, but a way of life.

CALIFORNIA CHAPTER ASA
1999
BOARD MEMBERS

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Three-Year Term:

Jerome Pier, J.R. Simplot Company, Lathrop
Daniel G. Hostetler, Horticulture/Plant & Soil Science, Cal Poly Pomona
David Zoldoske, CIT, California State University, Fresno
Lee Bucknell, Modesto Jr. College, Modesto

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California Agriculture - Impact of 8 Billion People; What Does It Mean?

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University of California
Davis, California 95616
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Email: derains@ucdavis.edu

The world population exceeded six billion in mid October, 1999. From that time to the date of this conference approximately eighteen million individuals have been added to the world's population. To an agriculturalist this means that six billion, eighteen million mouths require nutritious, safe food. How will this be accomplished, what will be the impact and how does California agriculture fit into this?

A critical question in any discussion on food supply is what resources are required to feed this many people. Productive agriculture among other things, requires a number of natural resources , reasonable climate, technology intervention at various levels and a demand for the product. Increasing numbers of people will continue to demand that the agricultural system provide the nutrients and energy for this burgeoning population. In ecological terms we are asking the question, what is the human carrying capacity of the world? In this context carrying capacity is a measure of the largest number of a given species (people) that a habitat can support indefinitely. However, when the maximal sustainable population level is surpassed, the resource base begins to decline and soon after the numbers of that species begins to decline. This ecological principle has been demonstrated a number of times and its role in human population growth and development has been observed in limited areas. For example we have seen mass starvation in Africa in recent years; a combined effect of climate and politics. Immediately following WWII there was a potential mass famine in the Indian Subcontinent. These situations were wake up calls and resulted in organized responses including the "Green Revolution" of the 1950's and 1960's. Recently a number of studies suggest that as a result of population growth, consumption patterns and the impact of technology we may exceed the carrying capacity of the world. The response of the agricultural community has been to manipulate resources and biological materials to meet the increasing demands on the food system. The focus has been on the productive capacity of agriculture and the resources required to sustain this productivity. These considerations, however, should be viewed in reference to economic, social and environmental constraints. It is essential that we view agronomic systems as integral components of agroecosystems functioning within a society which demands fairly priced, safe food produced in a socially and environmentally compatible manner.

In this paper we will attempt to address productive capacity of agriculture within the constraints imposed by limited resources and increasing demand due to increasing population and affluence.

Increasing Population - How Much, Where, Who?

The demographics of populations are not a simple numbers game. The population is made up of different age groups located in different regions of the world within political boundaries, often independent of natural resources required to sustain the current population. Figure 1 shows the current population trends. Although the rate of increase in population growth is beginning to decline the total number of humans continues to increase and is expected to reach nine billion by 2050.

The World at Six Billion

Figure 1. Long-term world population growth, 1750 to 2050

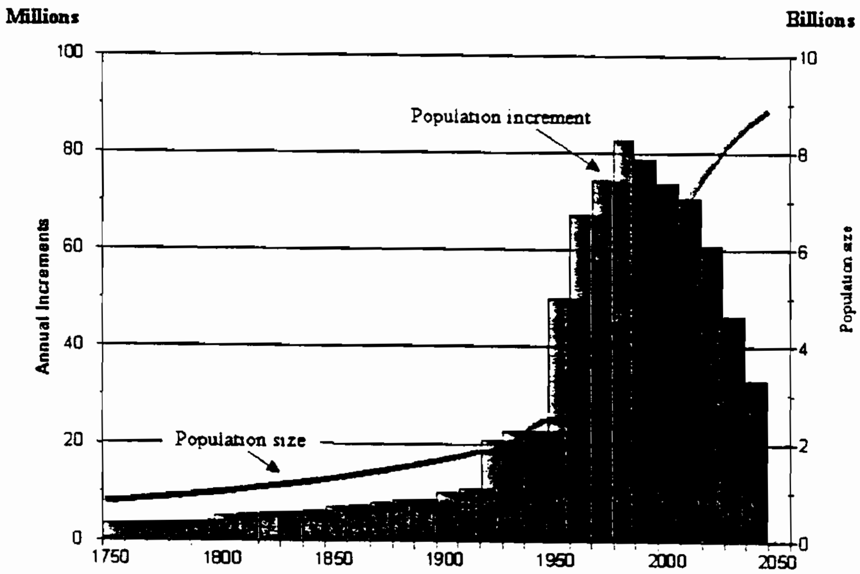

Table 1 shows the ten most populous countries currently and a projection of the population in 2050. China and India are the two most populous countries with a combined population representing over 35% of the total worlds population in 1999. If projections are accurate in 2050 they will represent 34% of the worlds population, however, India will now have the distinction of being the most populous country in the world.

Table 1 Ten most populous countries, 1999 and 2050

Country	*Population (thousands)*	*Percentage of world population*
1999		
World	**5 978 401**	**100.0**
1. China	1 266 838	21.2
2. India	998 056	16.7
3. United States of America	276 218	4.6
4. Indonesia	209 255	3.5
5. Brazil	167 988	2.8
6. Pakistan	152 331	2.5
7. Russian Federation	147 196	2.5
8. Bangladesh	126 947	2.1
9. Japan	126 505	2.1
10. Nigeria	108 945	1.8
2050		
World	**8 909 095**	**100.0**
1. India	1 528 853	17.2
2. China	1 477 730	16.6
3. United States of America	349 318	3.9
4. Pakistan	345 484	3.9
5. Indonesia	311 857	3.5
6. Nigeria	244 311	2.7
7. Brazil	244 230	2.7
8. Bangladesh	212 495	2.4
9. Ethiopia	169 446	1.9
10. Dem. Rep. of the Congo	160 360	1.8

Resources - Availability, Distribution and Sustainability

Land Land is the one basic resource on which all agriculture depends. In developed countries including California farmland per person is approximately 0.5 ha. This is a decrease from 1970 of about 0.65 ha. In California if one includes only the irrigated farmland and omitting the grazing areas then our farmland per person is approximately 0.2, a number similar to the developing areas of the world. The farmland per person in developing areas has shown a precipitous decline since 1980; declining from 0.33 to 0.20, an area 45 meters on a side. In China the situation is much more severe with only 0.09 ha per person available to produce all their food. It has been estimated that 80% of the potentially arable land is being farmed in Asia, currently. The general trend in land used per person for agriculture show a decrease in both developed and developing countries. This suggests that to obtain the food necessary for an increasing population we need to produce more food per ha. In some countries the land is limited and the resources are limited. This suggests that areas like California will have an increasing role in feeding these populations. We must preserve agricultural lands in California if we are to contribute to this need.

Water Water is crucial to both rain-fed and irrigated agriculture. Agriculture accounts for 70% of the water used in the world. In some developing countries as much as 90% of the water used is for agriculture. Of critical importance is the annual renewable water resources. Any country using over 20% of their renewable water resources has serious problems. This includes the Middle East and North Africa with all countries, including Israel, using over 90%. It also includes China and South Asia, areas with high populations. In the U.S. we use 19% of our renewable water resources. California in a drought year has used up to 70% of its water resource. Investment in water development has shown a decrease in the last few years and the area of irrigated land per person has been declining worldwide (see Figure 2). It has become increasingly obvious that water may be a major constraint to feeding an increasing population. California has made almost no new investments in water projects and as a result of water limitations will have difficulty in responding to future demands for food by the world market.

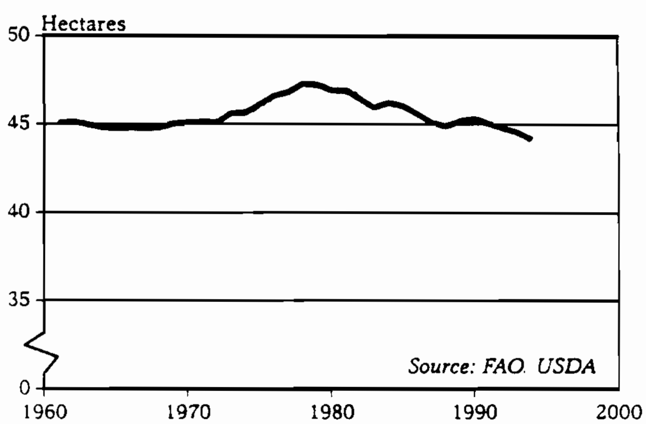

Figure 2: World Irrigated Area Per Thousand People, 1961-94

Production Food production has been keeping pace with population until just recently. The "green revolution" provided some breathing space and through the 1960', 70's and mid 80's the introduction of high yielding grains and appropriate inputs resulted in a output of food adequate to feed the majority of the population. There were examples of inadequate food supplies in certain regions, however, the overall production per person was increasing, even with a increasing population. Recently this has shown some changes. Figure 3 represents the grain out per person over the last few decades. The curve shows a flattening and some decline. This suggests that the population increases exceeding increases in agricultural output. It seems appropriate to analyze the output of agriculture and to ask the question what role will California play in the future.

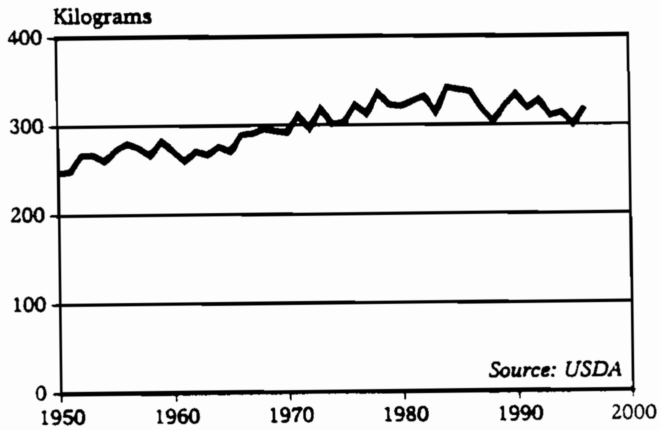

Figure 2: World Grain Production Per Person, 1950-96

Future?

California should have a pivotal role in meeting the future demand for food, feed and fiber. We have the climate , resources, technology and land. Our major constraint will be water. The current policies governing the development and distribution of water are not favorable for agriculture. The policies that have been imposed are predicated on the current situation of "excess" supply of agricultural products reflected in a lower pricing of these products. The future trends in population and the unequal distribution of agricultural resources suggest that California agriculture could be a major contributor to the Pacific Rim countries food and fiber needs. It may take 25 years for the demographics of human populations to express those needs and California should be ready to respond.

AGRICULTURAL WATER MANAGEMENT ISSUES FOR 2000 AND BEYOND

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Introduction

Water Management Issues at the beginning of the first decade of the new millennium will focus more on agriculture than they have in the past. These issues involve both water quality and water allocation challenges facing California. In the past, California agriculture met these challenges. Only through continued leadership by the agricultural community can these new issues be addressed. Three general water management issues are discussed: (1) the role of water transfers and agriculture, (2) what can be expected from Total Maximum Daily Load (TMDL) allocations under the Clean Water Act and (3) effects of the state and federal Endangered Species Acts and the public trust doctrine on water supplies.

The Role of Water Transfers and Agriculture

As we move into the next century, water supplies will continue to be limited in California. Water supply reductions caused by (1) implementation of measure to better protect fish and wildlife under the state and federal Endangered Species Acts and the public trust doctrine and (2) increased demand for water by a growing urban population in California. These two factors combine to put greater stress on agricultural water supplies. Agriculture water conservation activities and companion water transfers provide a tool to help meet these growing water supply challenges. In order to take advantage of water transfers and to understand the limitations of water transfers, agriculture needs to firmly grasp the rules related to the transfer of water.

Hundreds of water transfers take place every year in California between farmers within water districts. Water district managers have established rules to allow their farmers to obtain water from other farmers within the district. In addition, inter-district water transfers are common between contractors of the large State Water Project (SWP) and Central Valley Project (CVP). These transfers require approval of the Department of Water Resources (DWR) or the U.S. Bureau of Reclamation (USBR) respectively. Less common, but still important are transfers that extend beyond the existing water rights of a water district or agency. These transfers often require approval of the State Water Resources Control Board (SWRCB) of a change in the existing water rights. The general rules relate to water transfers are quite simple. However, their implementation can be complex.

Four general rules are common to water transfers which require SWRCB approval. They are:

- Rights to water to be transferred must exist;
- Water rights transferred remain with the original water right holder and not to those receiving the water transfer;
- Water transfers must cause "no injury" to any legal user of water;
- Water transfers typically can cause "no unreasonable effects" on fish and wildlife.

In order to transfer water involving a necessary change in a water right, the rights to the water must exist in the amounts and for the diversion season to allow the transfer. A careful review of the underlying water right is needed to understand the amounts and rates of diversion allowed under the water rights and the season of diversion set forth in the water right. The amounts and the season of diversion cannot be increased through a water transfer. However, the place of use, purpose of use or points of diversion can be changed to accommodate a water transfer. The SWRCB is evaluating the season of water availability for major water rights in the Central Valley through its Bay/Delta proceeding. The presentation of this paper will provide a status of this review.

Short-term water transfers (those less than one year) are allowed expedited processing and are exempt from review under the California Environmental Quality Act (CEQA). Short-term transfers are limited under the water code to water that has been stored or would have been stored or consumptively used in the absence of the transfer. Long-term transfers are not restricted to stored water or reductions in consumptive use. As will be discussed below, long-term transfers can include reductions in return flows. However, the transfer of reductions in return flows are not allowed to cause injury to any legal user of water.

The California Water Code states in, at least, eight different code sections that the act of transferring water does not adversely affect in any way the original water rights. There may be political concerns involving the transfer of water from an agricultural user to an urban water user when the agricultural user wants the water back. However, these concerns are best addressed in contracts between the parties. These issues are not water right issues. The legislature could not make its intent more clear that water transfers must not adversely affect the status or ownership of the underlying water right.

Perhaps the most controversial and misunderstood of the rules regarding water transfers is that they must cause "no injury" to any legal user of water. Water transfers are a special kind of change to water rights. All changes to water rights cannot injure any legal user of water. This applies not to just prior water users but any legal user of water of the water involved. This requirement dates back to a court case in the 1850s and was placed into the California Water Code in the early 1900s (see section 1702). It also applies to changes in pre-1914 water rights (section 1706). Water rights in California have been established to protect senior water right holders from those with junior water rights, also referred to as "first-in-time / first-in-right." However, the "no injury" rule protects the junior water right holders from changes in water rights by the senior water right holders. For example, a water right holder may reduce return flows in order to use the water saved to irrigate lands within the existing place of use of the water right. This is allowed even if a downstream water user relied upon the return flows. However, if the lands are outside the existing place of use in the water right, then a change to the water right is needed and the "no injury" rule applies. During the summer of most years, return flows are typically used by downstream users in most stream systems. This makes the transfer of return flows difficult without injuring downstream users. The figures below (Figures 1, 2 and 3) show how agricultural water conservation practices can result in reductions in consumptive use, which is easily transferable, or reductions in return flows which is more difficult to transfer without causing injury to downstream users. The presentation of this paper will explain how the Watershed Protection Act in the Central Valley affects the evaluation of "no injury" as it relates to the transfer of reductions in agricultural return flows.

Figure 1

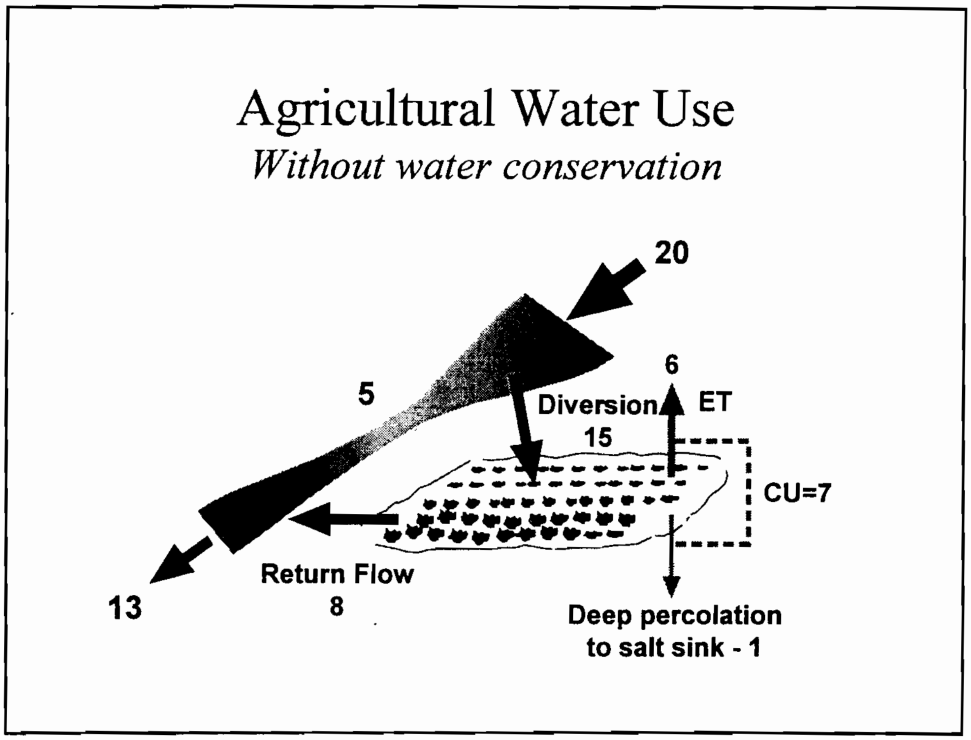


Figure 2

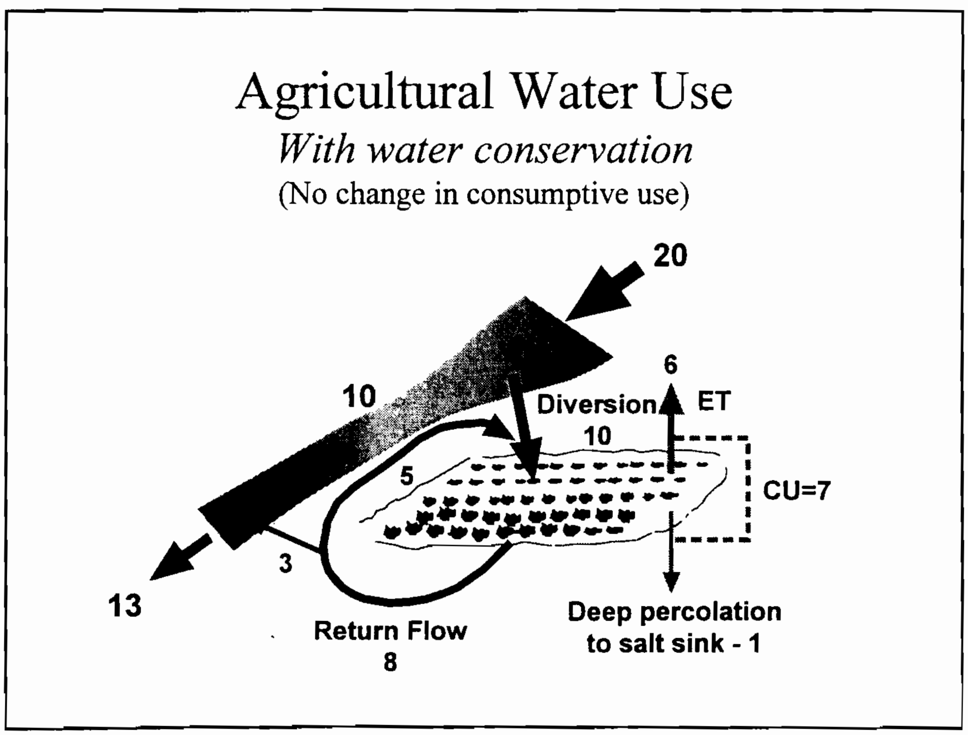
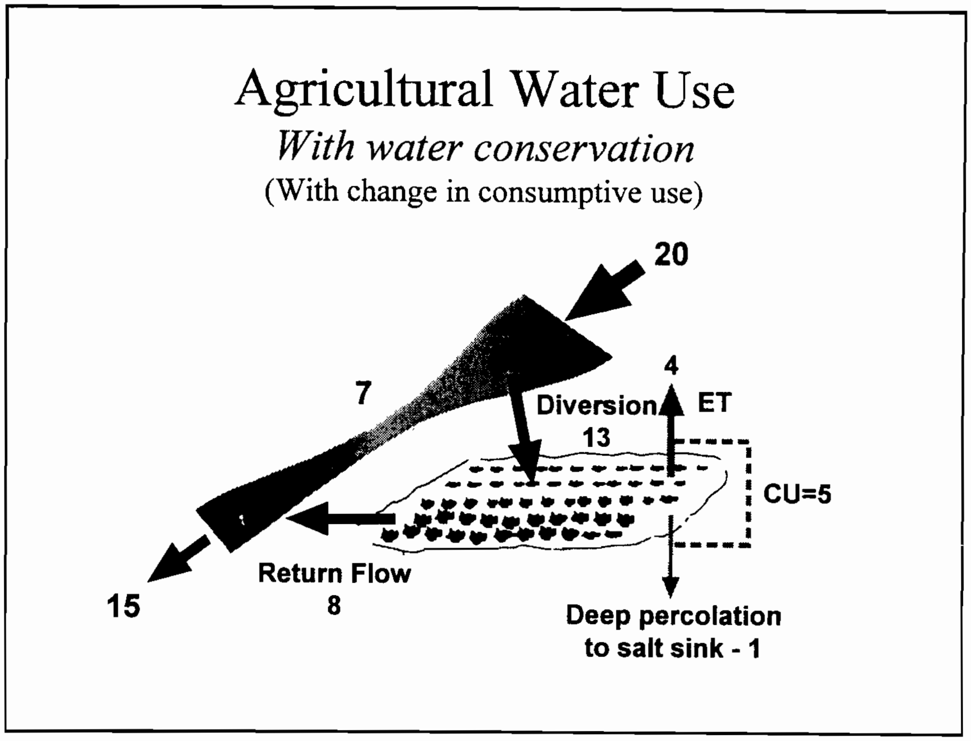


Figure 3



The last general rule related to water transfers is the requirement that they cause "no unreasonable" effect on fish and wildlife. Better water management can result in less water loss. These losses are often used by either water users downstream or fish and wildlife. Water transfers cannot result in "unreasonable" effects to fish and wildlife. In many cases, the remaining flows in a stream system provide protection to these resources even with the transfer of water. The "no unreasonable" effect test is not the same as the "no significant effect" test under CEQA. The "no unreasonable effect" test is a broader standard and requires judgement on the part of the SWRCB related to the reasonableness of the effects the may result from a water transfer.

Developing water transfers can be complicated. During the last year, the SWRCB staff worked the several interested parties in the water community to develop a draft "Guide to Water Transfers". This document explains the underlying water laws related to transfers and provides a "road map" for those wishing to develop water transfers. This document was released to the public in July 1999. While the parties that assisted in the development of the Guide do not necessarily agree with all the analyses provided by SWRCB staff, they generally agreed that this publication would help focus the debate on outstanding issues related to water transfers. *A Guide to Water Transfers* is available from the SWRCB and can be found on the Internet at "www.waterrights.ca.gov" under water right information.

What can be expected from Total Maximum Daily Load (TMDL) allocations under the Federal Clean Water Act?

When the Federal Water Pollution Control Act (now the Federal Clean Water Act) was implemented in the 1960s & 1970s, water quality improvement efforts focused on point sources. Agriculture was specifically excluded as a point source. However, during the 1980s and 1990s California began to focus its state regulatory efforts on non-point sources of water quality concerns. These actions have included such issues as selenium in the San Joaquin Valley and rice herbicides in the Sacramento Valley. However, water quality standards are not being met for numerous water bodies in the State. Many of these water bodies are affected by return flows from irrigated agriculture. The Clean Water Act calls for the development of Total Maximum Daily Loads (TMDL) for those constituents that exceed the standards so that these standards can be achieved. These loads are allocated to each source of these constituents. Programs are then implemented to achieve the needed load reductions. The presentation for this paper will discuss the areas where agriculture may be affected by the TMDL process and the role that agriculture should play as this program develops.

Effects of the State and Federal Endangered Species Act and the State's Public Trust Doctrine

The State Supreme Court established the California Public Trust Doctrine in 1983. The SWRCB used this responsibility in 1994 to issue a water right decision (SWRCB Decision 1631) to the Department of Los Angeles Water and Power to improve conditions in the Mono Lake basin for fish in the streams and wildlife in and around Mono Lake. This decision reduced the water yield from the Mono Basin by about half.

Implementation of the state and federal Endangered Species Acts over the last 10 years have affected water availability for out-of-stream uses including agriculture. Agriculture in the Central Valley has been particularly affected. In addition, implementation of the Central Valley Project Improvement Act (CVPIA) specifically those under "B2" along with recent proposals to allocate additional flows to the Trinity River system will affect the availability of water many to users in the Central Valley.

This trend to greater environmental protection than was afforded by historic water projects is not a passing fad. It reflects a paradigm shift in cultural values. Water project operators have a duty to protect not only the interest of their water supply and power customers, but to be stewards of the natural resources they have developed. In the past, society paid little attention to fish and wildlife values. We had plenty of natural resources and a few less fish made little difference. However, we have witnessed unprecedented reductions in these natural resources. Some of these reductions are likely caused by water projects. To the extent that water development is implicated in the reduction of fish and wildlife species, water development needs to be involved in the recovery of these resources. There have been success stories. Waterfowl along the Pacific Flyway is the most dramatic. Also federal, state, and local resources are being brought to bare in the Central Valley to provide better protection to fish through improved fish screens, removal of barriers to fish passage, shallow water habitat in the Sacramento/San Joaquin River Delta and higher flows in critical spawning reaches upstream. The presentation of this paper will outline these areas of success and encourage continued stewardship by agricultural interests of not only the lands that are farmed but the waters that we all depend upon.

FQPA, THE TIP OF THE ICEBERG

An Overview of Federal and State Pesticide Regulatory Initiatives Affecting Production Agriculture in California

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It has long been recognized that regulatory initiatives administered by the Department of Pesticide Regulation (DPR), such as The Birth Defects Prevention Act of 1984 (SB 950) and The Toxic Air Contaminant Act of 1983 (AB 1807), have the potential to alter the way farmers manage pests. These programs may eliminate preferred pesticide products or significantly modify uses. Recently, the implementation of the federal Food Quality Protection Act (FQPA) has gained the attention of production agriculture as well with the prospect of the wholesale loss of many uses of organophosphate insecticides. Initiatives of state and local agencies, such as the implementation of the Total Maximum Daily Load (TMDL) program for surface water (administered by the State and Regional Water Quality Control Boards), may also significantly impact crop protection strategies.

Today, environmental and public health regulations are tougher and far more complex than in the past, and efforts are underway to ensure more stringent enforcement of the environmental mandates established in the 1970s and '80s. In addition, there is renewed federal interest in pesticide worker safety, initiatives on children's health protection, and issues of environmental equity. It is clear that governmental scrutiny of pesticide usage is not going to subside in the near future.

The following is an overview of some of the things the modern pest manager has to worry about (besides managing the pests):

- Risk Assessment- SB 950 (The Birth Defects Prevention Act)- DPR will be completing the risk characterizations on most of the "priority chemicals" within the next 2 or 3 years, as many as 30 active ingredients by the end of this year. Mitigation measures, such as extended re-entry intervals and additional protective equipment, will be required for many uses, and some uses may be lost entirely.
- Air Quality --AB 1807 (The Toxic Air Contaminants Act)- As with SB 950, DPR has committed to expedite the process by which pesticides are designated as Toxic Air Contaminants (TACs). No one knows whether there will be a need to further restrict the uses of pesticide TACs, but the State Air Resources Board and local Air Pollution Control Districts will be involved in the decisions.
- Groundwater Safety. The Pesticide Contamination Prevention Act (PCPA)- New groundwater regulations, which will change the way this law is implemented, are well along at DPR.
- Water Quality. Total Maximum Daily Loads (TMDL)- This provision of the federal Clean Water Act is being applied to non-point sources, such as pesticide applications.

TMDLs involve setting limits for how much, if any, pesticide residue can be allowed in streams, rivers, and lakes and designing programs to achieve these limits. Responsibility for this program is vested in the State and Regional Water Quality Control Boards by the USEPA.

- Prop 65- The use of EPA's Toxic Release Inventory as an "authoritative body" for the nearly, automatic listing of pesticides as "known to the state" to cause cancer or reproductive toxicity could threaten many uses that would normally be considered within a reasonable margin of safety by DPR toxicologists.
- Federal Initiatives. The Food Quality Protection Act & federal Registration Eligibility Documents (REDs)- There has been a lot of focus lately on the FQPA and the loss of pesticide uses that don't fit into the "risk cup." Less notorious but equally as important is the RED program. Like DPR's risk characterization documents, REDs may require mitigation measures that eliminate uses or render them impractical.

Growers face significant challenges in dealing with this mountain of regulatory activity, not the least of which is that the regulatory programs themselves, while aggregate in effect, are not coordinated in implementation. Pesticides that provide alternatives to uses lost under the FQPA, may be disallowed or made unusable under other programs such as the Clean Water Act, SB 950, Proposition 65, etc. Unfortunately, the only place it all comes together is at the field, where growers must figure out how to do more with less (and avoid creating resistant pests at the same time).

Perhaps the biggest challenge commodity groups must face is being in the right place, with the right information, at the right time. The task of staying engaged in the political and administrative process becomes more difficult when the actions of several different federal and state agencies are involved. Producers must have a working knowledge of the regulations and the regulatory programs, a good regulatory tracking system, a well-developed profile of their pest management systems (the pesticides used, how they are used, registered or potentially registerable alternatives), and the scientific and technical resources to support their positions. Recent actions by USEPA, with regard to methyl parathion and azinphos methyl, demonstrate the importance of paying close attention to, and having input into, negotiations on product uses.

Assessment of Salinity in Irrigated Agricultural Soils

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Introduction

Irrigated agriculture makes an essential contribution to the food needs of the world. While only 15% of the world's farmland is irrigated, roughly 35-40% of the total supply of food and fiber comes from irrigated agriculture (Rhoades and Loveday, 1990). However, vast areas of irrigated land are threatened by salinization. Although accurate world-wide data are not available, FAO has estimated that roughly half of all existing irrigation systems (totaling about 250 million ha) are affected by salinity and waterlogging, and that nearly 10 million ha of irrigated land is abandoned annually (Rhoades and Loveday, 1990).

The predominant mechanism causing the accumulation of salts in irrigated agricultural soils is evapotranspiration. The salt contained in the irrigation water is left behind in the soil as the pure water passes back to the atmosphere through the processes of evaporation and plant transpiration. The effects of salinity are manifested in loss of stand, reduced rates of plant growth, reduced yields, and in severe cases, total crop failure (Rhoades and Loveday, 1990). Salinity limits water uptake by plants by reducing the osmotic potential and thus the total soil water potential and/or may cause specific ion toxicity or upset the nutritional balance (Rhoades and Loveday, 1990). In addition, the salt composition of the soil water influences the composition of cations on the exchange complex of soil, which influences soil permeability and tilth depending upon the salinity level and exchangeable cation composition.

Salinity within irrigated soils clearly limits productivity in vast areas of the USA and other parts of the world, and it is generally accepted that the extent of salt-affected soil is increasing. In spite of the fact that salinity buildup on irrigated lands is responsible for the declining resource base for agriculture, this country does not know the exact extent to which our soils are salinized, the degree to which productivity is being reduced by salinity, the increasing or decreasing trend in soil salinity development, and the location of contributory sources of salt loading to ground and drainage waters. Suitable soil inventories do not exist, and until recently neither did practical techniques to monitor salinity or to assess the impacts of changes in management upon soil salinity and salt loading. A means of assessing soil salinity across the landscape is an essential tool in the management of soil salinity.

Assessment encompasses both real-time measurement and model prognostication. Real-time measurements of soil salinity are essential to establish an inventory of salt-affected soils. This is needed to understand the scope of the salinity problem. Aside from identifying where areas of salinity development are occurring, there is a need for a practical, management-oriented model for simulating the movement and spatial distribution of salinity and salt-loading at field scales and larger.

It is the object of this paper to describe the practical technology and methodology for the real-time measurement and prediction of areal distributions of soil salinity and salt-loading to drainage and ground waters. Basic principles of soil electrical conductivity, recent technological advances in salinity measurement equipment, and advanced information methods and technologies used in predicting the spatial distribution of non-point source (NPS) pollution, such as salinity, are presented.

Results

Real-Time Measurement of Soil Salinity

<u>*Principles and Methods of Soil Electrical Conductivity Measurement*</u>

Electrical conduction in sufficiently moist soils is primarily via salts contained in the soil water occupying the larger pores; consequently, the measurement of electrical conductivity of bulk soil is closely related to soil salinity (Rhoades et al., 1999). However, there is also a contribution of the solid phase to electrical conduction in moist soils that is primarily via the exchangeable cations associated with the clay minerals (Rhoades et al., 1999). A third pathway exists through soil particles that are in direct and continuous contact with one another (Rhoades et al., 1999). These three pathways of current flow constitute the bulk electrical conductivity (EC_a) of a soil. Very simply, the EC_a is a function of the soil physical and chemical properties of soil salinity, water content, bulk density and texture.

Four major methods are available for determining salinity in soil: (1) visual crop observations, (2) collection of soil samples or soil solution extracts and the measurement of the EC_e (EC of the saturation paste) and the EC, respectively, (3) electrical resistivity techniques, particularly the Wenner array, and (4) geophysical techniques, particularly electromagnetic induction (EM) (Hendrickx et al., 1992). The Wenner array and EM measure EC_a. EC_e is actually the measure of salinity that has been used in all salt tolerance studies.

The first method, visual crop observation, is quick and economical, but it has the disadvantage that salinity development is detected after crop damage has occurred. The second method gives reliable quantitative data, but requires considerable resources for field sampling and laboratory analysis, plus the volume of measurement of soil is very small and ill-suited to characterize the extreme variability of salinity at field scales and larger. The final two methods, Wenner array and EM, are both well suited for field applications because their volumes of measurement are large, which reduces the influence of local scale variability. However, the Wenner array is an invasive technique that requires good contact between the soil and four electrodes inserted into the soil; consequently, the Wenner array produces less reliable measurements in dry soil than the non-invasive EM measurement. The EM has become the first choice for measuring soil salinity in a geo-spatial context because (1) measurements can be taken as quickly as one can move from one location to the next, (2) the large volume of measurement of soil reduces the local-scale variability, and (3) measurements in relatively dry or stony soils are possible because no contact is necessary between the soil and the EM sensor (Hendrickx et al., 1992). Nevertheless, the Wenner array has a flexibility that has proven advantageous for field application, which is that the volume of measurement can be changed by changing the distance between the electrodes.

Equipment for Real-Time Measurement of Soil Electrical Conductivity in a Geo-spatial Context

For the aforementioned reasons, the electrical resistivity technique of the Wenner array and the electromagnetic induction technique have been used to measure bulk soil electrical conductivity (EC_a).

Electrical resistivity. Based on the geophysical fixed-array electrical resistivity technique of the Wenner array, bulk soil electrical conductivity can be measured using four electrodes inserted into the soil. The depth of penetration of the electrical current and the volume of measurement depend upon the spacing between the current electrodes. The larger the spacing the deeper the measurement and the larger the volume of measurement. A mobilized, tractor-mounted version of the Wenner array has been developed that geo-references the EC_a measurement with a GPS (Rhoades, 1993). This equipment is well suited for collecting detailed information about the variability of average rootzone soil electrical conductivity within fields.

Electromagnetic induction. Soil electrical conductivity can be measured remotely with electromagnetic induction. An EM transmitter coil located in one end of the instrument induces circular eddy-current loops in the soil. The magnitude of these loops is directly proportional to the electrical conductivity of the soil in the vicinity of that loop. Each current loop generates a secondary electromagnetic field that is proportional to the value of the current flowing within the loop. A fraction of the secondary induced electromagnetic field from each loop is intercepted by the receiver coil of the instrument and the sum of these signals is amplified and formed into an output voltage which is linearly related to depth-weighted soil electrical conductivity, EC_a^*.

Mobile EM equipment (Rhoades, 1993) is available for the appraisal of soil salinity and other soil properties (e.g., water content and clay content). The coil configuration, frequency and intercoil spacing permit measurement of EC_a^* to effective depths of approximately 1 and 2 meters when placed at ground level in horizontal and vertical configurations, respectively. The mobile EM equipment is suited for the detailed mapping of EC_a* and correlated soil properties at specified depth intervals through the rootzone.

Calibration of EC_a and EC_a to EC_e*

Soil salinity, as conventionally expressed in terms of the electrical conductivity of the saturated-paste extract, EC_e, can be inferred from EC_a by two approaches: a deterministic and a stochastic approach (Rhoades et al., 1999). The preferred approach will vary with the size of the area to be assessed, availability of equipment, and the specific objectives. The deterministic approach is based on the direct application of an equation developed by Rhoades et al. (1989). The deterministic approach is the preferred approach to use when significant, localized variations in soil type exist in the field.

When measurements of EC_a^* are made using the mobile EM equipment, it is not possible to simultaneously estimate or measure the secondary soil properties that are required to use the deterministic-approach equation. Hence, a stochastic approach has been developed for use with the mobilized equipment. Statistically based calibration equations are established between the EC_a^* data and soil salinity (or other correlated properties of interest) for each field of interest using either spatial regression models or geostatistical models (such as co-kriging). This calibration is developed by acquiring soil salinity data (or other soil property data, such as sodicity, boron, saturation percentage, organic matter content, texture, depth, etc.) from a small percentage of the sensor measurement sites, and estimating an appropriate stochastic-prediction model for each depth increment using the paired sample and measurement data. Then, using the remaining sensor data in conjunction with the established model, the soil salinity levels (or other similarly calibrated properties) are predicted at all of the remaining non-sampled, measurement locations. The stochastic-calibration approach is described in detail by *Lesch et al.* [1995a, 1995b].

Modeling Soil Salinity in a Geo-Spatial Context

Soil and ground water quality affected by salinity depends on the spatially distributed properties that influence salt transport. The phenomenon of salt transport through the vadose zone (i.e., the zone extending from the soil surface to the ground water table) is affected by the temporal variation in irrigation water quality, and the spatial variability of plant water uptake and of chemical and physical properties of soil. Coupling a geographic information system (GIS) to a salt transport model potentially offers a means of dealing with the complex spatial heterogeneity of soils which influence the intricate biological, chemical and physical processes of transient-state salt transport in the vadose zone (Corwin, 1996).

Modeling the movement and accumulation of salinity is a spatial problem well suited for the integration of a salt transport model with GIS (Corwin, 1996). GIS serves as a spatial database to organize, manipulate and display the complex spatial data used by a deterministic model to describe the regional-scale distribution of soil salinity and salt loading to groundwater. The coupling of the spatial data handling capabilities of a geographic information system (GIS) with a one-dimensional salt transport model offers the advantage of utilizing the full information content of the spatially distributed data to analyze solute movement on a field scale in three dimensions (Corwin, 1996). As a visualization and analysis tool, GIS is capable of manipulating both spatially-referenced input and output parameters of the model.

The basic components of a NPS pollutant model (NPS pollutants are pollutants, such as salinity and pesticides, which are spread over a wide area, as opposed to point source pollutants, which are located at a specific site or point, such as a toxic spill) are: model, GIS, and data (Corwin et al., 1997). These components are dependent upon the advanced information technologies of a global positioning system (GPS), a geographic information system (GIS), geostatistics, remote sensing, solute transport modeling, neural networks, transfer functions, fuzzy logic, hierarchical theory, and uncertainty analysis (Corwin et al., 1999a).

An overview is presented of previously published work by Corwin and his colleagues (Corwin et al.,1995, 1996, 1999b) concerning the application of GIS-based models of salinity development and transport in the vadose zone. Two different GIS-based approaches are described for the prediction of the areal distribution of salinity at a basin scale. The first approach couples a regression model of salinity development to a GIS of soil salinity development factors (i.e., permeability, leaching fraction, and groundwater electrical conductivity) for the Wellton-Mohawk Irrigation District near Yuma, Arizona, over the study period 1968-1973. The regression model predicts the composite salinity of the root zone (i.e., top 60 cm.). Areas of low, medium, and high salinization potential are delineated for the entire 44,000 hectare irrigation district. Measured salinity data verified that 86% of the predicted salinity categories were accurately predicted. The second approach "loosely coupled" the one-dimensional, transient-state solute transport model, TETrans, to the geographic information system ARC/INFO. Slightly less than 2400 hectares of the Broadview Water District located on the west side of central California's San Joaquin Valley were used as the test site to evaluate the integrated GIS/transport model over the study period 1991-1996 (Corwin et al., 1999b). TETrans uses the GIS as a spatial database from which to draw its input data. Simulations are presented over a five-year period, 1991-1996. Display maps show spatial distributions of soil salinity profiles to a depth of 1.2 m, irrigation efficiencies, drainage amounts, and salt loading to groundwater over the 2396 hectare study area. These maps provide a visual tool for making irrigation management decisions to minimize the environmental impact of salinity on soil and groundwater. The first approach is best suited for areas where steady-state conditions are approximated, while the second approach can be used under transient-state conditions.

Summary

As the world's population continues to grow, mankind is faced with the onerous task of meeting the world's food demand. This can only be accomplished with sustainable agriculture. Sustainable agriculture requires a delicate balance between crop production, natural resource use, environmental impacts, and economics. The goal of sustainable agriculture is to optimize food production while maintaining economic stability, minimizing the use of natural resources, and minimizing impacts upon the environment.

Assessing the impact of salinity at regional and localized scales is a key component to achieving sustainable agriculture. Assessment involves the determination of change of salinity over time, which can be measured in real time or predicted with a model. Real-time measurements reflect the activities of the past, whereas model predictions are glimpses into the future based upon a simplified set of assumptions. Both means of assessment are valuable; however, the advantage of prediction is that it can be used to alter the occurrence of detrimental conditions before they develop. Predictive models provide the ability to get answers to what if questions. Forecasting information from model simulations is used in decision-making strategies designed to sustain agriculture. This information permits an alteration in the management strategy prior to the development of levels of soil salinity that detrimentally impact either the agricultural productivity of the soil or the quality of the ground water.

The ability to locate the sources of soil salinity within irrigated landscapes and to model the migration of salt through the vadose zone to obtain an estimate of salt-loading to drainage and ground waters is an essential tool in combating the degradation of our soil and water resources. This information is valuable for selecting alternate crops or alternate irrigation management practices to maintain crop productivity while minimizing the environmental impacts of salinity.

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Field-scale soil electrical conductivity characteristics and sugarbeet emergence, growth and yield.[1]

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1. Introduction.

Precision agriculture has many synonymous terms, including variable rate technology, prescription farming, soil-based farming, and site specific management. All of these terms refer to managing spatial and temporal variability within a field to improve crop management, particularly the use of crop inputs like fertilizers or other soil amendments (Pierce and Nowak, 1999). The attempt to manage diversity at the field-scale is based on the use new information technologies and data analysis techniques like systematic soil sampling and trend analysis (kriging), yield monitoring, and remote sensing to improve crop management decisions (NRC, 1997). A large amount of interest in these technologies exists as well as many questions about its uses. How accurate is the measurement of the soil or crop property involved and how precisely can additional values be interpolated from those measurements? Is there sufficient variation present to be of use in management? If variable rate technology is used, how accurately can it be applied? Lastly, if sufficient knowledge is available and precision is achievable, what practical, economic use in farm management is all this data ((Pierce and Nowak, 1999; Bullock, et al., 1998; Lowenberg-DeBoer and Boehlje, 1996)?

Most of the work on precision agriculture that has been carried out to date has been done in the mid-western states, particularly on corn, soybean, and sugarbeet fields. Some of the most successful applications of precision agriculture reported so far from the upper Midwest may involve sugarbeet production. Remotely sensed crop images of preceding wheat crops were used successfully to reduce variation in sugarbeet yields following the wheat. Different areas in the field with varying residual N fertility were identified and subsequently sampled (to six feet in depth). Soil test N levels were used to variably apply fertilizer N to the following beet crop (Reitmeir et al., 1999; Cattanach, et al., 1996). Sugar yields were made more uniform and higher on average than in neighboring fields using whole field management. The success of these approaches to sugarbeet fertility management was based on the existence of different levels of productivity within a field that could be managed using a traditional input (N fertilizer). The basis of crop response to the field's variability was understood. In this case, sugar concentrations were reduced in areas of the field with large amounts of residual nitrogen. And this variability could be

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reduced by applying well understood principles of sugarbeet crop response to soil and fertilizer N (Hills and Ulrich, 1977). In other words, the variation had an interpretable structure (Gotway et al., 1997) and was responsive to traditional management practices.

The use of precision agriculture in California is more recent than in the Midwestern United States. There are several important differences between the irrigated agriculture practiced here in a Mediterranean region, and the rain-fed, temperate agriculture of the Midwest. Most importantly, almost all crop production is based on irrigation in California, so water is provided more or less in a timely and sufficient manner to crops and the severe effects of periodic drought are eliminated. Huggins and Alderfer (1995) reported that 67% of the variation in yield across year and sites in a long-term trial in the Midwest was due to temporal variation, compared to 10% to 15% due to spatial variation within the field. In California, because of irrigation, a larger percentage of variation is likely to be due to spatial variation, and the absolute amount of variation within a field that is manageable using precision agriculture techniques may be less. Instead of drought, moisture-related yield effects will be due to non-uniformity, which is a combination of irrigation technology and soil properties, including texture and drainage. Erosion is less of a concern because most irrigated fields are leveled. Other important differences include a far-wider range of crops produced in California than in the Midwest, and in parts of the state, salinity is a problem.

Yield variation has not been well-characterized in California. Since perennial crops increasingly are planted on better, more uniform soils, the most responsive locations to site specific management likely will be those with the largest amount of variation, where lower valued field crops are produced. In general, crop responses under these conditions are less understood than on better soils, and can be erratic in response to management inputs. Precision management techniques might be of use, but their successful adoption is dependent on poorly characterized crop response. An assessment of field-scale variation and the characterization of correlated crop response to this variation are first steps in evaluating the potential for variable rate technologies and other aspects of precision agriculture. As an initial attempt at site characterization, the response of sugarbeets to salinity and residual nitrogen was studied at sites in the Imperial and San Joaquin Valleys. Evaluation of the usefulness of the salinity assessment technology developed by Rhoades and fellow workers at the U.S. Salinity Lab (Rhaodes et al., 1997) for precision agricultural management and the possible correlation of salinity and nitrate, especially deeper in the soil profile, were the objectives of this study.

2. Materials and methods

Two farm fields were identified in regions of California which have saline soils and were planted to sugarbeets. One was in the Imperial Valley (IV) near Brawley, the other was in Kings County (KC) near Stratford. The soils at the IV site were an Imperial-Glenbar silty clay loam and Imperial clay loam. This site was underlain with a series of tile drain lines at approximately 2m (6 feet) in depth. This 83 acre site was furrow irrigated. The Kings County site was located along the western edge of the old Tulare Lake bed and was underlain with tile drains at 1.1 m. The soils were Westcamp loam (fine-silty, mixed (calcareous), thermic Aeric Fluvequent) and Houser clay (fine, montmorillonitic (calcareous), thermic Vertic Fluvequent). Some Pitco clay loam soil is present along one corner of the field. This 143 acre site was sprinkler irrigated. It lies in a region with some of the most saline and sodic soils used for crop production in California. Details about planting, harvest, and crop management are summarized in Table 1.

At both sites, bulk soil electrical conductivity (EC_a) was mapped directly in the field prior to planting using techniques and equipment developed at the U.S. Salinity Lab by Rhoades and his colleagues (Rhoades, et al., 1997). Both surface variation and salinity distribution within most of the root zone can be estimated using their electromagnetic induction methods. Soil samples for calibration were collected at each site. At IV, 16 samples were taken to a depth of 6 feet, and composited at each site into four equal depths (18 inches). At the KC site, 19 soil samples were taken to a depth of 4 or 5 feet at one foot intervals. The sites for sub-sampling were chosen using a multiple linear regression algorithm developed by Lesch et al., (1995a). Soil samples were analyzed for EC_e, SAR, saturation percentage (SP)--a measure of soil clay content, NO_3-N, bulk density, and Se and B using standard procedures.

At the IV site, seedling emergence was followed at 6 of the sub-sample sites, selected to represent a range of soil EC_e values. There were two counts made over a period of two weeks following the initial irrigation. Four hundred seed positions were counted at each site. Seeding rates were known and uniform planter performance was assumed. Composite soil samples from each site from the surface 2 inches were collected at the first count 10 days after irrigation to determine electrical conductivity (EC_e) in the seed zone at the time of maximum emergence. During the growing season, leaf petiole samples were collected periodically at both sites from sub-sample locations, and analyzed for NO_3-N. A harvest master yield monitor fit with a GPS collected yield data at harvest in both locations. Just prior to field harvest, small plots were harvested at each of the sub-sample locations in both fields for plant population, yield, and root quality analyses (sucrose and impurities).

At the KC site, high resolution, multi-spectral remote sensing imagery was acquired on five dates during the growing season (3/29/99, 6/1/99, 6/30/99, 7/28/99, and 8/13/99), using the SAMRSS digital airborne imaging system developed by the USDA-ARS at Shafter, California (Maas et al., 1999).

Soil bulk electrical conductivity and correlated data were analyzed using ESAP v2.0 software developed by Lesch (1995b) for the U.S. Salinity Lab, crop data were analyzed using SAS, Inc. and aerial images using ENVI software from Research Images, Inc. The majority of this report focuses on analyses of data collected in the subplots in each field.

3. Results

3.1 Field soil characteristics:

Salinity. Average profile salinity (EC_a) varied significantly in both fields (Fig. 1a, 2a). At the IV site, EC_a varied from 2.1 dS m^{-1} to 9 dS m^{-1}. In a large portion of the field, salinity increased with depth and was correlated with irrigation patterns, (increasing from the furrow head end of the field (east) towards the furrow tail end). Salinity also increased with depth. An increase with depth suggests that leaching is occurring. A second cause of variation in salinity was associated with average profile SP, particularly in the deepest two profile layers sampled. The lower the SP, the lower the EC_e value. In general, the subsurface SP values are reflected by lower bulk average conductivity values (EC_a). Lower SP areas near the tail end of the field had higher EC_a values than those near the head end, an irrigation related effect. EC_a and SP values corresponded approximately to soil map units from the NRCS survey.

At the KC site, EC_a varied from 3.1 to 24 dS m^{-1}. These soils are marginal for crop production for all but the most salt-tolerant crops. Sugarbeets are salt tolerant, but yield declines are expected above approximately 6 dS m^{-1} levels (Maas, 1990). EC_e values were lower in general in the first foot, otherwise the soil profile tended to be uniformly saline with depth. This suggests that leaching is not occurring or that perched, saline water is a problem. Lower SP values were observed in the southeast portion of the field, but no correlation between EC_a and SP was apparent (Table 2).

Correlated soil characteristics. The most important correlated soil variable among those analyzed was NO_3-N. At the IV site, NO_3-N was weakly correlated with SP and EC_e (expressed as natural logs, Lesch et al., 1995b), (Table 2). The correlation was greatest deepest in the profile (not shown). Soil surface NO_3-N was extremely variable. For the most part, values in the field were low (from 3 to 14 ppm NO_3-N).

In contrast, at the KC site, NO_3-N and EC_e where more strongly correlated in the profile, except in the top foot of soil (Table 2). Bulk average NO_3-N values ranged from 20 to160 ppm in the surface four to five feet of soil. It is unclear why such large amounts of N were present. SP was not correlated to ECe or NO_3-N (Table 2).

3.2 Crop performance:

Seedling emergence at the IV site. The number of sugarbeet seedlings emerging at the IV site was strongly correlated to the values from soil samples collected at the first counting date, following initial irrigation (Fig. 3). The emergence of seedlings was also correlated with EC_a values estimated using the EM38 array of Rhoades et al. (1997), suggesting that emergence rates could be reasonably predicted from field EC_a maps at this site (Fig. 3).

Root yields and soil properties (IV). At the IV site, sugarbeet root yields and sucrose content on average were very good for the May harvest date (Table 3). Root fresh weight and gross sugar yields overall were not correlated with increasing salinity based on hand yield samples, but sugar percentage was (Table 4, Fig. 4). The plot yield map suggests some negative correlation between EC and root yield, however (fig. 1b). Gross sugar yields did not decline, however, because root sugar concentration (%) increased with increasing salinity (Table 4). This is likely due to increasing dry matter concentrations in roots. Leaf petiole NO_3 was initially higher in subplots with larger residual soil NO_3 levels, and remained higher for the early part of the season, but all plots declined below the critical 1,000 ppm threshold by harvest (fig. 4). This demonstrates that throughout the field, residual NO_3 was not sufficient to reduce sucrose percent.

Root yields and soil properties (KC). At the KC site, results were different. The range in yields was much larger than in the IV, from approximately 7 t ac^{-1} to greater than 40 t ac^{-1}, average root and sugar yields were much lower, while sucrose content was comparable (Table 3). Root and sugar yields were correlated with EC_a and soil NO_3, but the most significant correlation was with SP (Table 4). Despite tile drainage being present, soil salinity and texture appear to restrict root growth significantly in most of this field. Also, despite extremely large amounts of nitrate in the soil, sugar concentrations in roots were higher than expected. SP was negatively correlated with soil NO_3 (Table 4) suggesting that N was lost from saturated portions of the field. Anoxic soil conditions can cause de-nitrification, and this process may have been important. The presence of ammonia-N can interfere with nitrate uptake by roots under anaerobic conditions, and chloride and other ions can compete with nitrate uptake and induce nitrate efflux from roots

(Aslam, et al, 1984).

Plant population. Because stands were over-planted and then thinned, there was no correlation between plant population and salinity at the IV site. At the KC site, stands were not thinned. If salinity affected emergence and survival, then plant populations should be correlated with salinity, but there was no apparent tendency for root number to decline with increasing salinity levels.

3.3 Remote Sensing.

Different wave lengths from the remotely sensed images were analyzed and the Near Infra-Red band was found to correspond most closely to sugarbeet root yield (Fitzgerald et al., 1999). But data had first to be aggregated into three natural groupings using an unsupervised classification routine in the ENVI software package. Doing so allowed for a good correlation between reflectance data, crop yield, and salinity, so crop canopy characteristics were a good indicator of agronomic performance (Remote sensing images can be seen at: http://pwa.ars.usda.gov./uscrs/prj.htm). Yield monitor maps also correspond with salinity maps at both sites (Fig. 1 and 2). Further analysis of the larger scale data sets remains to be done.

4. Discussion

The detection of manageable variation. Imperial Valley (IV). Bulk soil electrical conductivity values were accurately mapped using the techniques of Rhoades et al (1997). The close correlation between EC_a and EC_e has been observed repeatedly (Table 2). That makes this technique accurate and precise. It is also fast and relatively inexpensive. Is the variation observed correlated with crop performance and can this assessment technique provide useful information for precision agricultural management? EC_e varied over the range of 1 to 9 dS m^{-1} at the IV site. At the high end of this range, sugarbeet yield should be adversely affected (Maas, 1990). EC_e was correlated with field position, (salinity was higher at the tail end of the field) and there were differences in profile salinity with depth. Lower SP in the lower half of the profile was also correlated with lower salinity levels throughout the profile, except in locations at the tail end of the field, which received larger amounts of salts due to irrigation management. Nitrate was correlated with EC_e at depth, but differences in residual profile NO_3-N content were largely irrelevant by harvest, so profile residual NO_3-N differences did not adversely affect sugar content in roots. So variable rate N application was unlikely to have been useful.

Average yields were much larger at the IV site and the variation in yield was much less than at the KC site (Table 3). Even at the higher EC_e levels, the combination of crop tolerance and management resulted in relatively uniform yields (Fig. 1). Sixty percent of the field had yields at or above the field average. Based on the yield map, the lowest yielding portions of the field were the most salt-affected areas towards the tail end of the field. But higher sugar concentration in theses areas reduced the importance of root yield differences. Growers are paid on a gross sugar basis. Gypsum application at variable rates only in the most saline areas might improve infiltration and drainage enough to affect yields. Variable rate application can be guided by maps derived using the assessment technology of Rhoades et al. (1997) and is worth investigating. But increases in yield would have to more than offset any reduction in gross sugar content that might occur. If there were no reduction in gross sugar content, then variable rate application might be profitable.

Despite emergence differences, adequate stands were achieved throughout the field by over-planting seed and then hand thinning, the current management strategy. Since plant stands were adequate, it is not clear that variable rate technology is needed. Emergence rates also might be improved through the use of gypsum. Corresponding planting rates might be adjusted if variable rate seeding equipment were available, but adequate performance and profitability are possible currently.

(Kings County). The range of variation in EC_e at the KC site was much larger (from 3 to greater than 24 dS m^{-1}). Beets tolerated the high ECe levels found in portions of this field because the use of sprinkler irrigation throughout the season likely maintained tolerable levels of salinity in at least the first two to three feet of the profile. Nonetheless, the performance of sugarbeets under such highly saline conditions was unexpected and exceeds their reported salinity tolerance (Maas, 1990). Similarly, the effects of large amounts of soil NO_3N were minimized.

The management of difficult or marginal soils and crop response under such conditions is poorly understood. The correlations between root and sugar yield and SP were unexpected, but in retrospect can be understood by hypothesizing a relationship between soil drainage and chronic anoxic conditions in the root zone. Beets grew best where soils were had lower SP, and where soils were presumably were less anoxic. Root systems were able to develop. But even in the best parts of the field, root uptake of NO_3N apparently was restricted sufficiently to allow beets to accumulate reasonably high sugar concentrations..

Other factors also may have contributed to increased variability at the KC site compared to the IV site. The field in KC was twice as large as the one in IV. Increasing field size increases in turn the chance to include greater field variation. One alternative to the use of Variable Rate Technology would be to decrease field size, especially if an obvious discriminatory characteristic is available like soil type differences. However, the lack of a strong correlation between SP and EC_e at this site reduced the value of field scale salinity assessment as an aid to management.

Economic considerations. Lowenberg-DeBoer and Swinton (1997) reviewed a number of economic analyses of precision farming. These were largely of Midwestern origin. Most were partial or incomplete. Of the well conducted studies, most suggested that these techniques would not be profitable. In their own analysis of site-specific fertilization, the authors reported that the use of variable rate technology was unprofitable because of the large capital cost for equipment and the short amortization period assumed for its purchase (due to rapid technological obsolescence). They also suggested that larger scale farms and fields were more likely to be profitable than small-scale uses, because of economies of scale.

In our trials, greater variation was found at the larger KC field site, though this was only partly due to the size of the field. Variable rate fertilizer application would not have been useful there to overcome differences in residual NO3-N content if our hypothesis about SP is correct, but it may have been useful if soil amendments like gypsum were applied. Gypsum, at high enough rates, would have improved infiltration and drainage and may have affected sugarbeet growth. Additionally, emergence was poor in parts of the field, and soil amendments may have helped ensure better plant populations.

The greater variation at the KC site suggests that variable rate technology would have been more useful than at the IV site. The IV was the better yielding location, and the amount of gross sugar yield variation was much less. The expense of variable rate technology, however, may be less affordable at the site where it is most likely to have the greatest use because erratic or poorly understood crop response may not generate sufficient income to pay for its use.

Environmental considerations. Nitrate leaching from fertilized fields is a nationwide problem. It is difficult to sample sufficiently in many instances to allow for an accurate estimate of field variability, especially if nitrate is located deeper in the profile. For sugarbeets, nitrate deep in the soil profile can lead to reduced sugar concnetrations in roots (Kaffka et al., 1999). At both field locations, nitrate was correlated with salinity, particularly deeper in the profile and at higher EC_e levels. This means that where nitrate and salinity are correlated, higher salinity values can be used as a means of identifying likely locations in the profile to sample for residual NO3-N. The techniques of Rhoades et al (1997) have the advantage of being inexpensive, accurate, and precise, especially in comparison to attempts to describe NO3-N directly through grid sampling or random sampling. The use of electrical induction to evaluate variation in soil residual nitrate may make field scale assessment for this purpose far less expensive and much more practical and accurate than other ground-based attempts reported before, and allow for sufficient amounts of data to be collected to make precision agricultural practices profitable (Bullock et al., 1999; Lowenburg-DeBoer and Swinton, 1997).

The fastest way to collect large amounts of information about fields is aerially, either using an airplane or a satellite image. Aerial images correlated well with sugarbeet yield, yet the basis for crop yield variation could not easily have been inferred from the aerial image. Or if inferred, may have been attributed to the wrong factor, like N availability, rather than to soil drainage characteristics. For remotely sensed images to be of use, they must be interpretable in terms of management practices, and at least initially, supported with assessment of soil conditions.

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Table 1
Field management information

	Imperial Valley (IV)	Kings County (KC)
area (ac)	83	143
soil type(s)	Imperial-Glenbar silty clay loam and Imperial clay loam	Wellbank clay, Houser clay, (Pitco clay)
planting date	Sept. 19, 1998	Nov. 5, 1998
harvest date	May 22-23, 1999	Sept. 9-15, 1999
fertilization (lb N /ac)	200	100

Table 2
Soil property correlation matrix

IV	*ln (CECa)*	*ln (ECe)*	*SP*	*ln (NO3)*
ln (CECa)	1.000	0.979	0.903	0.507
ln (ECe)		1.000	0.802	0.451
SP			1.000	0.553
ln (SAR)				1.000

KC	*ln (CECa)*	*ln (ECe)*	*SP*	*ln (NO3)*
ln (CECa)	1.000	0.982	0.262	0.719
ln (ECe)		1.000	0.091	0.780
SP			1.000	-0.296
ln (NO3)				1.000

EC_a: bulk average electrical conductivity estimated from field survey data; EC_e: electrical conductivity, estimated from soil samples; SP: saturation percentage; NO3: nitrate. Correlations derived from the ESAP software (Lesch et al., 1995).

Table 3
Yields, sucrose percent, and ranges observed at each location

	Imperial Valley (IV)	Kings County (KC)
subplot mean yield (t/ac)	37.2	26.2
subplot range (t/ac)	31.2 to 44.4 (13.2)	7.0 to 41.4 (34.4)
subplot mean sucrose percent	17.8	16.7
subplot sucrose range (%)	16.4 to 19.1 (2.7)	15.0 to 18.7 (3.7)
subplot sugar yield (lb/ac)	13240	8670
subplot sucrose range (lb/ac)	11930 to 15820 (3690)	2580 to 12660 (10,080)
yield monitor mean (t/ac)	36.6	25.8
yield monitor range (t/ac) and acres harvested within that range	0 to 26 (3.0 ac) 26 to 32 (2.1 ac) 32 to 38 (13.9 ac) 38 to 44 (37.2 ac) 44 to 60 (14.2 ac)	1 to 12 (14.8 ac) 12 to 22 (32.6 ac) 22 to 30 (49.4 ac) 30 to 38 (39 ac) 38 to 50 (11.2 ac)

Table 4
Regression relationships: parameter estimates and p > |t| .

IV	Equation*	
Root yield (t/ac)	= 38.1 + 0.017 SP - 0.43 ECa + 0.083 NO3 (0.944) (0.479) (0.893)	(F=0.37, p=0.773)
Sugar yield (lb/ac)	= 11829 + 23.8 SP - 22.2 ECa - 6.04 NO3 (0.768) (0.914) (0.977)	(F=0.05, p=0.986)
Sugar %	= 15.82 + 0.017 SP + 0.193 ECa + 0.042 NO3 (0625) (0.046) (0.643)	(F=5.83, p=0.018)
SP	= 50.8 + 1.81 ECa + 0.747 NO3 (0.0029) (0.298)	(F= 13.25, p= 0.0007)
KC		
Root yield (t/ac)	= 87.23 - 0.69 SP + 0.72 ECa - 0.12 NO3 (<0.0001) (0.071) (0.025)	(F=13.32, p=0.0002)
Sugar yield (lb/ac)	= 26118 - 196.9 SP + 214.7 ECa - 36.5 NO3 (<0.0001) (0.109) (0.039)	(F=9.79, p=0.0008)
Sugar %	= 11.04 + 0.063 SP -0.039 ECa + .0008 NO3 (0.005) (0.547) (.331)	(F=3.89, p=0.031)
SP	= 103.7 + 1.2 ECa - 0.123 NO3 (0.342) (0.046)	(F=2.60, p=0.105)

*The F-test and probability of significance for the regression equation is given, and the probabilities of significance of each of the parameter estimates (x). EC_a (dS/m); NO_3 (ppm). D:\WORK\Site specific ag\tables.wpd

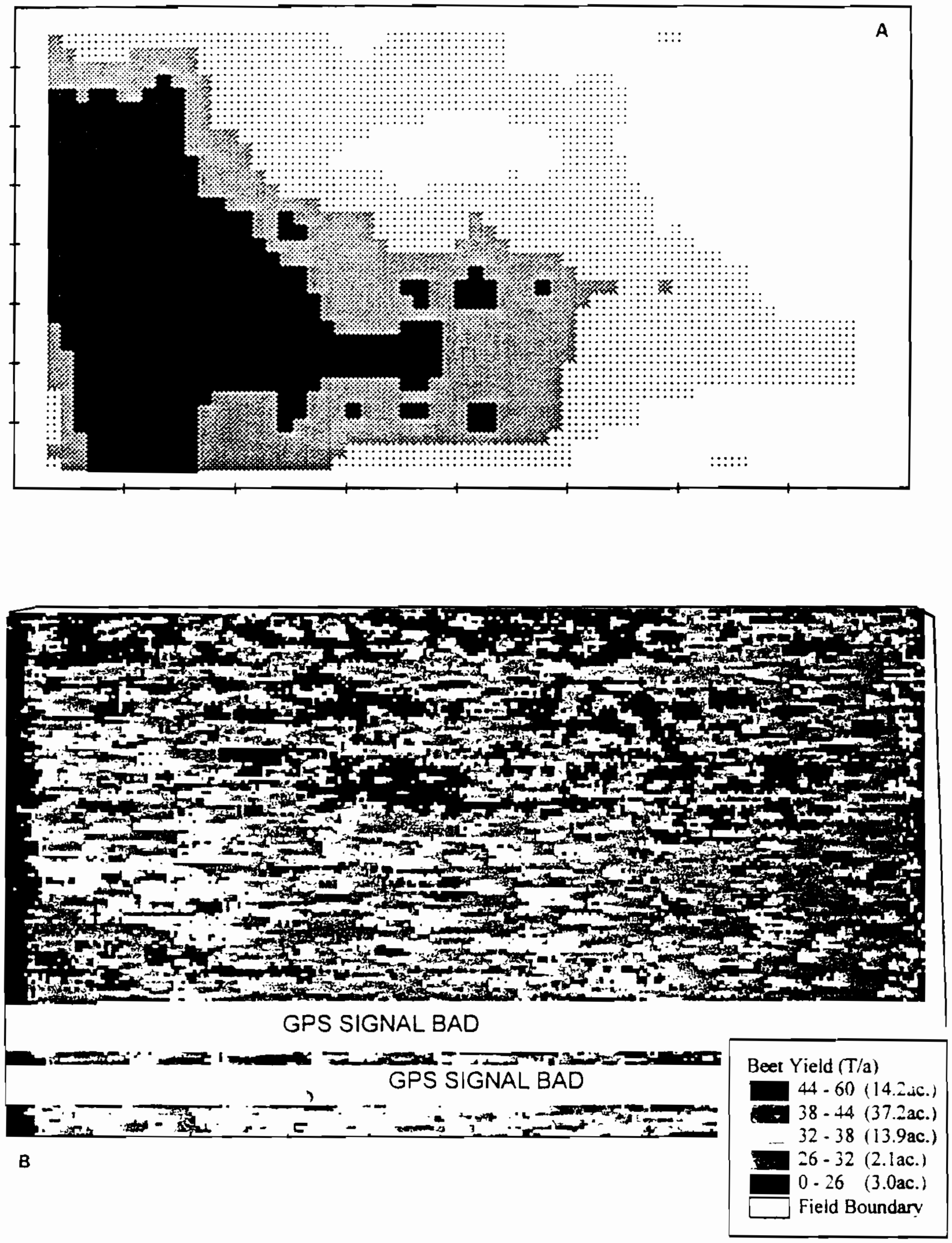

Figure 1A. (Imperial Valley). ECa (0 to 1.6 m) mapped using the techniques of Rhoades et al., 1997. The range is from 1 to approximately 9 dS/m. Darker colors are higher values. **2B**. Interpolated root yield map based on data collected with a Harvest Master monitor. Yields were lowest in the southwest end of the field. North is towards the top of the image. Map and equipment supplied by supplied by Precision Farming, Inc., Davis.

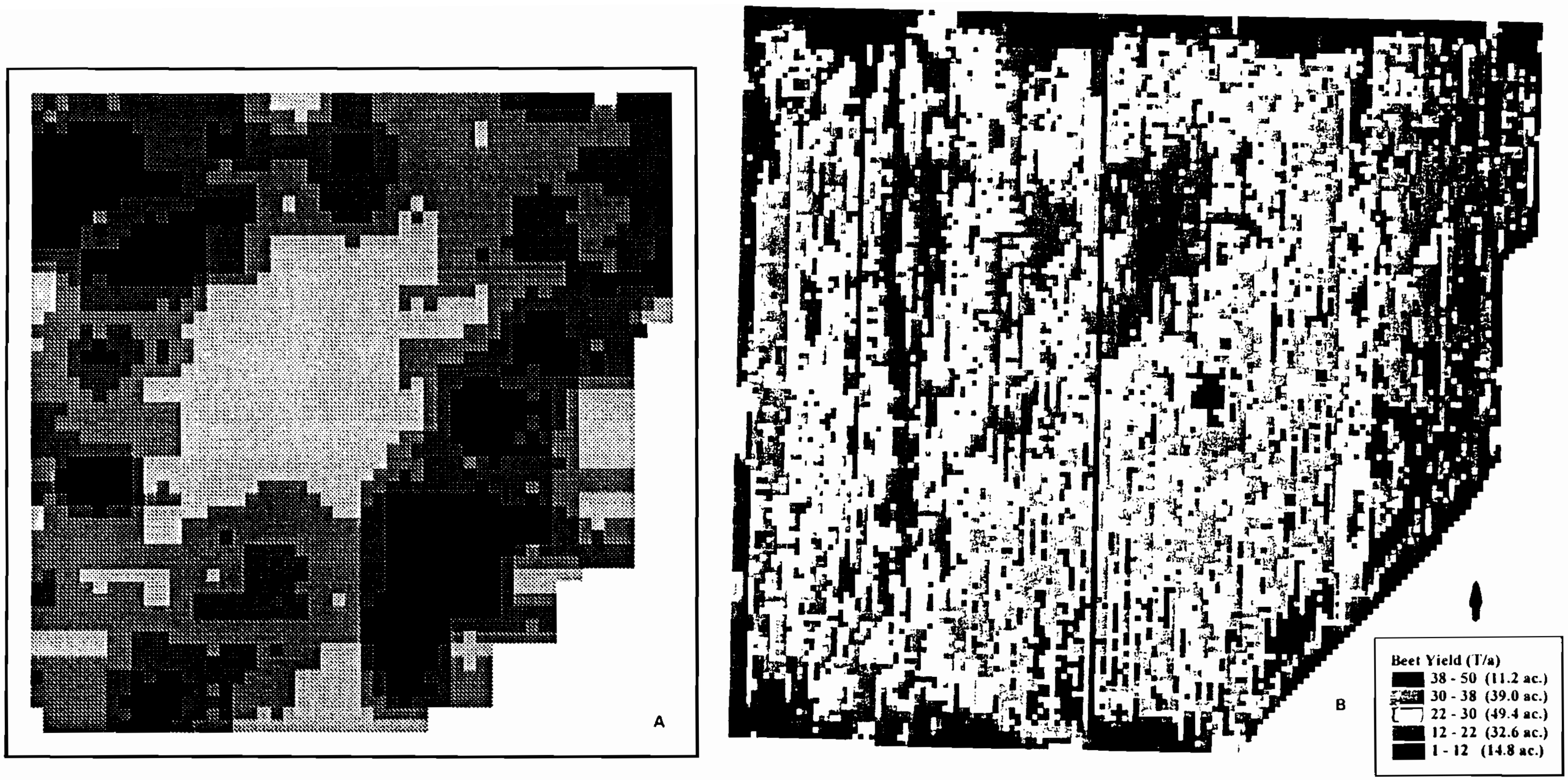

Figure 2.A. (Kings County). ECa (0 to 1.1 m) mapped using the techniques of Rhoades et al., (1997). The range is from 3 to approximately 24 dS/m. Darker colors are higher values. **2B.** Interpolated root yield map based on data collected with a Harvest Master monitor. Yields were lowest in the center of the field, and highest along the south and southeast edge. North is towards the top of the image. Map and equipment supplied by supplied by Precision Farming, Inc., Davis.

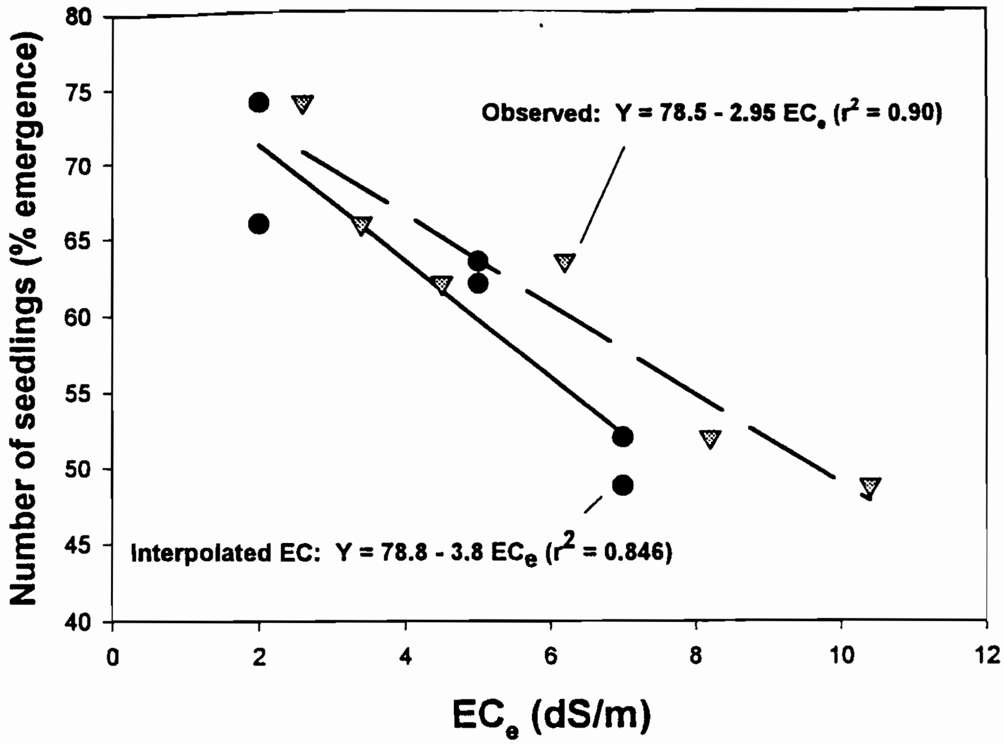

Figure 3. Percent of seeds resulting in seedlings. (Imperial Valley). "Observed" is the relationship between soil samples collected at the time of counting in the seed zone (0 to 2 inch depth). Predicted is the calibrated average ECe value (0 to 18 inches) at that site from the field survey data collected prior to irrigation using the methods of Rhoades et al., 1997.

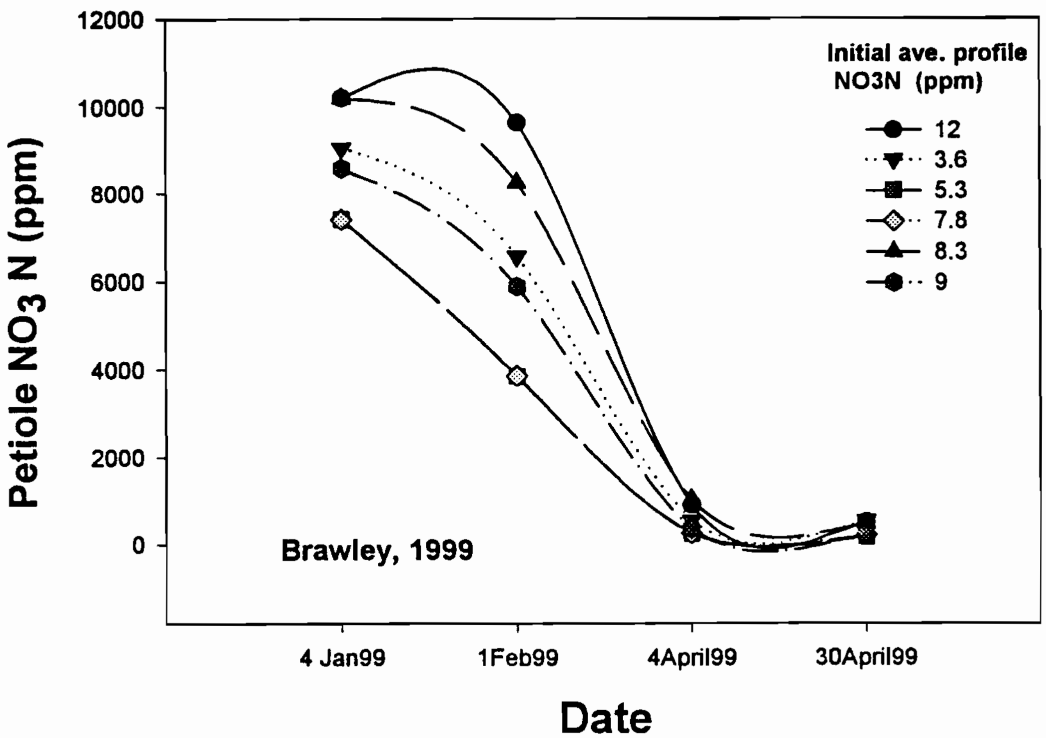

Figure 4. Petiole nitrate N over time at the Imperial Valley site. The objective in good sugarbeet management is to achieve a level of 1,000 ppm six to eight weeks prior to harvest. All locations were below that level by harvest.

Comparison of Crop Yield Maps across a Four Year Rotation

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Introduction

An oft-heard statement is that the real value of crop yield mapping will be realized when maps collected from a field over several years are analyzed. There are few examples of this multi-year analysis in the scientific literature. In the private sector, this is also relatively uncommon. Many farmers with yield monitors save the paper copies of yield maps, and they may save the yield data in a computer file. But, because yield data are incomplete or of uncertain quality, and the farmer has not been consistently collecting or recording spatially tagged pest, irrigation, nutrient, and weather information, the comparison of yields across years will be difficult to do and of limited use.

Most of the published research on multi-year yield comparisons describes two-year comparisons of corn, soybeans, or wheat. In an on-farm wheat study in Montana, grain yield and protein content in the first year were mapped and were then used to design a variable-rate N fertilizer program for the following year's wheat crop. In California's irrigated row crop fields, growers often choose from a list of possible crop species, and they may not keep to a consistent order of cropping. In the Central Valley, it is not unusual to grow four or five different crop species in four years on a single field. There are very few published comparisons of multi-year, multiple crop yields.

Yield comparisons can be as simple as a visual inspection of two-color yield maps from a field. The grower or crop consultant puts the two maps side by side on the desk and tries to remember what factors might have caused the displayed pattern. This low-tech method is useful but is not very good at finding relationships where more than one factor has influenced the yield. In our project, we are using various statistical tools to examine cross-year/crop species yield relationships.

Why compare yields across years?

The main reason for comparing crop yields in a field across years (and crop species) is to determine the stability of low and high-yielding areas. The comparison across years can help the grower or crop consultant infer the cause of low yields in some areas, and it might help them decide whether the field can be divided into management zones.

If low yields occur in the same place each year, this could be due to a cultural practice carried out annually that influences the crop in a similar manner each year. An example would be low yields due to under-irrigation of sandy areas. Also, cross-year yield patterns could be caused by some stable environmental or soil characteristic, for example, presence of a hardpan in one part of the field.

If low yields of each crop or year occur in different areas of the field, yield variation is likely due to management or environmental factors that were unique to that year. An example of this cause of yield variation would be when a rainstorm arrives mid-way through a tillage or harvest operation, forcing the farmer to finish that operation while the soil is too wet or to discontinue it. Also the yield pattern may vary from one year to the next when there is a strong yield-by-environment interaction. For example, in a high rainfall year, a sandy loam area may produce the highest small grain yield within the field, but when there is drought, the same area may produce the lowest yield.

Requirements for cross-year yield comparison

Obviously, the cross-year comparison of yields requires several years of yield data. Less obviously, it requires a higher level of care and consistency in data collection than when only a single year's yield map is to be analyzed. The more years of yield data that are available, the more detailed and reliable are the conclusions regarding causes and stability of yield patterns.

Also, it is a requirement that ancillary data be recorded if one is to infer the causes of low yield in parts of a field. Ancillary data include pest level, irrigation dates, soil and plant analyses, and unusual events such as rain interrupting application of herbicide to a field. All this ancillary information must be tagged with spatial coordinates. This might be latitude and longitude measured with a GPS or it could be crop row numbers, distance from telephone pole, etc. If in an 80-acre field, a different ten-acre area of the yield monitor data were missing in each year of a four-year rotation, then one would be restricted in determining yield stability and causes of low yield to only 40 acres out of the whole field. However, in such a case, it may be possible to estimate yield in the missing areas. The estimate would be based on a mid-season aerial photo, a detailed soil survey, or nutrient levels in plant and soil collected from the areas with missing yield and from the rest of the field.

In this paper, we describe statistical approaches being used to make cross-year yield comparisons.

Project Description

Over the past four crop seasons, we have collected yield monitor data from two row crop fields in Yolo County. The crops were grown by the cooperating farmer using conventional practices in the area. Soils range from Capay silty clay to Yolo silt loam. The Capay is a regionally important soil with poor subsurface drainage and often producing below-average crop yields. The Yolo silt loam is a Class I soil with good subsurface drainage. A serious management challenge for the grower is to optimize irrigation, subsurface tillage, seedbed preparation, and fertilization in fields that contain significant areas of both the Class I and Class II soils.

The yield maps for Field 1 (wheat-tomato-dry edible bean-sunflower) and Field 2 (wheat-tomato-sunflower-corn) are displayed in the accompanying figures (Figs. 1-4). The wheat, sunflower, bean, and corn yield maps were produced from data logged by an Ag Leader® yield monitor-GPS system installed on the grower's combine. Tomato yield was monitored with a prototype weighing system developed at UC Davis. It was mounted on the discharge conveyor of one of the grower's tomato harvesters. Tomato yield monitors are now available commercially. For the Ag Leader® system, yield data files contain latitude, longitude, point yield, GPS clock time, distance (in inches) traveled from last data point, etc.

In our project, the cross-year yield comparison must address the following limitations:

1. No crop species was repeated during the four years of the project.
2. The crop calendars within each field do not match very well. Each field had one fall-planted crop, one planted in late winter-early spring, and two planted in the late spring-early summer.
3. Yield monitor data quality was not consistent across the four years. Due to differences in the yield monitor technology being used for different crops, there was also significant year-to-year difference in data spacing in the direction of harvester travel, data precision, and accuracy/precision of spatial coordinates determined by GPS.
4. All crops were planted on 60-inch beds, but harvest swath width ranged from 5 to 45 feet in Field 1 and from 5 to 24 feet in the Field 2, depending on crop species.
5. Completeness of yield monitor coverage varied from year to year on each field.
6. Other data – primarily soil and plant analyses, field observations, and aerial photographs were collected at varying densities. Collection of soil and plant samples at 200 x 200-ft grid points means that sometimes there are significant features on the yield map or aerial photos that contain one or two grid samples.

None of these limitations is insurmountable and some could have been avoided. They add complexity, cost, and time to the data preparation before the cross-year comparison can be made.

Methods to be used.

Below are listed the statistical tools we will use to determine whether crop yield spatial patterns from multiple years are helpful for determining causes of yield variation. These are not techniques that a grower would carry out or even have to know about. Rather, these methods should be used by an individual or company specializing in agricultural yield mapping and interpretation services. If the interest is only in single-year analysis and/or only in the yield itself, interpretation might be done by the grower or crop adviser using a printed color yield map. If cross-year and cause-and-effect interpretations are desired, more rigorous techniques are required. Some of these techniques are listed here.

- Scatter plots that compare yields in two different years with each point representing yield in one location in the field. Each of our fields will produce six such scatter plots and six correlation coefficients.
- Lag scatter plot is one tool for assessing the distance over which neighboring yield points are related to each other. It can also be used to identify outliers. In a lag scatter plot, each data pair consists of the yield at one location and the yield at a nearby point. A single graph consists of all the pairs that are approximately the same distance apart (expressed in lag units). A collection of these scatter plots, each one representing a different lag distance, produces the same information as calculation of the variogram but allows for a more detailed look at the variation associated with each lag distance.
- Production of smoothed maps to remove yield monitor noise using variograms and kriging. Kriging is a statistical technique for interpolation or creation of a

point yield (or in our case, estimation of an average yield for a point or small area) based on the yield values at nearby points. In kriging, the weight given to each neighboring point is based on the distance and the degree of spatial dependence (autocorrelation) as defined by the variogram model. This is in contrast to more conventional interpolation procedures, which are often based only on distance, e.g., the inverse square of the distance. Kriging is usually limited to a specified number of nearby points, commonly 8 to 16.

- Comparison of kriging residuals in smoothed map. Residuals are differences between estimated values and true values or between estimated values produced by different techniques.
- Co-kriging to determine whether yields from nearby points in other years' crop contribute to the variability of the present year's data.
- Spectral analysis of aerial photographs and yield maps. Spectral analysis is a type of autocorrelation analysis that determines whether data in a transect display periodicity, i.e., a repeating pattern. In Field 2, corn and sunflower yields, as well as crop appearance in color infrared aerial photographs appear to display some periodicity across the plant row direction. Spectral analysis of yield data or crop appearance in an aerial photograph might reveal yield-limiting factors, if for example, there is a pattern equal to multiples of the harvester width, the tillage/fertilization/planter width, or irrigation blocks, all of which are carried out in the with-row direction.

Acknowledgements

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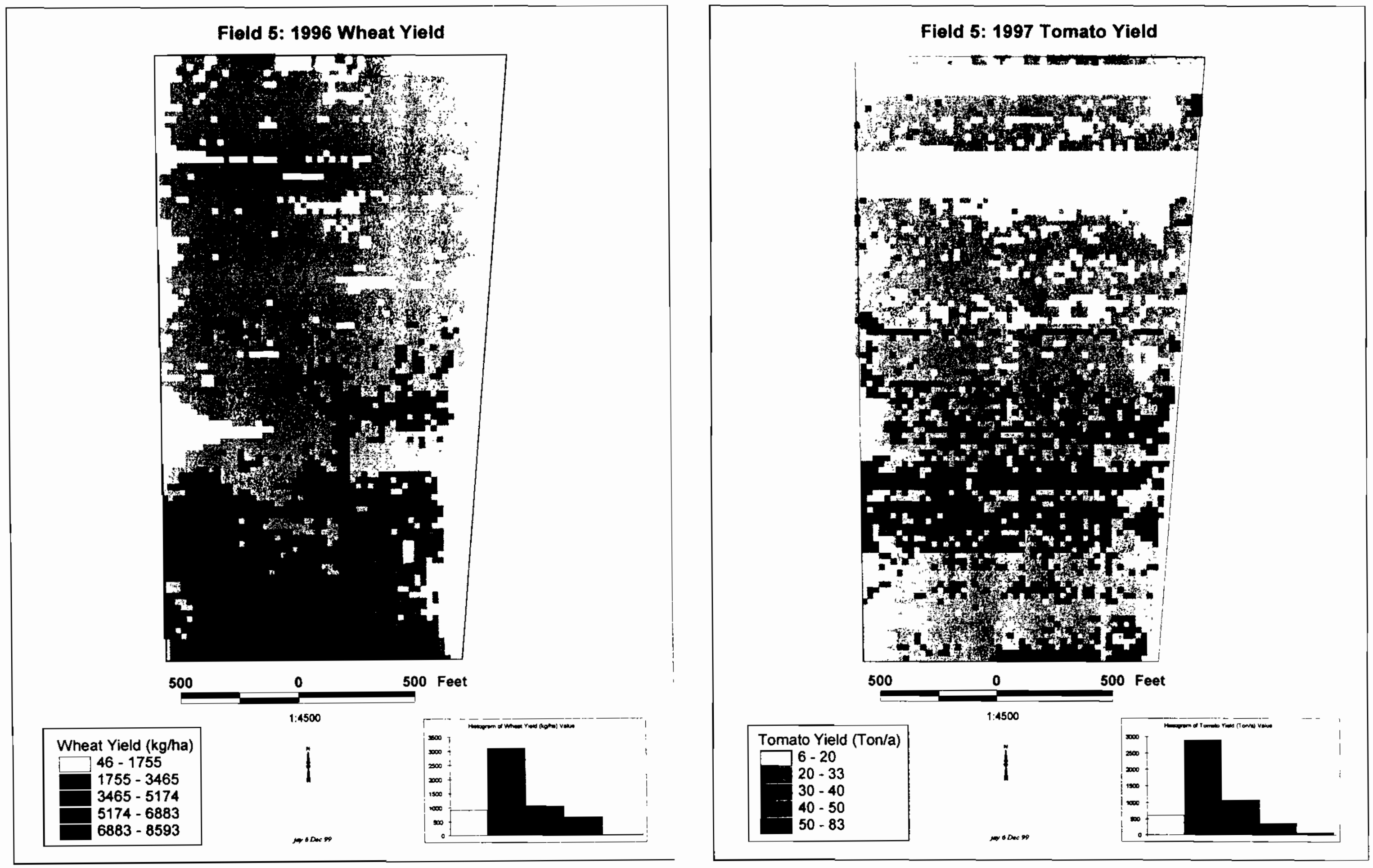

Fig. 1. Wheat (year 1) and tomato yields (year 2) in Field 1. Wheat was harvested with 24-ft swath width. Tomatoes were harvested in single 5-ft beds. Tomato yield data were not collected in blank areas on top (north end) of the map.

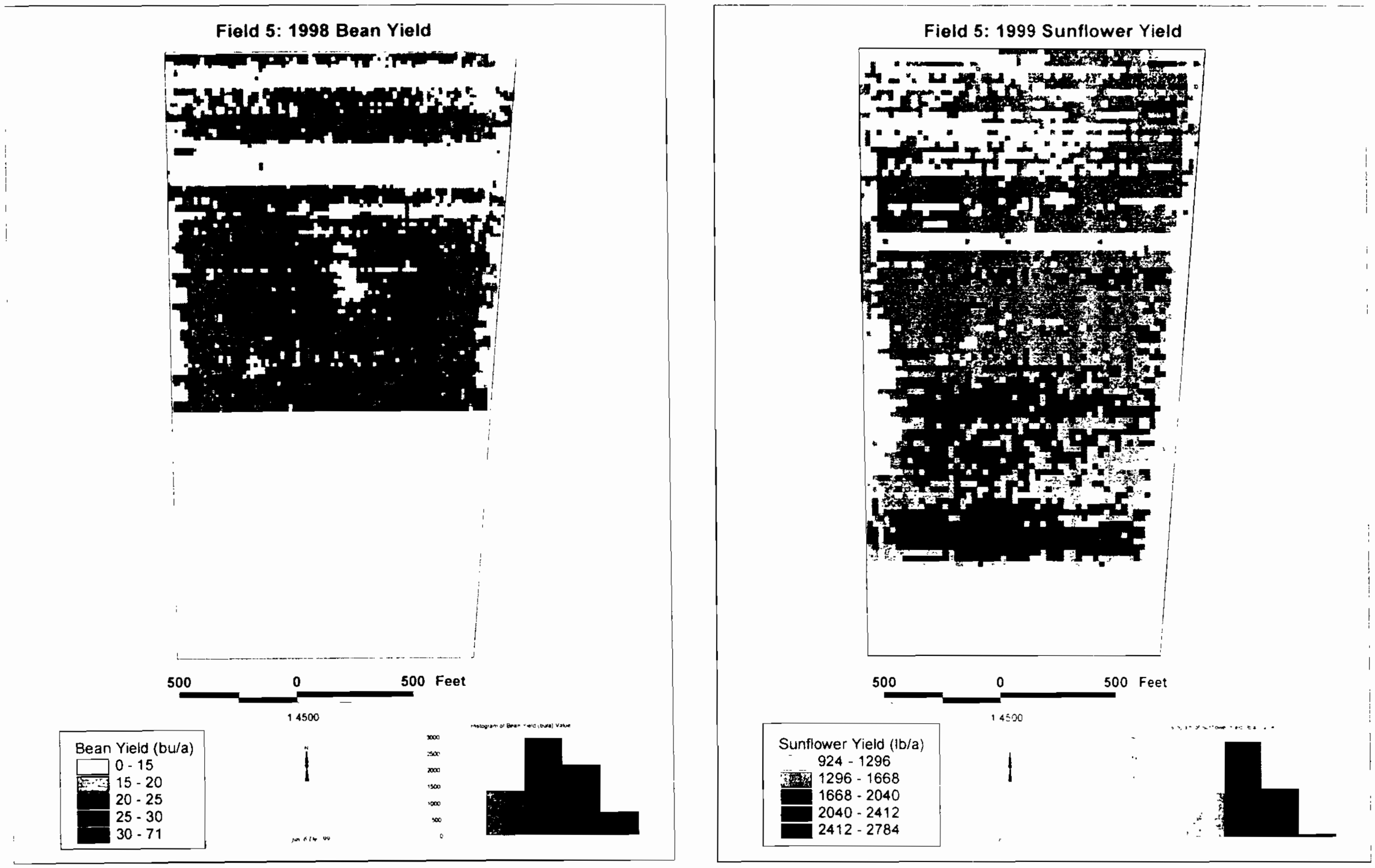

Fig. 2. Dry bean (year 3) and sunflower (year 4) yield maps from Field 1. Before year 3 began, the southern (bottom of map) 10 acres was planted to a different crop. Bean yields are also missing where a second harvester was used. Beans were swathed, and 9 rows representing 45 feet were put together before combining. Sunflower was harvested in 20 ft-wide combine widths.

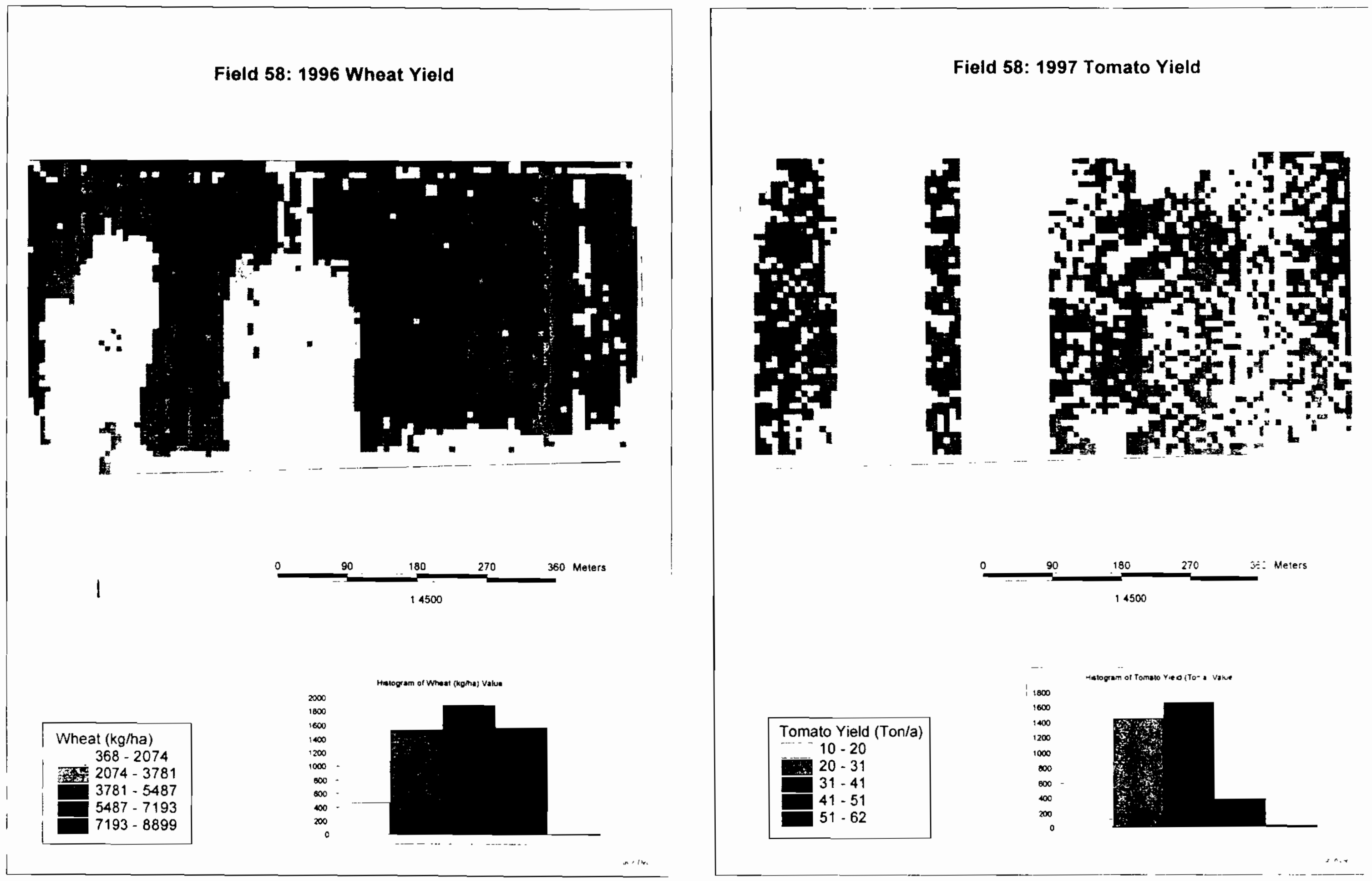

Figure 3. Wheat (year 1) and tomato yield (year 2) maps from Field 2. Wheat was harvested with 24-ft swath width. Tomato harvested in single 5-ft beds approximately on every fifth bed. In blank areas on the tomato yield map, a second harvester was used that did not have a yield monitor.

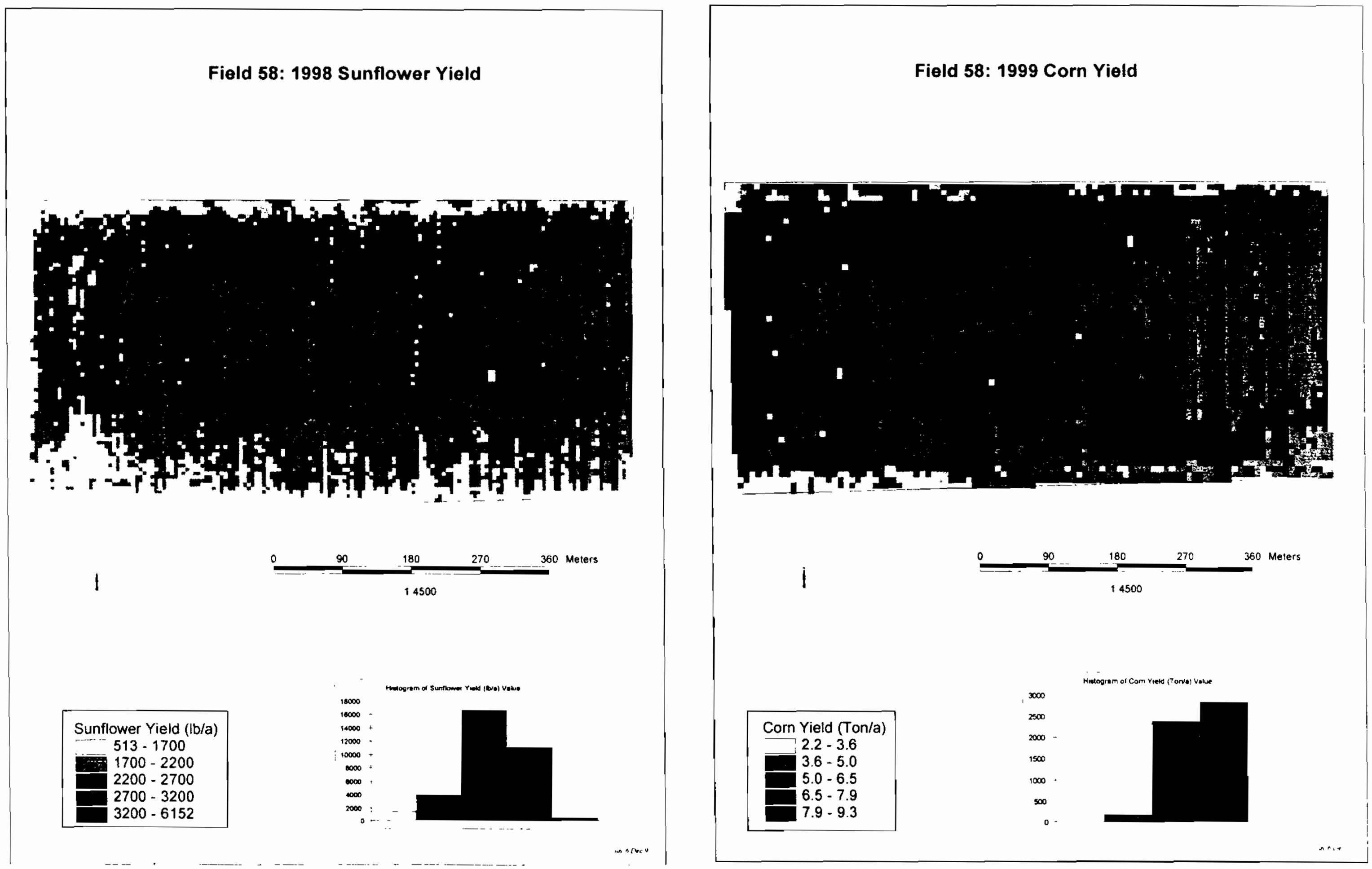

Fig. 4. Yield maps of sunflower (year 3) and grain corn (year 4) from Field 2. Both crops were harvested in 20-ft widths.

AN OVERVIEW OF PRECISION AGRICULTURE TECHNOLOGIES

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Precision agriculture (PA) has been called "farming by the square foot" because it focuses on collecting data and managing inputs at a very small scale. PA technologies have been in use in the Mid-west for since 1995 and much of the research in this area has been done on Mid-west crops and non-irrigated agriculture. Precision agriculture uses a group of the technologies that includes Geographic Information Systems (GIS), Global Positioning Systems (GPS), Remote Sensing, Variable Rate Technologies (VRT) or Variable Rate Applicators (VRA), and Yield Monitors. These technologies are also called Site Specific (SS) technologies.

Geographic Information Systems provide a repository for data with a spatial component. This tool is critical for storage and analysis of PA data. A broader term for GIS is Spatial Information System (SIS). Simply put GIS is the joining of maps and data. For example a GIS can easily track the attributes of a grower's fields (such as crop, irrigation method, and planting date), soil types of a farm, and well locations. GIS data is stored in layers. A layer contains some specific spatial data (i.e. location) and tabular data (i.e. well hp, yield, and pumping water level). The real power of a GIS is the ability to do analysis between layers. For example you can calculate how many acres of cotton are planted in class I soils or how many acres of grapes are planted on slopes greater than 10%. It is this type of analysis that allows you to view data in new ways. The typical output of a GIS is a map, but it can also generate tabular output.

Global Positioning Systems are the means used to accurately associate data with a spatial position. GPS is a satellite based positioning system created and maintained by the U.S. Military. The user uses a receiver that receives data from at least four satellites to triangulate a very accurate position. Typical uncorrected accuracies for civilian GPS receivers are 25-50m. While this is accurate enough to locate a favorite fishing spot we need better accuracy for PA. Increased accuracy is achieved by use of a differential correction (DC) and this is known as Differential GPS or DGPS. For most PA applications the Coast Guard or private satellite service is used for the DC and the error is improved to "sub meter". With local DC the error can be further reduced to less than 2 cm.

GIS and GPS are often combined to map fields and accurately locate sample points. A common use of these technologies is for grid sampling. Grid sampling is a technique where GPS is used to guide a field person to points on a uniform grid where samples are taken. Once the samples are analyzed the data is entered into the GIS and it is mapped. Soil analysis is often performed on 1, 2, or 4 acre grids. The data is then used to create a contour map of similar nutrient levels or soil textures.

Remote Sensing as the name implies is sensing from a distance. Our most common experience of remote sensing is the weather satellite images we see on the nightly news. The most common application of remote sensing in PA is to collect data from aircraft or satellite in the blue, green, red, and near infra-red (IR) bands, however research is also being conducted using RADAR, passive microwave, thermal IR, and other wavelengths. Red and near-IR are often combined into the Normalized Difference Vegetation Index (NDVI) which is called a "greenness index". Images outside the visual range are converted into "false" color so we can view them. One quality of remote sensing data is the resolution. Resolution is the size on the ground of the smallest piece of data (one pixel). Typical data collected by aircraft is 1-4m resolution. Data collected by satellite is 2-15m resolution. Data from aircraft has the advantage of faster turn around (delivery time). Satellite data generally costs less per acre. Currently remote sensing data is being used in PA to create maps and locate problem spots.

Variable Rate Technologies (VRT) or Variable Rate Applicators (VRA) are used to vary the rate of application of seed, nutrients, and soil amendments within the field. The two strategies used to determine when to vary the application rate are location and sensors. Sensors are used to detect weeds or soil moisture as the equipment moves through the field and rates are adjusted based on the sensor measurement. The location method uses DGPS to locate the position of the equipment and compare it to an electronic application map that has been downloaded into the equipment. The rate is varied as the equipment moves into different regions on the application map. VRT is currently being used to vary seeding rates and for the application of liquid and dry chemicals. Often growers have found that they have not reduced the overall application of chemical, but rather applied them more strategically which has increased yields, increased soil fertility, reduced leaching, and reduced runoff.

Yield monitors measure crop yields as the crop is being harvested. This results in a "yield map" of the field, which has resolution in the range of 100 square feet or less. Yield monitors are available for grains, silage, cotton, and other crops. The yield monitor is used in conjunction with DGPS (location) and software that accounts for measurement lag and other variables. The data is stored and then uploaded to a GIS where it is plotted. Yield maps are used to locate problem areas in fields that are not apparent with average per/acre yield data.

Precision agriculture technologies are being used singly and in combination to collect more detailed data and to manage production at the sub-field level. PA technologies are still evolving and are often crop specific. The cost of PA is falling as more growers adopt it and specific crop data is increasing. These factors are making PA technologies valuable tools for production agriculture managers and consultants.

Using Geo-Referenced Aerial Imagery in Production Agriculture

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The use of imagery in agriculture has virtually been around since the early days of the airplane. Today, there are numerous image products to choose from. Both satellite and fixed wing (airplane) companies offer imagery services.

Imagery can be important to growers for two reasons:

a) It provides the grower with the truest map of a field or fields

b) In most cases, it provides a description of field variability, letting the crop act as a bio-indicator of crop-soil interactions. This visible variability can be physical (differences in soil texture or areas of hard pan), biological (nematodes or pest outbreaks), chemical (soil fertility differences) or combinations thereof.

Imagery Vs photos

The term "imagery" essentially refers to a digital file format while "photos" taken with analog or film cameras can be digitized. Having the image in digital form *and* geo-referenced, permits it to be interlaced with G.I.S. software such as Arc View, Map Info and others.

Satellite data is available from 10 to 3 meter resolutions. A 3-meter resolution for example, means that each pixel within the image is 3 meters wide by 3 meters tall (10 ft x 10 ft). Fixed wing or airplane imagery can provide higher resolutions due to the closer proximity to the ground. Imagery resolutions ranging from 2 to 1 meters (80 to 40 inches, respectively) are common with fixed wing imagery products. Resolutions higher than 1-meter (down to one foot or less) can be accomplished, yet this process generates more data than the average computer can process, especially for large fields.

NIR and NDVI

The most common image product available today is false color near-infrared or (NIR). The NIR spectrum ranges from 760-1000 nm. Any crop that has a large enough canopy and with any level of photosynthetic activity will reflect electromagnetic radiation, specifically near-infrared radiation, to the digital camera's near-infrared band sensor. The capture of this band will eventually be assigned a red color, and is traditionally known as false color near-infrared.

Within the last decade, imagery experts have been able to assess both leaf area and photosynthetic activity by looking at two image bands. Using the infrared (IR) and red (R) bands (610-680 nm), photosynthetic health can be quantified and measured. By rearranging the infrared and red bands in the simple equation [IR-R]/[IR+R] and color coding the algebraic output, a process known as *normalized difference vegetation index* or NDVI is derived.

The Importance of Geo-Referencing

Having the image geo-referenced means that a geographic information system (GIS) code or set of coordinates is imbedded or combined within the image. The geo-referencing of the image provides numerous advantages over non-geo-referenced imagery. Any spot within a geo-referenced image can be interpolated to latitude and longitude coordinates. Geo-referencing helps present the image correctly by automatically placing north at the top of the screen. It also enhances the gathering of numerous images or tiles into a mosaic, aligning them perfectly together like a puzzle. It permits the ability to quantify how large certain trouble spots within the image are, and usually to the nearest fraction of an acre. Finally, it also allows other precision ag files such as yield or variable rate technology (VRT) prescription map data to be placed over the image for visual assessment and correlative analysis.

The images described in this presentation are geo-referenced by the use of stamping a DGPS code within the image during image capture. The original image vendor company TASC, has a patent on this process. The DGPS stamping technique was originally derived by Litton for Cruise missile technology of the late 1980's. Technically, the digital image itself is created in a TIFF format while the DGPS code is created as a TIFF WORLD FILE or .tfw. These files have identical file names with each image tile. Hence, when pulling the image into any GIS viewer, both the TIFF image and the TIFF WORLD FILE are imported as a pair, yet only the image itself is seen. The TIFF WORLD FILE is used behind the scene of the GIS viewer.

Current Trends in California for Using Imagery

The wine industry in northern California has been using remote sensing imagery since the grape phylloxera outbreak of the early 1990's. Currently, vintners are keying in on NDVI imagery products to assess stressed areas of the vineyard for better wine quality. If the image is geo-referenced and its NDVI colors are calibrated to certain degrees canopy stress associated with good wine quality, then "differential harvesting" techniques can be accomplished by zoning off these high quality regions of the vineyard (usually with flagging tape) and harvested separately. Without NDVI and geo-referencing technology, only the average quality of the field would be harvested, thus diluting the higher more profitable grapes with the rest of the field.

Field Crops, Smart Sampling and VRT

With field crops such as cotton, processing tomatoes or cantaloupes, imagery can be obtained to assess field variability or to correlate with yield monitoring data. The current trend in precision ag is to use the imagery to micro-manage the field by carving the field into zones based on observed field variability. These zones allow soil-sampling crews to focus on major regions of sampling and away from traditional grid sampling. This type of soil sampling is termed "smart sampling". With the image being geo-referenced, zones for sampling are easily assessed for acreage thus allowing sampling crews with GPS equipment to find the newly created smart sampling zones.

Soil analysis results from smart sampling can be automatically generated into prescription maps (e.g. p.p.m. nutrient = lbs of fertilizer). This electronic map can be loaded into a variable rate fertilizer application unit whereby nutrients are applied throughout each zone in the field as needed, thus leveling the field's nutrient variability. This variable rate technology is common place in the Midwest, yet is now just evolving in the arid irrigated west.

New Image Products

For growers who have bare ground fields or have just purchased a parcel of land with little and no knowledge of field variability, there are new products on the horizon. One of these new bare ground image products is SoilView, produced by TASC and Emerge. SoilView measures bare ground soil reflectivity. Within the SoilView image product, natural soil reflectivity has been calibrated with basic soil textural differences. This is somewhat analogous, yet not identical to, the Munsell color chart used in basic soil taxonomy. Within the typical SoilView image, seven different zones of "variability" are automatically generated as GIS shape files along with cultural (housing or roads) and vegetative (large trees etc.) color coded shape files.

Several examples of SoilView will be shown during the presentation. SoilView images will be compared to other spatial data used to assess field soil variability. Although TASC's SoilView process is patented, it can be noted that the SoilView process uses the same bands as NDVI (red and infrared) yet with different algebraic functions to create the final image product.

Currently, SoilView is beginning to be used in newly purchased vineyard land. It could be used for varietal planning along with irrigation design.

GIS and Image Viewers

If growers want to dive into and explore the GIS and imagery world, many software packages are available which range from free to as high as $6000. The package price depends on the number of GIS and image viewing functions included. It is suggested that GIS software be as agriculture friendly as possible, thus allowing the grower to measure anything within the image or GIS shape files in familiar units such as acres and feet.

Summary

Geo-referenced aerial imagery can prove beneficial to production agriculture by giving the grower an efficient tool to assess field variability in a quantitative fashion. The geo-referenced code accompanying the image also helps other spatial files to be over-laid on top of the image for numerous correlative studies. Finally, geo-referenced imagery can quickly help the grower define micro-management zones for soil sampling, variable rate fertilizer applications and better irrigation design.

The Power of Integrating GPS Technologies

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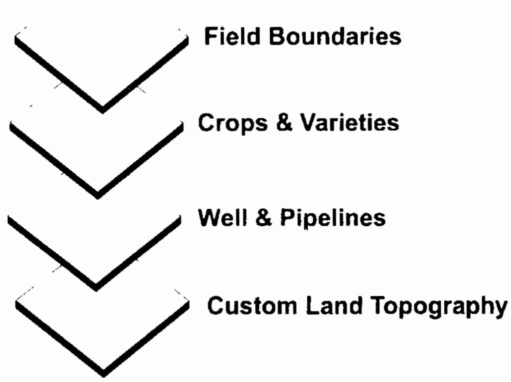
As a commercial provider of technical services to agriculture, California AgQuest Consulting has adopted Global Positioning Systems (GPS) and Geographic Information Systems (GIS) technologies as an integral part of their business. GPS and GIS have been integrated with other services including crop water management, nutritional analysis, pest management, land use planning, and field problem analysis.

GPS and GIS are directly useful any time you are working with information which is geographic in nature. In agriculture, this applies to a great many activities since we are frequently working with cropped fields and trying to describe some characteristics about them or trying to solve a problem. These technologies give you the ability to relate information you have and will acquire to geographic areas of land.

GPS and GIS can be used for storing historical information, including field cropping and yields from previous years as well as water, fertilizer and chemical applications on individual fields. These technologies can also be used for land use planning such as future cropping patterns for field crops, realigning fields, and new developments for permanent crops. Another major area for GPS and GIS is in analyzing problem situations. Applying GPS and GIS do not necessarily give you solutions to problems, but they do make it much easier to identify the problems, quantify their effect, and suggest possible solutions.

How GIS Organizes Information

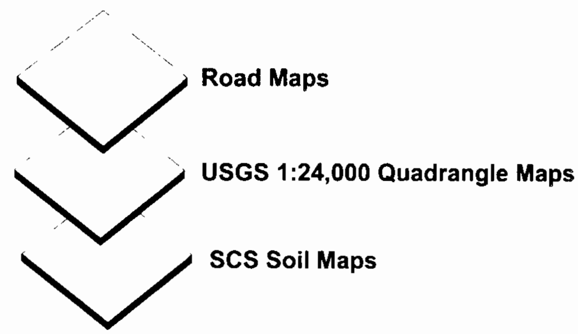
GIS is a system of building layers of information, by organizing sets of data into layers or themes of information. Each layer includes particular information about a geographic location or area. You can start with very basic information such as the boundaries of the fields on a ranch, then build the layers as you identify other important data you want to add. All of the information you collect can be put into its own layer or theme, but the important thing is that it is all "geo-referenced". This means that everything you have collected in the past and that which you collect in the future will always be related to the same geographic area.



One important caution is that some people are selling data (or services) which they say can be "geo-registered". While geo-registered data is useful at times, it usually takes more time to work with and does not necessarily yield any better information than true geo-referenced data.

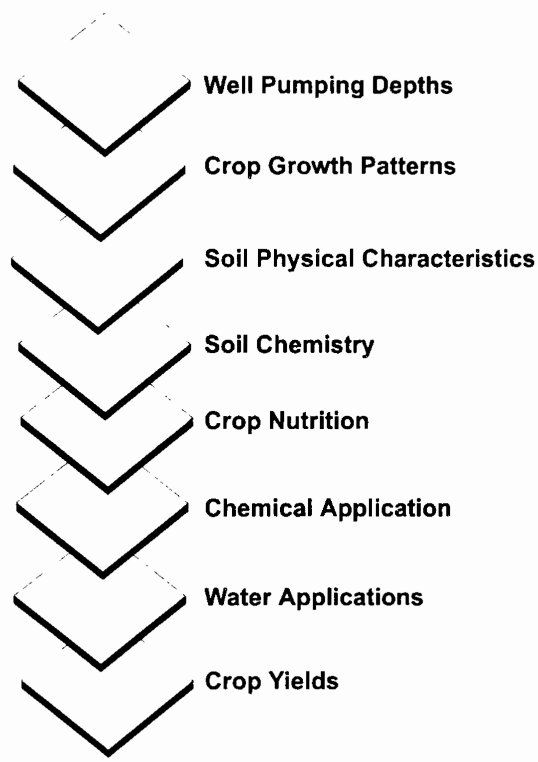
Generally Available Geo-Referenced Information

There are a number of general information sources which have existed for some time and are now becoming available in a geo-referenced format. These include such simple things as road maps which can be integrated into your data base to let other people know where you are located. The USGS Topography maps are now available in geo-referenced formats. These can be obtained as a single "layer" of data (including everything you see on a USGS topo) or as separated layers of data (one layer each of topography, water ways, and roads). The National Resources Conservation Service soil maps (formerly SCS) are in the process of being provided in a geo-referenced format. These digital, geo-referenced maps make it very easy to over-lay the soil series which are expected to exist on a piece of land.



Farm & Field Specific Information

Whether or not you utilize the general information sources discussed above, you will definitely want to develop some basic infrastructure data for the fields on a ranch. One of the most useful layers of information is field boundary data. This layer of data will be used as a template for several other data layers. The locations of wells, canals and pipelines is frequently collected as a part of basic ranch infrastructure. Land topography is typically added as a layer of data in hilly terrain, especially when the land is in a development planting process.



Additional layers of data beyond the basic infrastructure will depend on the objectives of the grower. These can include monitoring data on pumping depths of deep wells on larger ranches, or monthly depths to a shallow perched water table which can be used in field irrigation scheduling.

Record keeping of farming information can be maintained and presented in a map format for soil chemistry, plant nutrition and applications of fertilizer, chemical and water. Crop yield mapping can be easily done on a full field basis. When in-field crop yield monitoring technology becomes commercially viable, we will see a major upturn in the use of GPS based data. With in-field yield data, you can then identify the exact crop yields in different areas of a field. With this knowledge, you will be able to compare the yield patterns with any other data layers you have collected. Since you know where the yields are highest and lowest, you will be able to search the other data layers to identify what factor(s) are enhancing or limiting crop yields.

End Uses of GPS Data

The end use application of GPS based data can start with the simple production of ranch maps (because it is GPS data, it is always to scale). By adding a crop planning layer to the field boundaries layer, you can easily evaluate alternate cropping plans and produce tentative crop maps for two or three years into the future.

We currently have some very useful individual in-field data sources available. One of these is aerial infrared imagery, which is geo-referenced (1 meter resolution, 1 meter accuracy). We can now identify areas of stronger and weaker plant growth which will likely relate quite directly to in-field yield monitoring when it becomes available. These infrared images can also be used in problem analysis and some of the other data we have collected that can be used to help identify possible causes of the problems.

Another currently available tool is soil conductivity measurements coupled with a GPS instrument to log the location of each measurement in the field (within 1 meter). The conductivity of the soil increases with clay content of the soil and with higher total salinity. With some field verification, you can separate these components and end up with a detailed soil texture map and have the salinity pattern quantified in the field. Depending on the detail you need, you would typically take from 50 to 150 readings/acre.

We also have variable rate application equipment available for fertilizers and soil amendments. These units can be set up with a GPS program to vary the material application rates in a field. The trick, of course, is to know which areas of a field should receive various rates of material. We already have aerial applicators using GPS to identify correct field locations for treatment and to maintain parallel swaths through the field (eliminating a flag man). Some applicators actually have GPS units in their airplanes which continuously record their position and rate of material application so that you can place a layer of data in your GIS system which shows how well a chemical was distributed in a field application.

Getting Started with GPS and GIS

When you feel that you are ready to start utilizing the power of GPS and GIS, begin with a specific objective. It is always good to start with gathering data for the boundaries of fields. If your objective is to solve a problem, first identify possible causes so you know what data you need to collect (i.e. what layers you will create). Look for existing sources of geo-referenced data such as SCS soil maps. Next, look for historical information which is in paper files in an office that can be entered as a layer of data. After you have completed this process and evaluated the data, you can then examine what new information may be needed. Throughout this process, you should be in contact with someone who has practical experience in applying GIS to ag situations. This type of contact can save you a lot of time in your first application.

GIS Software

There are several manufacturers of GIS software, however, ESRI is by far the most popular. ESRI has three basic products – ArcInfo, ArcView, and ArcExplorer. ArcInfo is a very sophisticated product ($20,000+) intended for GIS professionals. ArcView is the commonly used product for most agriculture applications. ArcExplorer is a "read only" program, available as a free download from the Internet. ArcExplorer can be used for viewing and printing maps (layers of data). However, you cannot enter new data or make changes to existing data.

With a specific goal in mind, talk with people experienced in GIS for agriculture who can help you "design" your overall approach. Even though you may be doing only a portion of an overall plan, having a design in mind will insure that you do not waste any efforts. When you become involved with an organization that has worked in GPS and GIS, insist on receiving a copy of the data and a copy of ArcExplorer. It is your data and any reputable company should not have a problem with giving it to you.

If your are thinking about buying a copy of ArcView, you should be ready to spend some time learning the software. While ArcView is a powerful program, it is somewhat complex.

GPS & GIS Impact In Agriculture

These technologies are having a unique impact in the agricultural industry. What is really interesting is that in bringing layers of data together, you also bring people together. Many times these various groups do not communicate with each other regularly. Because data is brought together, people of different disciplines also need to relate and are sometimes almost forced into relationships. People who think that their particular approach to solving problems is the final answer will not succeed in the GPS/GIS world simply because the end-users will insist on integration. Individual applications in GPS frequently have significant value, however, the real power is in integration.

[PrdGud\Presents\ASA Power of GPS Integration 1-00 Text]

MADERA RAISIN GROWER NAMED CALIFORNIA IRRIGATOR OF THE YEAR

Lee Simpson, a Madera County raisin grower has been honored as California Irrigator of the Year for his long-term efforts to maximize the use of his irrigation water while out-producing the industry average for raisin production. The award, given jointly by the Center for Irrigation Technology at California State University, Fresno, and Rincon Publishing, publishers of *California Grower* and *California Vegetable Journal* magazines.

Simpson began his efforts to reduce his usage of irrigation water 16 years ago when he saw hillside Hawaiian sugar cane fields irrigated with a buried drip irrigation system. Since then he has experimented and modified his own system to the point where he now uses just 60% of the irrigation water he used to use while producing three times the crop; in essence using just 20% of his former irrigation water per ton of raisins produced.

Some growers have been slow in converting to buried drip irrigation systems, Simpson says, because they can't see the irrigation taking place. The soil in Simpson's 160 acres of vineyards stays dry at all times so that no water is lost to evaporation. He also monitors moisture at several levels in his soil so that no excess water falls below his grape vines' root zone where it is unavailable to the plants.

A sophisticated moisture monitoring and irrigation system has been installed in Simpson's vineyard. He can access it by phone from anywhere in the world to get important information on the condition of his vines and make adjustments to his irrigation schedule.

In general, Simpson prefers to pulse the irrigation in his vineyards, turning irrigation on in one irrigation block for a short period of time before moving on to the next block. This way allows the moisture to be used by the plants without allowing it to fall below the root zone.

Using a dried-on-vine (DOV) trellising system, which not only allows his vines to receive more sunlight but also lets him keep his raisins off the ground, Simpson has harvested 4.5 and 5.5 tons per acres in 1997 and 1998 respectively, compared to an industry average of about 2 tons per acre. This year he expects to harvest 5.5 to 6 tons per acre.

The complete story of Lee Simpson's irrigation-efficient raisin-growing operation is in the October issues of *California Grower* magazine.

CALFED BAY-DELTA PROGRAM
AGRICULTURAL WATER USE EFFICIENCY
PROGRAM OVERVIEW

by
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CALFED Bay-Delta Program
Water Use Efficiency Program Manager

Agricultural Water Use Efficiency Program Overview

Background

The CALFED Bay-Delta Program is a cooperative effort among state and federal agencies and the public to ensure a healthy ecosystem, reliable water supplies, good quality water, and stable levees in California's Bay-Delta system. The Water Use Efficiency Program is one of the Program elements common to the potential solutions developed by CALFED. The Water Use Efficiency Program represents a significant investment in the system and will greatly reduce system conflicts.

In its June 1999 Revised Phase II Report, CALFED stated the intent to develop a Strategic Plan for Agricultural Water Use Efficiency. For the past year, a small group of agricultural, environmental and agency interests – known as the Agricultural Water Use Efficiency Steering Committee – has been working collaboratively to provide guidance to CALFED on the development of the Strategic Plan.

Strategic Plan Approach, Objectives and Key Components

The purpose of the Strategic Plan is to articulate a prioritized, strategic, aggressive program for the achievement of efficient water management for all purposes throughout the many different agricultural regions of the state.

The Strategic Plan – to be developed by a Technical Team working closely with CALFED staff and the Steering Committee – is to draw on the work of local agencies and other sources to: 1) assess what efficient practices are already being carried out; 2) identify additional opportunities for improved water management; 3) recommend goals; and, 4) recommend incentives and other means to overcome any barriers to adoption of more efficient water management practices (please refer to attached Figure 1).

As currently envisioned, the Strategic Plan will consist of six main components: targeted benefits and quantifiable objectives; reference conditions; incentive program; appropriate measurement; monitoring, reevaluation and consequences; and linkages with other CALFED programs and related efforts.

The focus of the Steering Committee's deliberations thus far has been the development of a Strategic Planning process that will rely heavily on locally inspired actions to meet specific objectives related to water quality, timing and flows. In essence, this approach embodies the adage: "Think globally, act locally."

Elements of the evolving program include:

Reliance on Flowpaths and Water Balances. Past efforts at agricultural water conservation have focused on Best Management Practices. The new approach focuses on the identification of specific benefits – related to CALFED-driven objectives around water flow, timing and quality -- that can be achieved through the management of flow paths and water balances. (Flowpaths characterize the course water follows between entering and exiting a particular area, such as evaporation or deep percolation.) This approach was developed by the Independent Review Panel on Agricultural Water Conservation Potential, which was convened by CALFED in December 1998.

Development of Targeted Benefits and Quantifiable Objectives. Closely linked to the focus on flowpaths is the Program's reliance on an objective-driven approach. This strategy requires a number of crucial steps, including:

1. Developing targeted benefits, or qualitative changes, for any of three broad areas consistent with CALFED objectives: flow and timing; quality; and quantity. Associated with this step is the development of reference conditions indicating the quantitative baseline.

2. Estimating agriculture's potential contribution to targeted benefits. This step relies on the flowpath approach to develop a ballpark estimate of how much agriculture can potentially contribute toward reaching targeted benefits. This analysis is then further refined to develop a range of quantifiable objectives – specific criteria that represent the practical contribution agriculture can likely make towards achieving the targeted benefits.

The Strategic Plan looks to a multi-disciplinary Technical Team – including experts in water conservation, water quality, aquatic biology, irrigation engineering and local operations expertise – to develop the targeted benefits and quantifiable objectives, as well as performance indicators and a monitoring strategy.

Incentive-Driven Local Actions. Rather than imposing top-down, one-size-fits-all requirements, the Strategic Plan looks to different agricultural regions for the solutions. Specifically, the Program relies on an incentive program – rather than a regulatory approach – to encourage local entities to identify and implement creative actions that will contribute to achieving the targeted benefits and quantifiable objectives in a cost-effective manner. CALFED will use a mix of loans and technical assistance to fund actions that are locally cost-effective. Actions that are not cost-effective at a local level will be eligible for CALFED grant funding. Early implementation is expected as soon as mid-2000.

Linkage with Agricultural Water Management Council. The current Strategic Planning process involves the Agricultural Water Management Council in several key ways. Most notably, the Council's review of water management plans will help CALFED determine which measures are cost effective at a local level and how much funding a district or region should receive to implement additional measures or programs that are not cost-effective at the local level.

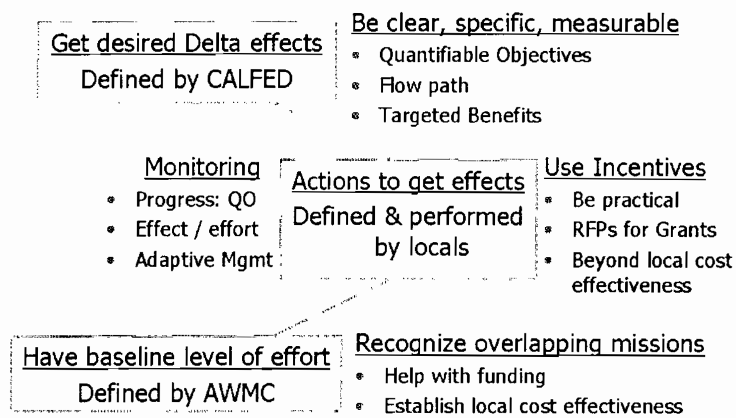
Schedule:

With general agreement on the broad outlines of the Program, the work in the coming months now shifts primarily to the Technical Team charged with developing the targeted benefits, quantifiable objectives and targeted flowpath changes. Key actions in the months ahead include:

- Working with local experts to piece together a detailed picture of key regions' water balances and flow paths;
- Convening a series of meetings with technical team experts, locals and others to identify targeted benefits, targeted flow path changes and quantifiable objectives;
- Launching an early implementation program with a few willing local entities to develop actions related to the quantifiable objectives. This is to be followed, in late-2000, by a more extensive Request for Proposals.

As well, the Steering Committee will continue its deliberations on two crucial issues still to be resolved: 1) defining appropriate measurement; and 2) developing a package of assurances.

Figure 1
Elements of CALFED Agricultural Water Use Efficiency



MECHANICAL IRRIGATION SYSTEMS

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The use of the automated mechanical irrigation machines since the early 1970's has been the dominant type of equipment used in the irrigation segment of the United States as well as the world. This equipment consists primarily of the center pivot and linear machines.

Since agricultural irrigation is the largest user of fresh water, it represents the biggest potential contributor to water conservation. This is where we should look first for these water savings. Based on experiences, vast water savings are possible.

The center pivot was introduced to the market in the mid 50's but in the 70's and 80's the market grew at an accelerated rate, because of the tremendously reduction in labor and water required over traditional surface irrigation. The application of the pivot also provided a method to irrigate areas and soils that could not be irrigated with surface irrigation because of the soil texture or field terrain. Dr. Bill Splinter at the University of Nebraska has stated in the Scientific American, "The center pivot is perhaps the most innovative product since the replacement of the draft animal by the tractor." The present design of the machines and the technique in designing and operating the machines has had numerous improvements over the years. The initial center pivot was driven by water pressure using high pressure impact type sprinklers and very high flow rates which, in many cases, was the incorrect machine specifications and sprinkler package to meet the field conditions involved.

Traditional row-crop irrigation, commonly called furrow irrigation, is normally the least efficient irrigation water user. Operating costs, may be low, but the civil works for land preparation and high volume pumping can be the highest-cost irrigation system, in terms of total cost.

Center pivot and the similar linear move machines deliver a precise amount of water at a reasonable installation cost. These machines can also apply fertilizer and chemicals in the exact quantities needed.

Lets examine the design and operation characteristics of the center pivot. The unit is made up of spans, or also known as drive units, of varying lengths from 115' to 205'. A combination these spans and the overhang, which is cantilevered from the last drive unit, can be assembled to fit most sized fields. The length of the span must be reviewed based on the soil texture, and terrain. As it can be easily understood the longer span weight could cause deep wheel tracks in some soils. Also the longer spans cannot easily absorb extreme slopes because of crop clearance. At the end of each span is a joint which allows for slope absorption and misalignment.

Also at the end of each span or drive unit, a drive mechanism is located. This drive is normally an electric motor, which then drives each wheel. The electric motor is controlled by a micro-switch which measures the angle of misalignment between the span pipes. The electric motor is switched on and off to provide the proper alignment based on a straight line operation of the machine. Other electrical components are available for possible failure of components to prevent machine failure. For example, in the event that the machine becomes stuck in the mud, an overwatering timer is actuated that will shut down the machine. Also the misalignment is measured, and if a motor, gearbox, or other component fails, the unit will be shutdown.

The speed of the machine is controlled by the speed of the last drive unit with all other drives maintaining the alignment with that unit. The speed of the last drive unit can be varied controlled from the main control panel where the percentage timer will run the electric motor any percentage of one (1) minute. If the timer is set to 50% the motor will run 30 seconds and not run for the other 30 seconds. The speed of the motor on the drive unit can selected from a number of different output speeds. The typical minimum speed for a 1300 ft center pivot machine would be approximately 24 hours, or 12 hours if the high speed option is chosen.

The linear machine functions basically the same, except the machine moves down the field in a straight line. The water can be supplied to these machines either by a flexible hose that is pulled by the machine or from a open ditch. The flexible hose must periodically be moved and connected to another hydrant along the length of the field. The ditch feed machine will be typically equipped with an internal combustion engine, which drives a centrifugal pump and electrical generator.

The purpose of the hardware described above has the primary purpose to effectively distribute the water uniformly and efficiently. The distribution system can use sprinklers ranging from high to low pressure, as low 10 psi at the end of the equipment. As a general rule the high pressure, impact-type sprinklers, which were used prior to the last 15 years, has a lower efficiency because of the wind drift, small droplet production, and evaporation. The most common sprinklers presently involve lower pressure. These pressures range from 10 to 20 psi at the end of the machine. Each of the various sprinkler types has both positive and negative factors.

The high pressure impact sprinklers had a wide, wetted diameter but the energy used is costly. The mixture of droplets contains a percentage of large droplets which could compact the soil and cause excessive run off. The wetted diameter was very effective for reducing the instantaneous application rate, but with the reduced efficiency from the losses has caused a shift to lower pressure units.

The low pressure nozzles can be mounted on the top of the pipeline, but most are lowered below the pipeline truss structure or down into the crop canopy. Placing the water output closer to the crop has improved the efficiency as shown by the graph in Figure 1 . Even though these sprinklers have a smaller wetted diameter which causes a higher instantaneous application rate, the consistently smaller droplets tend to infiltrate into the soil at a faster rate. The common types of sprays varying from units such as the various spray nozzles, Nelson Rotator and Spinner, and Senninger I-Wob. The operating characteristics of each type is different, relative to pressure required, droplet size production, and angle of discharge. As the sprinkler selection and placement has been changing an improved application efficiency has resulted. This efficiency improvement is shown in Figure 2.

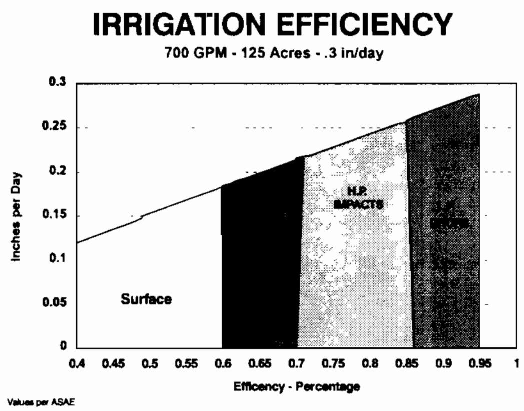

Figure 1

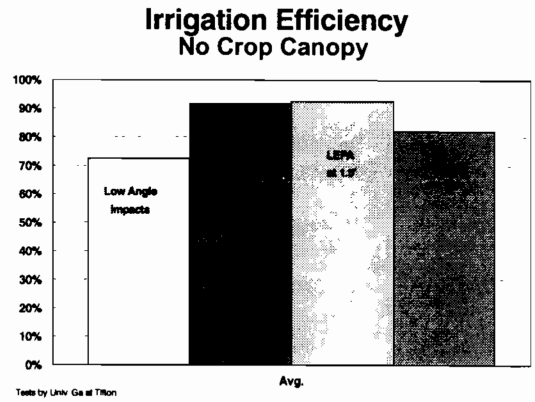

Figure 2

The most common sprinkler package uses spray nozzles with a variety of pads to provide the type of droplet best suited for the conditions. These sprays commonly include the Valley LEN, Senninger LDN, and Nelson D3000. The spray pads may be flat, concave, or convex and involve surfaces from smooth to a varying number of grooves which also may vary in depth. The smooth pads provide very small droplets, which are suitable for some crop germination, infiltration into heavy soils, and sensitive crops. Deep groove pads produce larger droplets which will have a slightly larger wetted diameter and resist the wind better.

As the discharge of each of the sprinkler types is lowered from the pipeline, the spacing distance between the sprinklers must be reviewed for proper overlap. The crop canopy will also affect the sprinkler overlap Typical guidelines for sprinkler spacing relative to drop height from the soil surface without considerations for the crop canopy are as shown in Figures 3 and 4. Other conditions and sprinkler types are available for the various manufactures.

The placement of the sprinklers very close to the soil surface has resulted in a concept commonly referred to as LEPA, or Low Energy Precision Application. The concept has resulted in measured application efficiency of up to 98%. The LEPA machines may be equipped with specially designed sprinklers, which are capable of only providing a bubble distribution or normal spray nozzles, which may be covered with a sock or tube for distribution directly into the furrow. On pivots this usually involves planting the crop in a circle, whereas, on linear machines, the furrows are planted parallel to the wheels.

SPRAY NOZZLE SPACING at 6 psi (0,41 bars)

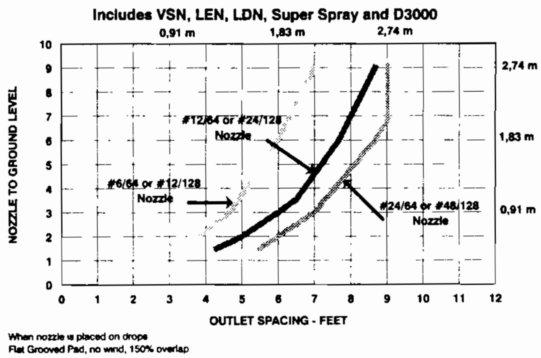

Figure 3

SPRAY NOZZLE SPACING at 15 psi (1,03 bars)

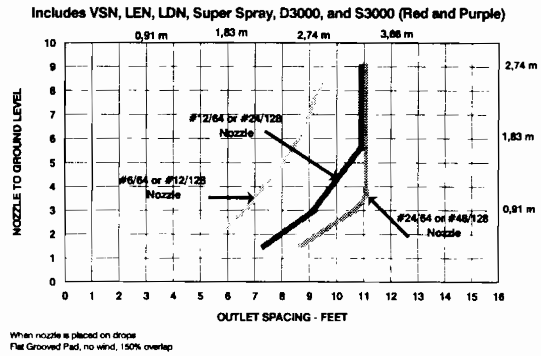

Figure 4

The design of the sprinkler package may also include special methods and/or devices to keep the wheel track of the machine in a relatively dry area during the operation. This can involve using the drag sock or LEPA units adjacent to the wheels. Another method is to use boombacks or offsets, which are extensions behind the wheels in the direction of travel where 180 sprays are used, thus applying the water behind the wheels.

In conclusion the initial design of a mechanical irrigation machine involves, not only the structural, mechanical, and water delivery for the soil, climate, and crop conditions, but the most important is the design of the type of sprinkler package to meet the existing conditions. Proper design and operation of the machine will result in lower labor requirements, lower operating costs, and equal or improved crop yield and quality results.

SUBSURFACE DRIP IRRIGATION: WHY AND HOW

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For presentation at the Annual Meeting of the California Chapter of the American Society of Agronomy Stockton, CA, January 19-20, 2000

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INTRODUCTION

Subsurface drip irrigation (SDI) is the latest, most sophisticated and most efficient method available for irrigating agricultural crops, landscape and turf. It is capable of providing the greatest yields and water use efficiency of any irrigation method now in use in the World. However, unlike most conventional irrigation methods, SDI requires intensive and accurate management of water and nutrients in order to produce these expected results. Without the proper management, SDI may result in great disappointments. Thus SDI is not for everybody because it requires the user to trade his shovel for a computer and to change his ways of thinking and of managing his agricultural enterprise. Among the major changes recommended, SDI requires (1) the use of high frequency irrigation, (2) accurate and continuous injection of fertilizers and (3) real time automation. In concept, it is similar to most of today's automobile engines which have achieved increased horsepower and fuel efficiency through the use of sophisticated, on-board computers requiring real time feedback techniques to constantly adjust the ignition and fuel mixture fed to the engine. For SDI to perform successfully, it will also require water availability on-demand, frequent and accurate fertigation, a control system to sense weather and soil moisture continuously and make irrigation decisions in real time in response to weather changes and without human intervention. The purpose of this paper is to expose potential users to the SDI concepts and some of the management requirements and procedures necessary for the SDI system to perform successfully.

I. CONCEPTS

The use of drip and subsurface drip irrigation has entirely changed the concept of traditional irrigation from one where the soil is used as a water reservoir and transport system and water is applied infrequently to fill the entire soil profile to one where water is applied very frequently to satisfy immediate plant water requirements and only a small portion of the soil profile is wetted. Figure 1 shows the approximate volumetric composition of the soil constituents found in a silt loam soil. The soil air and water are extremely variable and their relative proportion controls plant growth. Therefore, one of the major objectives of irrigation should be to maintain an optimum balance between the percentages of water and air in the soil pores so that the roots can take up water and nutrients without being waterlogged.

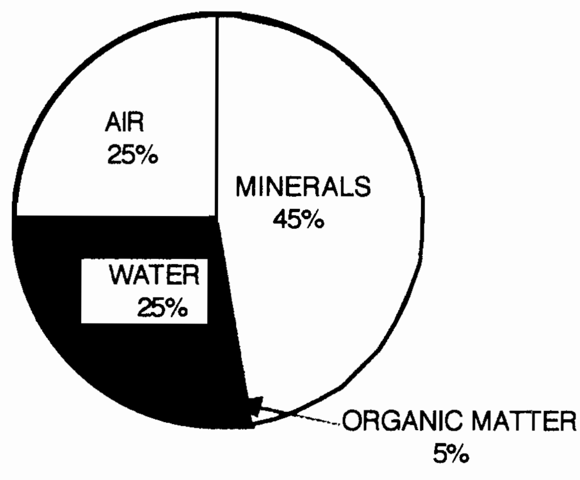
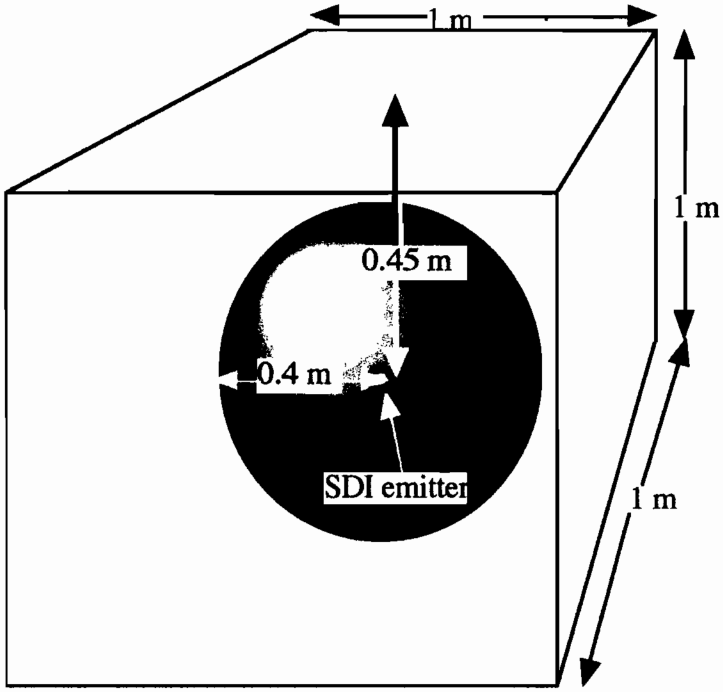


Figure 1. Approximate volume fractions of a surface silt loam soil required for adequate plant growth.

Another important irrigation concept deals with water movement. Water moves in soil under mass flow (liquid state) and/or diffusion (vapor state). Forces controlling the movement of water are mostly due to the capillary nature of soil (capillary force) which acts equally in all directions and the gravitational pull of the Earth (gravitational force) which is constant and downward. The capillary force decreases as the soil wets. Hence, in dry soil, the capillary forces are much greater than the gravitational force and tend to move water equally in all directions, including upward. As the soil becomes wetter and wetter, the soil pores become saturated with water, the capillary forces weaken, the gravitational force takes over and moves water downward, many times below the root zone, where it cannot be used by the crop. The basic management then consists in irrigating the soil in short pulses (high frequency irrigation), similarly to what is done with greenhouse pots. By managing SDI with high frequency irrigation, the water movement is controlled mostly by the capillary forces and not by the gravitational force; plants frequently receive their water and nutrients directly in a small portion of the root zone which can be maintained at a nearly constant soil moisture and nutrient concentrations. Figure 2 shows the relative wetted dimensions for a soil volume of 1 m^3 (for a soil bed and lateral spacing of 1 m).



Wet Soil dimensions.	CUBE	SPHERE
Side (m)	1	
Radius(m)		0.4
Volume (m^3)	1	0.268
% wetted Volume	100	26.8

Figure 2. Wetted soil volume available for water and nutrient uptake in a flood-irrigated soil unit of 1 m^3 and in a similar unit irrigated by a subsurface drip system, with a point source drip line and emitters spaced 1m apart.

Starting up a new SDI system requires a large capital and time investment, the willingness to forget the old irrigation practice, a steep learning curve and often the advice of knowledgeable consultants. To be successful, the switch to a SDI system will require sequentially considering several equally important steps, such as: site evaluation, system design and review, installation and testing, management, data base generation and yearly results evaluations.

II. SITE EVALUATION

Site evaluation is the first step in the process of developing a successful SDI system and it requires assessments of the soil, topography, water quality and availability, crops to be irrigated, crop rotation, irrigation system capacity and environment. Each of these factors will be important for the proper design and management of the future SDI system.

The soil texture, depth and chemistry should be analyzed for suitability and for setting the basic design criteria for the SDI system. For instance, a rocky, coarse-textured, stratified and undulating soil would not be a good candidate for a simple SDI system; but with proper design and pressure compensated emitters, it could be managed.

Topographical evaluations are needed for slopping and undulating sites as they require strategically located pressure regulation, vacuum relief and check valves. Water availability, capacity, quality and price (including energy cost) will play important roles in the decision and design processes. Water should be available on demand and in quantity sufficient to meet peak crop requirements or a reservoir should be built to store water.

Climatic and weather evaluations will be needed to determine peak evapotranspiration rate and water requirement, need for drainage, leaching requirement and frost protection. When possible, long term historical data should be reviewed and used for establishing broad design guidelines. The Peak Irrigation Water Requirement must be calculated to determine the irrigation system capacity (the amount of water which must be delivered to the field to satisfy the maximum amount of water needed by the crop).

The **Irrigation Water Requirement** is defined as:

$$I = Q + D + E + T - P \pm \Delta\Theta \qquad 1$$

In which, **I** is the irrigation water requirement of the crop
Q is the runoff
D is the drainage below the root zone
E is the evaporation from the soil and plant surfaces
T is the transpiration from the plant
P is the precipitation and
$\pm\Delta\Theta$ is the allowed change in soil water content.

For well designed and managed SDI systems using good quality water, **Q, D, E** and $\Delta\Theta$ should be zero (some **D** may be needed to maintain a viable salt balance in arid regions). In arid regions **P** can be neglected so that for a SDI system operating at an efficiency of less than 100%, $\mathbf{I_{peak}}$ can be reduced to:

$$I_{peak} = \frac{T_{peak}}{E_i} \qquad 2$$

In which, $\mathbf{E_i}$ is defined as the ratio of water consumed by the plant to the water applied; for a SDI system, $\mathbf{E_i}$ should be at least 85-90% (0.85-0.90), $\mathbf{T_{peak}}$ is the maximum transpiration (mm/day) and it can be determined directly by lysimetry (5) or indirectly using peak reference evapotranspiration $\mathbf{ET_{o(peak)}}$ from weather station, screened evaporation pan or other methods (6) and the maximum crop coefficient $\mathbf{K_{c(max.)}}$:

$$T_{peak} = K_{c(max.)} \times ET_{o(peak)} \qquad 3$$

The system capacity may be calculated using $\mathbf{T_{peak}}$ in the following equation:

$$Q_s = 2.77 T_{peak} \times \frac{A_i}{[\tau_i \times E_i]} \qquad 4$$

In which,
$\mathbf{Q_s}$ is the water supply rate (L/sec)
$\mathbf{A_i}$ is the area being irrigated (ha)
$\mathbf{t_i}$ is the net irrigation operating time (hours/day); $\mathbf{t_i}$ should not exceed 20-22 hours/day to allow for down time and repairs.

Water quality criteria are usually divided into physical, chemical and biological. Usually, physical criteria (suspended solids) are used to determine filtration requirements, chemical criteria (pH, dissolved solids, sodium, calcium, magnesium and total iron) are used to prescribe water treatment to prevent chemical precipitation and biological criteria (algae and bacterial populations) are used to determine chlorination and/or acidification for control of biological growth and contamination.

The type of crop and the farming practices used to manage and harvest the crop will need to be well defined before the design process is started because they may affect the placement of the laterals. Unforeseen adaptations of local cultural practices may also be required to fully take advantage of the SDI technology. To avoid soil compaction, tractor wheel paths should not be located on top of SDI laterals.

III. DESIGN OF SDI SYSTEMS

The basic design and management of SDI systems differ only slightly from that of standard drip systems, except for four important factors: (1) backflow preventers, check valves and vacuum relief valves must be installed at several locations, the latter, principally at the highest elevation points of the system; (2) SDI systems require frequent flushing of the mains, submains and laterals, especially during their first 6 months of operation (installation of a buried flushing submain can be used to facilitate lateral flushing); (3) because the root systems of crops irrigated via SDI are usually located deeper in the soil profile than for crops irrigated by surface drip systems, fertility management becomes more critical because the root zone will extend into soil lacking many immobile nutrients (phosphorus in particular) and (4) chemigation to prevent root intrusion into the emitters.

Although commercial SDI systems may vary significantly in physical layout, they usually will consist of similar components such as pump, filters, chemical injection pump and fertilizer tanks, flow meter, pressure sustaining valve, solenoid valves, pressure and vacuum relief valves, mainline, submain lines, laterals and emitters. Figure 3 shows a typical SDI system layout. However, each system and its components are site- and crop-specific and will need to be designed according to the particular conditions under which the SDI system will operate. Several design programs for personal computers (PC) are available for designing microirrigation systems which are based on standard design equations. Besides the understanding of hydraulics and engineering, the design of a SDI system also requires broad understanding of soil, agronomy, plant nutrition, plant water requirements, environment and micrometeorology.

The subsurface drip irrigation system (SDIS) consists of several components (Fig. 3) which are more finitely specified following a site inspection:

a. The emitter and the subsurface drip irrigation laterals.
b. The main, submain and flushing lines.
c. The Pumping unit.
d. The Filtration system.
c. The pressure control, regulation and air relief system.
f. The chemigation & fertilizer injection systems.
g. The data acquisition and irrigation control system.

Pressure reducing and sustaining valves are needed to maintain system pressures during operation and back-flushing of the filter. The pressure control and regulation system, the main, submain and flushing lines and the drip irrigation laterals should be designed to supply sufficient water pressure and flow to maintain adequate water distribution throughout the whole system and to meet the daily evapotranspiration demand of the crops being irrigated without having to run continuously. The coarser the soil texture, the more frequent and the shorter the irrigation cycles must be and the discharge rate of emitters should be adjusted based on water transmission properties of the soil. For example, in a sandy loam soil with a bulk density of 1.5 g/cm^3 and a SDI system installed at 45-60 cm depth, irrigation should never be on for more than 45-50 minutes in order to prevent surfacing of the water. In a clay loam soil, this time can be increased to 90 minutes, but rarely more than 120 minutes. The system should then be left off for a nearly equal amount of time as it was on but never less than 30 minutes.

The system capacity should be designed to meet a peak evapotranspiration demand of the crop in less than 24 hours, typically 16-18 hours. The drip irrigation laterals should be designed for high frequency operation and laterals should be short enough to reach operating pressure quickly (no more than 2-3 minutes). Laterals for permanent crops (orchards, vineyard, turf, landscape, etc...) should be of the heavy wall type with a 1.2

mm wall thickness; tubing coils should be ordered so that no connections are needed in the middle of a row. Laterals should be connected to the submain unit at the upstream end of the laterals and to the flushing submain units at the downstream end of the laterals. Pressure relief, vacuum relief and flushing valves should be installed at each flushing manifold. Flushing manifolds should be designed to have a flushing velocity between 2 and 3 m/sec. In addition, pressure relief/vacuum breakers should be installed at all the high points of the drip laterals and check valves should be used on sloping land to prevent back flow and vacuum from being generated.

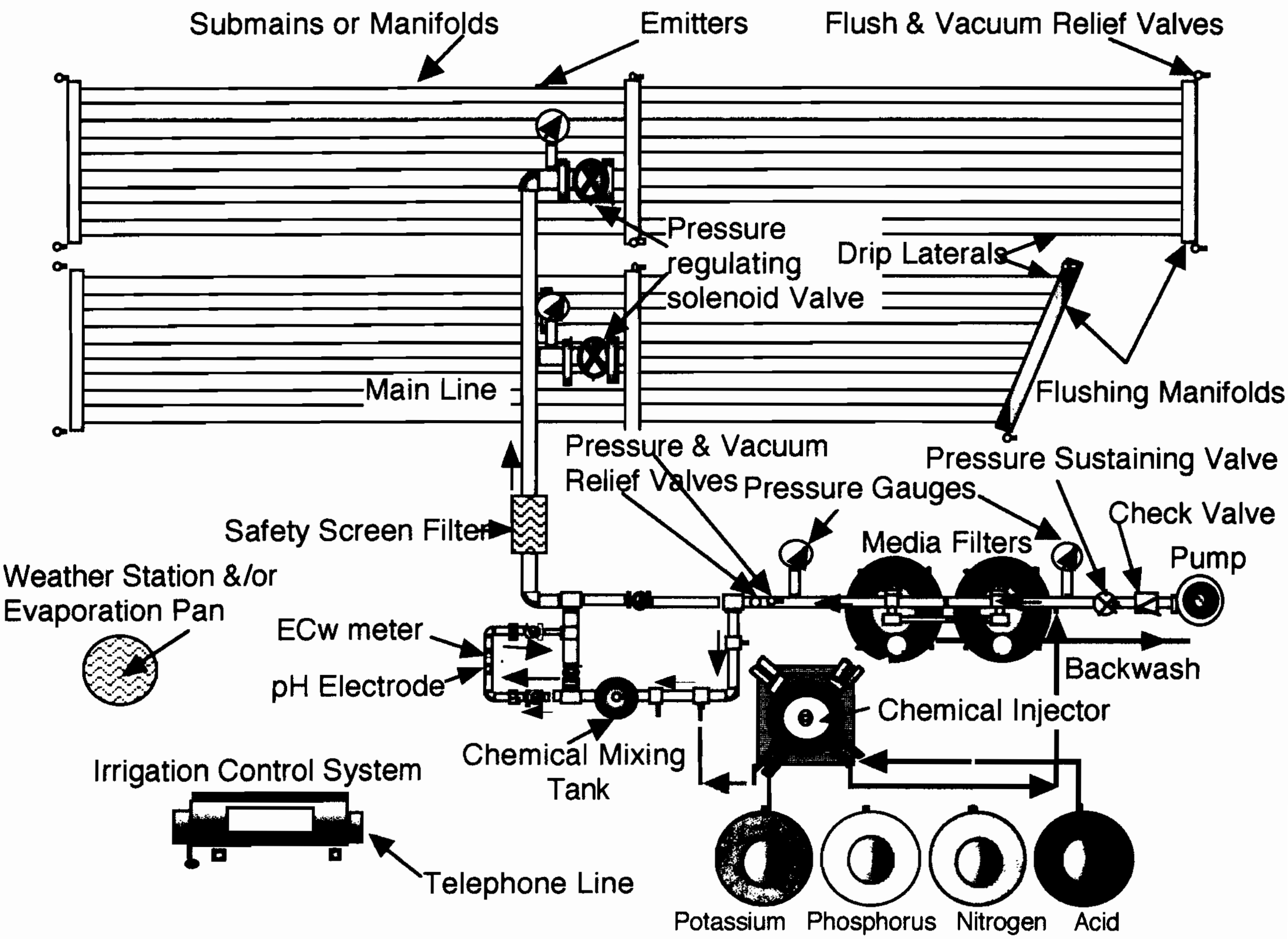


Figure 3. Typical SDI field layout showing various components and their locations.

Headworks components required to control and deliver water to the field include filtration, water conditioning, fertilizer and chemical injections, pressure control and regulation and the data acquisition and irrigation control system.

The irrigation monitoring and control system–Because the high performance of SDI systems greatly depend on high frequency irrigation and fertigation they almost always require the adoption of automation with real time monitoring of several feedback sensors and control devices. Meeting the rapidly changing evapotranspiration demand of the crop requires instrumentation to measure weather conditions in real time so that the irrigation schedule can be adjusted immediately and without delayed human intervention. SDI systems and the water they apply are not visible like in most other irrigation systems. Ensuring adequate operation requires continuous measurements of water flow and pressures to determine water availability, broken lines and/or small changes which might be caused by plugging due to root intrusion, soil accumulation in the flow path of the emitters, biological growth and chemical precipitation. Changes in water quality due to source changes and mixing of waters also require pH, water temperature and EC_W measurements in real time. The user should also be willing to adopt daily computer monitoring via telephone modem or radio frequency and data bases generation for record keeping and progressive changes in system management.

Access to the monitoring and control system from a remote location can be performed via telephone (practically from anywhere in the World where a "touch-tone" telephone is available and soon via the internet). Remote access to the system should allow: 1. downloading of the hourly data stored in the monitoring and control system; 2. loading new software or software changes into the system; 3. modifying various control and monitoring parameters and functions; and 4. monitoring the irrigation system in real time.

A written Report should be generated by the monitoring and control system to provide the user's staff with a permanent hourly account of the previous day's measurements at each site. These data should be stored in a permanent database and should be be manipulated to provide, weekly, monthly or yearly summaries. Later, data could be analyzed statistically, mathematically and/or graphically to provide powerful background for production, maintenance and economic decisions. Data should also be used to detect problems with the operation of the irrigation system.

IV. INSTALLATION AND TESTING

The proper installation of the SDI laterals is extremely important and will greatly depend on site, crop type, maturity and equipment available for the job. The following sequence of steps has been used successfully:

a. Shape the installation area as flat as possible and eliminate ruts. If installing in an existing orchard or vineyard, make one or two passes with the shank only (no tube); this will cut off existing roots and provide an open channel for installation of the SDI laterals with minimum mechanical impedance. Practicing without tube will also help the driver get a feel for the procedure and for the layout.

b. Plow in drip tubes in the chosen location, extending the ends of the tube beyond the edges of the field by 2-3 m. Extending the tube outside of the orchard will allow time and distance for the driver to pull up the shank outside of the orchard while keeping the tube at the right depth at both ends of the rows. The driver should avoid splicing the SDI laterals in the middle of a row. If planned in advance, drip lines can be ordered to match the length of the orchard (or multiple lengths). Avoid installing laterals in an implement wheel traffic area (Fig. 4).

c. After each lateral is installed and depending on the soil type and moisture conditions, the driver may need to run the tractor wheel on top of the bed to pack the soil around the drip tube. This is usually not necessary in sandy soils but is usually needed as the solid fraction of the clay/silt content of the soil increases.

d. After all the SDI laterals have been installed, each drip line should be cut at the edge of the field or dug up and pulled out, then the operator should trench perpendicular to the beds at the location where the submains/manifolds will be buried. Lateral connections to the submain are subject to modifications, based on what labor, tools and connectors are available.

e. Following connections, flushing of lines and successful leak test (all leaks should be repaired before covering the trenches), trenches can be backfilled manually (to avoid pinching) around each riser, then with the back hoe. Flow measured by the flow meter should be relatively close to the calculated design flow, based on factory emitter discharge rate and for a given pressure. **DO NOT LEAVE THE PRESSURIZED WATER RUNNING FOR MORE THAN 30 MINUTES AT A TIME.**

f. Reshape the area between the laterals. The SDIS is now ready for operation.

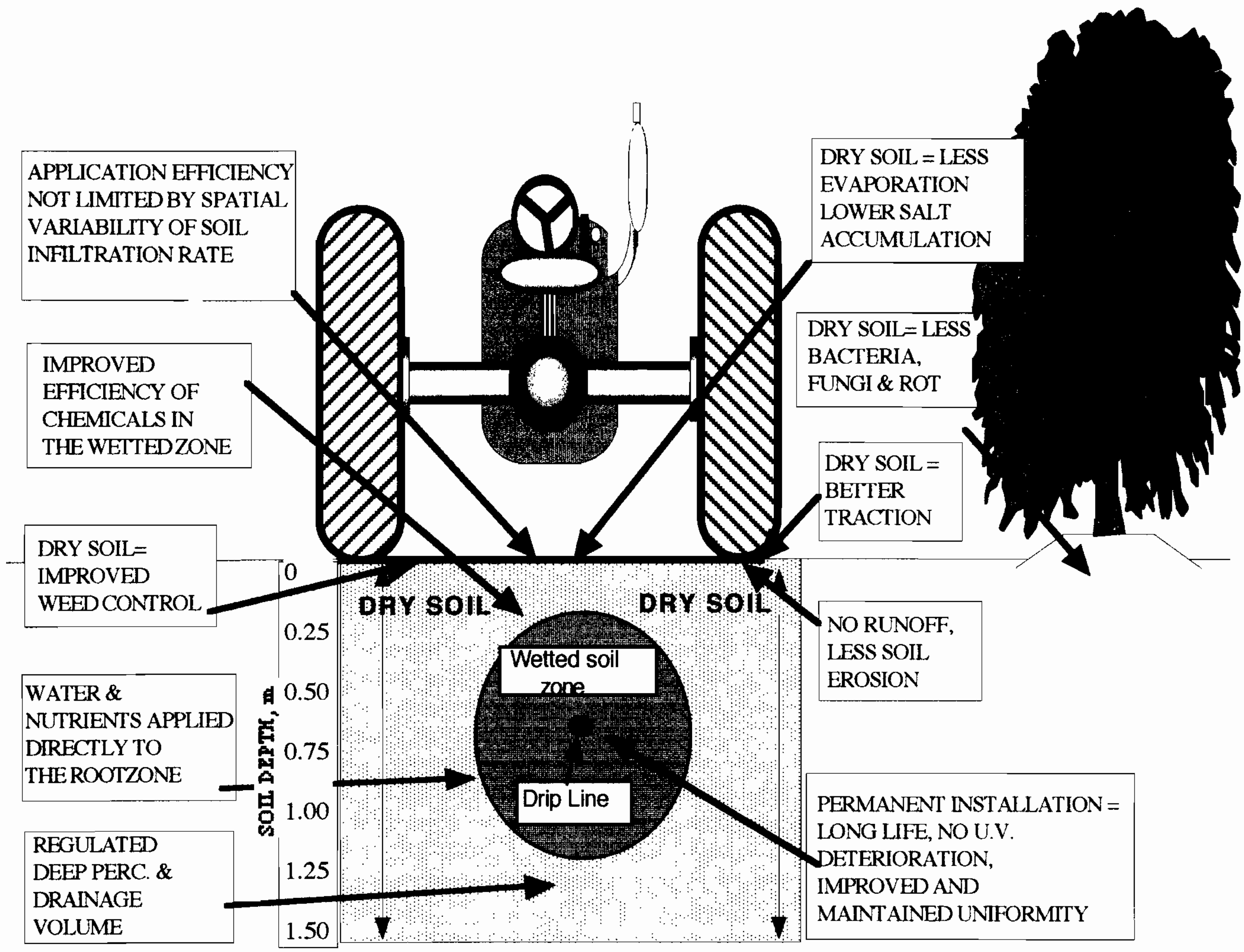


Figure 4. Preferred location of the tractor wheel path with respect to the SDI lateral and some of the benefits and advantages of the SDI method.

V. MANAGEMENT

a. High Frequency Irrigation--The ultimate goals of irrigation scheduling are to prevent plant water stress from occurring, to maximize plant growth and yield per unit of water applied and/or to manage stress as desired to achieve pre-defined economic, plant growth and quality objectives. High frequency irrigation is the frequent application of water (several times each day) via a low volume irrigation system (drip or similar) to accurately replace water lost by soil and plants by the evapotranspiration process, to maintain a portion of the root zone under nearly constant soil moisture while simultaneously minimizing deep percolation of water below the root zone and leaching of salts to the ground water.

The basic soil water concepts outlined in Part I above imply that irrigation water must be applied in short pulses so that the water movement is controlled mostly by the capillary forces and not by the gravitational force. Furthermore, under conventional irrigation scheduling, water is applied to replace several days of evapotranspiration, regardless of the future water demand by the crop, hence there is a low probability of applying the correct amount of water for the next cycle. On the other hand, the high frequency system has the potential to be adjusted for the change in evapotranspiration demand as often as once an hour, hence the probability of applying the correct amount of water for the previous hour is high.

b. Fertigation and Chemigation/Tissue Analysis The main objective of fertigation is to control and maintain the availability of various nutrients injected into the irrigation water as close as possible to the specific concentrations required for optimum plant uptake rate to maximize plant growth. Concentration of nutrients should be low and one should avoid applying fertilizer in large quantities at any time. Fertility management is more critical with SDI because the effective root system will develop in a more concentrated soil volume and deeper in the soil profile than with any other irrigation method. The concentration of slowly moving nutrients, such as phosphorus, is usually weak at that depth and can be rapidly depleted from this concentrated root volume to an amount and release rate insufficient to produce high, uniform yields and quality. Frequent (daily) applications of complete but weak fertilizer solutions will provide necessary nutrients for vigorous plant grow and also prevent movement of soluble nutrients to the groundwater.

SUMMARY

Subsurface Drip Irrigation is more than a tool for applying water. Over the last two decades, SDI has evolved into a very sophisticated system with potential high crop productivity and water use efficiency. The concepts and management of SDI systems have been discussed and summarized. Subsurface drip irrigation is the latest most sophisticated and most efficient irrigation method available. It is capable of providing the greatest yields and water-fertilizer use efficiencies of any irrigation method now in use but it also requires intensive and accurate management of water and nutrients in order to produce these expected results. Among the major changes needed, SDI requires (1) the uses of high frequency irrigation, (2) accurate and continuous injection of fertilizers and (3) sophisticated automation. The design and installation of a SDI system requires knowledge and understanding of hydraulics, engineering practices and standards and control systems; management of SDI systems requires a good understanding of the soil-plant-water-nutrient system, computers and measuring equipment. When in doubt, seek advice from a knowledgeable Federal, State or private consultant. The ultimate SDI objectives are to prevent plant water and nutrient stresses from occurring, to maximize plant growth and yield and/or to manage stress as desired to achieve pre-defined plant growth and quality objectives. Because the SDI system is usually located in the middle of the highest root concentration, it has great water and nutrient delivery and efficiency advantages over other irrigation methods and these advantages should be exploited to their fullest potential. When SDI design, installation, management and maintenance practices are fully implemented and rigorously adhered to, yields are increased so significantly that the original investment capital can be fully recovered within two to three years, depending on the type of crop being used, the original conditions, the crop price for these years and the existing economic conditions. As a final recommendation, the various design steps which are either presented or suggested here are not optional: THEY ARE REQUIRED for the SDI system to perform successfully for the long term. Also, Prospective users should investigate and take full advantage of existing and up-coming Federal and States grant and funding resources for implementation of improved irrigation and conservation practices.

Irrigation Management for Grapevines

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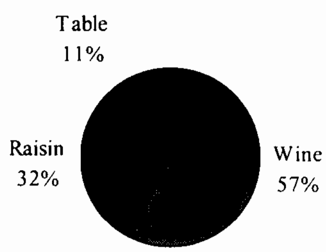
As a commercial provider of irrigation management services, California AgQuest Consulting has found that an integration of soil moisture measurement, observations of vine balance, and ET modeling can be effectively used to meet a range of grape growing objectives.

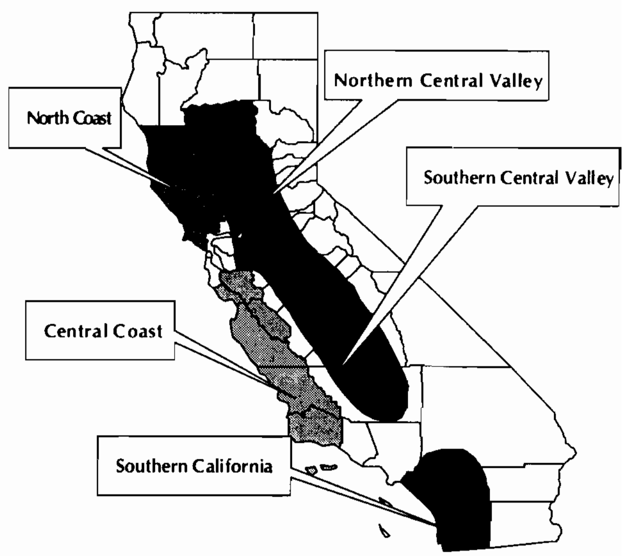
Deciding when to irrigate and how much water to apply is done by every person who is involved with farming grapevines. In most situations, individual growers make these decisions based on their own experiences. In some situations, a person who specializes in crop water management assists in the decision making process. As a commercial service company, California AgQuest Consulting provides irrigation management as a service to growers.

Grape Growing In California

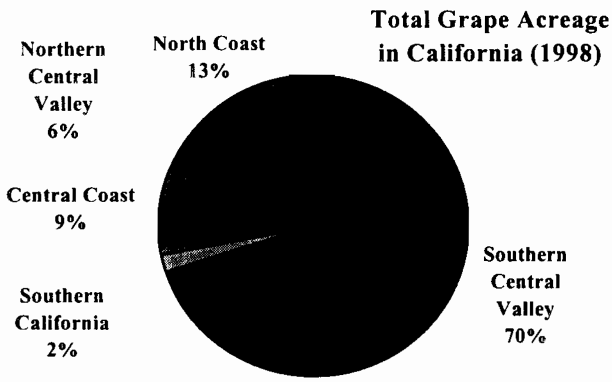
California vineyards produce grapes for use in wine production, raisins, and for the fresh market. A total of 794,000 acres of grapes are planted in California. The primary use of these grapes is for wine production (57% of the acreage). Raisin production is the next largest use (32%) and fresh market, table grapes account for the remaining (11%).

Destination for 794,000 acres (321,000 hectares) of California Grapes (1998)





The largest grape growing area in California is in the Southern Central Valley, which accounts for 70% of the total acreage. Grapes from the Southern Central Valley are used for wine, raisins and fresh market. Grapes grown in the North Coast, Northern Central Valley and along the Central Coast are used almost exclusively for wine production. These three areas account for 28% of the total grape acreage. Grapes from the Southern California area are primarily sold in the table grape market.



Goals of Irrigation Management

The goal of irrigation management should be to meet the grower's objectives in crop production. These objectives vary by the end intended use of the grapes. For table grapes, the objectives are focused on fruit appearance and yield and for raisin grapes, grade and yields. The objectives for wine grapes vary by the market demand which is a function of the area in which they are grown. In the central San Joaquin Valley, the emphasis is on yield, with a minor emphasis on quality characteristics. On the North Coast and along the Central Coast, there is much more focus on grape quality.

Irrigation Management Methods

There is a wide range of techniques and tools which can be employed to help make water management decisions for grapevines. One of the most commonly used techniques involves monitoring the visual appearance of the vine combined with a grower's experiences from prior seasons. Measuring the soil moisture levels is the first tool "upgrade" in making water management decisions. Soil moisture measurement tools include simple approaches such as using tensiometers, gypsum blocks or Watermark sensors, and a hand soil probe. More sophisticated devices are also used which include neutron probes, Frequent Domain Reflectometry (FDR) and Time Domain Reflectometry (TDR) instrumentation.

Plant based measurement approaches are almost always an integral part of an irrigation management system. These can be sophisticated instruments like infrared thermometers, pressure chambers, and stomatal resistance devices but are more commonly less complicated approaches such as watching tendril growth or observing fruit/canopy balance. Evapotranspir-ation (ET) computer modeling can be successfully used in grapevine water management as a short/medium term scheduling tool or as part of a longer range planning approach.

In our experience, the selection of which tools to use is really quite simple. It is that tool or combination of tools which helps to make the best decisions to reach the crop growing objectives while being consistent with the economics afforded by the crop. The tools chosen must also fit the growing circumstances for the grapes including the type of irrigation system, soil physical and chemical characteristics, and soil the moisture regime which the grapes will experience.

For grapevines, we have found that a combination of three tools has provided the best results. We use neutron probes to measure soil moisture, observations of vine balance to monitor vine growth, and ET modeling to determine irrigation timing and amounts. This system of tools integrates soil conditions with vine growth characteristics and can be adapted to varying crop growing objectives. In practice, vine growth is monitored weekly along with weekly neutron probe data collection. Available moisture is calculated from the neutron probe data and a graphic report generated. These activities essentially set the timing of each irrigation event. ET modeling and personal experience are used to determine irrigation amounts.

Irrigation Timing Decisions

Decisions concerning the timing of irrigations must ultimately be based on the crop growing objectives. Other considerations which will play a role in the decision are the availability of water resources and any special considerations concerning an individual vineyard site such as soil pests or adverse soil chemistry. We have found that one of the best approaches to timing decisions is to use a system based on the percentage of available moisture in the soil.

The percentage of available moisture can be assessed by hand probing the soil or by using neutron probe data. Available soil moisture can be derived from neutron probe data by setting a full point and permanent wilting point for each depth in the soil (soil moisture is monitored at one foot increments to a depth of five to seven feet). Each reading is then translated to the percentage of available moisture. A field capacity soil moisture condition is set at 100% and the permanent wilting point at 0%. Based on our experience and through replicated trial work with the Viticulture and Enology Research Center (California State University, Fresno), we have been able to develop available soil moisture thresholds which can be used as guidelines for irrigation timing decisions. The typical seasonal threshold levels varies for different grape growing areas and grape end uses.

Table 1

Typical Available Soil Moisture Thresholds for Irrigation Timing

Area / End Use	Bud Break to Bloom	Bloom to Veraison	Veraison to Harvest	At Harvest
SJV Table	75%+	75%+	75%	70%
SJV Raisin	75%+	75%+	75%	60%
SJV Wine	75%+	75%+	70%	60%
NC & CC Wine	75%+	75% decrease to 50%	50%-60%	50%

Irrigation Amount Decisions

Individual seasonal irrigation amounts as well as totals for the season are dictated by the grape growing area and by the end use objective for the crop. In the central San Joaquin Valley, growers are paid for total yield as long as that yield is consistent with minimum quality standards. This means that in the San Joaquin Valley, we strive to apply irrigation amounts that produce the highest tonnage. This is typically 70% to 80% of a well watered, full crop ET. At the end of the season, as we summarized our total Net Vine Water Use, we should have applied enough water such that our total Net Use is equal to 70% to 80% of full ETc.

On the North Coast and along the Central Coast, the quality characteristics of grapes plays a more significant role and to achieve this goal we practice Regulated Deficit Irrigation (RDI). As can be seen from Table 1, beginning at a point about two to three weeks before veraison, we decrease our irrigation timing threshold and start irrigating with less than full crop ET. The effect of this RDI strategy is to reduce the vine water use to 40% to 60% of full ET for the season.

Table 2 summarizes the Net Vine Water Use guidelines which we use in providing irrigation scheduling services to growers. Net Vine Water Use is calculated by summing the net amounts of seasonal irrigations plus net seasonal rainfall plus stored winter rainfall.

Table 2

Net Vine Water Use as a Percentage of Full ETc

	Net Vine Water Use as a Percent of Full Etc (RDI)	Typical Annual Net Vine Water Use
SJV Table,	80-90%	25 inches
SJV Raisin	70-80%	22 inches
SJV Wine	70-80%	22 inches
CC Wine	40%-60%	16 inches
NC Wine	40%-60%	11 inches

Conclusion

Understanding the grape growing objectives for an individual vineyard are important to the selection of the tools, techniques, and methods used to make irrigation timing and amount decisions. Crop economics as well as water resources frequently dictate the choices of the tools and methods. The key to successful water management is to select a strategy and appropriate support tools to meet the growing objectives of the grapes.

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Water Management Using Continuous Soil Moisture Monitoring

by Dale Handley

California Plant and Soil Conference – Stockton, Ca. -January 19, 2000

In recent years, 22 California crops, primarily vegetables, fruits and nuts, covering about 2.8 million acres, influenced or dominated the U.S. market, and produced average yearly gross revenues of about $7 billion. It is this segment of the agricultural market that is growing at the fastest rates. However, the viability of this sector will be severely impacted in the next ten years by:

- the availability of an affordable water supply
- water quality regulation
- urban encroachment
- access to world markets
- emergence of agricultural export capability in other countries
- the availability of labor
- pesticide regulation

In order to remain viable in spite of these impacts, California growers will need to become much more efficient with their water management, especially as it impacts of the quality of the end product. One promising new technology for water management is the "continuous" soil moisture monitoring system.

Dale Handley Irrigation Consultants have worked closely with 25 of the top agricultural companies and research organizations in California during the last five years to implement continuous soil moisture monitoring in their operations. In this paper we will describe some of the principles of using continuous soil moisture data for scheduling irrigations, and point out some areas of research that we feel should be pursued, in order to increase the efficacy of this technology.

Background

Efficient water management requires decisions to be made regarding when to irrigate, how much water to apply and where is should be applied. There are many economic, agronomic, meteorological and soil factors which influence these decisions. Traditionally, three systems have been used to facilitate these decisions:

- Evapotranspiration models – Crop water use is estimated based on climatic data and crop coefficients. Irrigations are scheduled to replace estimated crop water use.
- Soil Water depletion- Sensors that measure soil water content are used to estimate the soil water depletion, and irrigations are scheduled to replace the depleted water.
- Plant Water Stress – Plant water stress is monitored, and irrigations are scheduled based on threshold values of crop water stress.

In practice, these methods are often combined. A common method is to schedule irrigations based on evapotranspiration estimates, and to monitor soil water content or soil water suction, in order to verify the evapotranspiration estimates.

Soil moisture has traditionally been measured by periodically reading sensors, which are installed in the soil, or by using portable devices to periodically measure soil moisture status. All soil moisture sensors can be divided into two groups, those that measure soil suction (tensiometers, gypsum blocks, granular matrix sensors, heat dissipations sensors) and those that measure soil water content (neutron probe, time domain reflectometry, and frequency domain capacitance).

Continuous monitoring of soil moisture uses the same sensors (with the exception of the neutron probe), but differs in the frequency of measurements. "Continuous monitoring of soil moisture" is defined here as very frequent measurement of soil water content or soil suction. A measurement interval of less than 30 minutes was used in all the work described here.

A continuous monitoring system consists of sensors permanently installed in the field, and a data logging system, which may be in the field or in the office if remote communications are used. Most systems use loggers in the field to store the data, and data is retrieved remotely using radio or telephone communications systems, or data is retrieved on-site, using portable computers or hand-held devices, and a hard-wire connection. Continuous monitoring systems can be interfaced with the irrigation controller, to provide an automated irrigation system.

From 1995-1999, our company has worked with the EnviroSCAN continuous soil moisture monitoring system. We have installed 45 systems in 14 different crops, and reviewed the data on most of these projects. The EnviroSCAN is a system of frequency domain sensors inside permanent access tubes, which are wired to a data logger for "continuous" measurements at multiple sites and multiple depths at each site. The EnviroSCAN sensors are calibrated to measure soil water content. Downloading of logged data was accomplished in the field with a laptop computer. (The EnviroSCAN capacitance probe has been described in more detail by Paltineanu and Starr (1977).

Based on our experiences, we feel that continuous soil moisture monitoring can be very valuable, especially in certain situations. We have also become aware of problems, which can occur, with use of this type of system.

Principles of Use

The continuous data can be used as the primary scheduling mechanism, or as a supplemental mechanism. In most of the systems we worked with, it was used as the primary scheduling mechanism. The summed water content for the root zone was plotted on a graph. The goal of irrigation scheduling was to keep the water content between a refill level and a maximum level of water content. These levels can be changed during the season.

Figure 1 illustrates the use of continuous data to schedule irrigations. Data was downloaded on 9/16, and based on the water content pattern since the last irrigation and the weather forecast, the decision was made to irrigate for 8 hours every 3 to 4 days. The resulting pattern indicates that water content stayed between the refill and "full" points. After an 8-hour irrigation, the water content increases by approximately 30 mm, and after 4 days it decreases by approximately 30 mm

It is obvious from these examples, that this system is based on measuring soil water depletion. The same ends could be achieved with periodic monitoring of soil water content, but to achieve a rough approximation of the resolution, measurements immediately before and after each irrigation event would be required. Unfortunately, this is unlikely to be done in a commercial situation. Typically periodic measurements are made on a weekly basis.

Figure 2 plots the same water content data as Figure 1, based on a weekly measurement of water content. If the first measurement is on Sept. 13, it appears that water content is increasing each week. If the first measurement is on Sept. 14, it appears that water content is decreasing each week. Obviously, if weekly measurements are made, they make sense only if viewed in relation to the timing and amount of the last irrigation.

Figure 1. "Continuous" Plot of total water content in 5' soil profile in wine grapes.

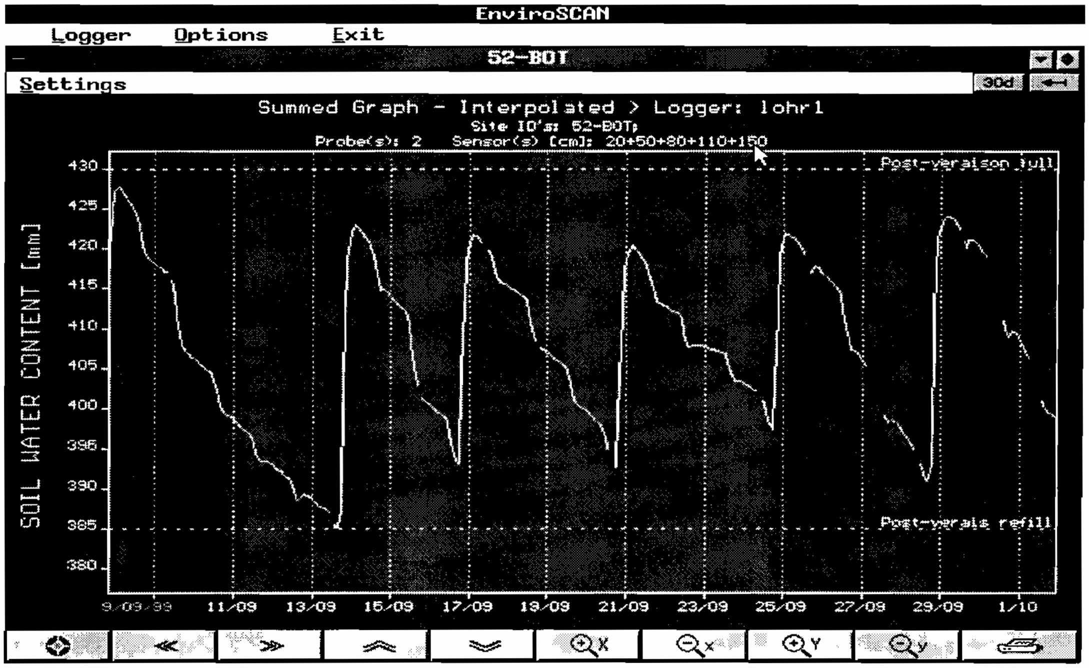
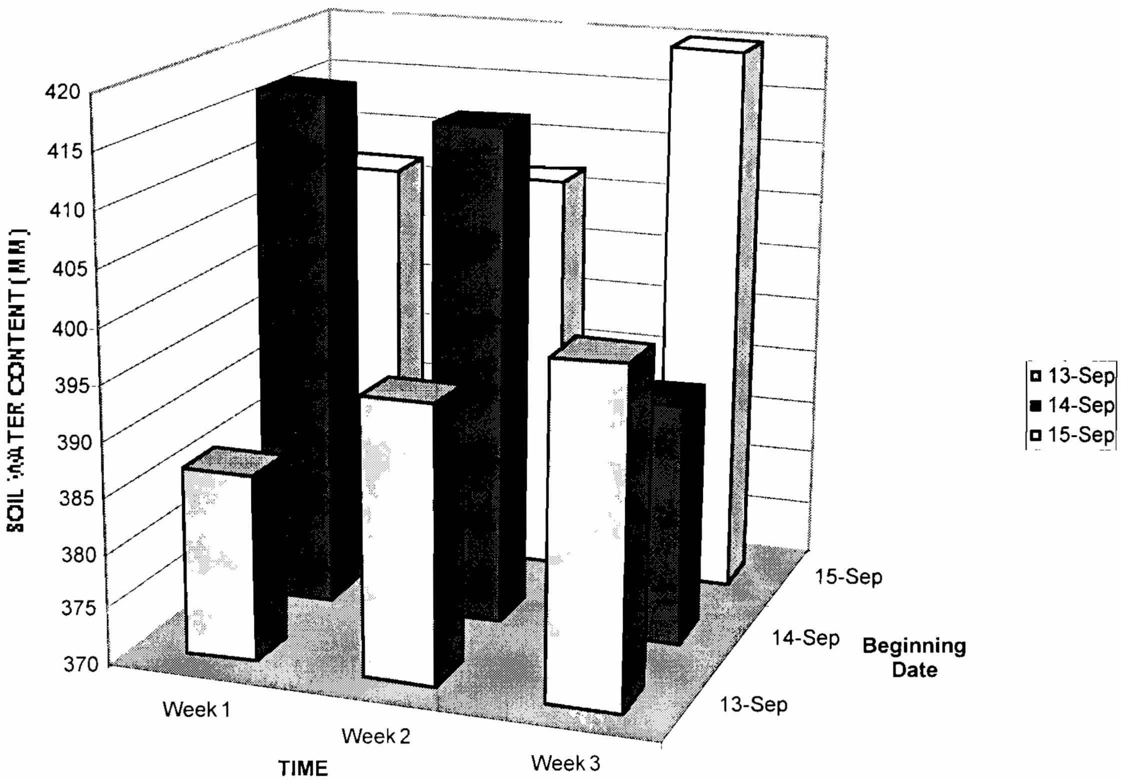


Figure 2. Periodic plot of water content in 5'soil profile in wine grapes.



Comparing the data from Figure 1 and Figure 2:

In Figure 2, based on **periodic monitoring,** we can see:

1) The water content on the dates of measurement

In Figure 1, based on **continuous monitoring,** we can see:

1) The water content at any point in time over the whole period.
2) The change in water content on a daily basis.
3) The dates of irrigation.
4) The length of irrigation. (Requires zooming in).
5) The amount of water applied in the wetted zone around the tube.
6) The continuous trend of water content over the whole period.

As mentioned above, scheduling with continuous data requires setting a maximum level of water content and a refill level. This is true with any scheduling system based on soil water depletion. In order to set these points it is helpful to know the water content of the soil at field capacity, and the water content of the soil at "onset of stress". With continuous soil water content data, it is possible to specify these levels fairly precisely.

Figures 3 and 4 show the summed water content and the separate sensor water content from an EnviroSCAN probe in wine grapes. In Figure 4, **the full point** has been set at 495 mm and the onset of stress at 350 mm. The full point setting in Fig. 4 is actually based on the separate sensor graph in Fig. 3. In Fig. 3, on 4/9, a rainfall event is shown, which infiltrated water to 150 cm. (based on an increase in water content at 150 cm.) There is some indication of infiltration past 150 cm. (a continuous decline in water content, from 4/12-4/17). We want to set the full point at the summed water content resulting from an infiltration event that reaches 150 cm., but does not infiltrate beyond 150 cm. Therefore, in Fig. 3, we have set the full point at 485 mm., since some deep infiltration resulted from this infiltration event which produced a total water content of 495 mm.

The "**onset of stress"** line in Fig. 4, is set 350 mm., which is the level at which the slope of the decreasing water content line changes on 6/5 and again on 7/3. The slope of the line changes, because the daily extraction of water begins to decrease at this point, due to soil dryness.

The ability to identify the full point and the "onset of stress" point is very useful for irrigation scheduling. For many crops, it is desirable to keep the soil profile near the "full point" during most of the season. For other crops, it may be desirable to maintain the water content near the full point for part of the season, but to allow some stress during part of the season. In Fig 4, irrigations from 4/5 through 5/9 were scheduled at a refill point of approximately 450 mm, and the duration was such that the full point was not reached. From 5/9 until 6/24 there were no irrigations, because the goal was to deficit irrigate the grapes during the post-bloom period, in order to decrease berry size.

Once the full point and onset of stress lines are set, an irrigation strategy can be laid out, based on maintaining the soil water content within a certain range, during different phenological stages of the crop. A successful template can be used in subsequent seasons to produce the same results (hopefully).

Figure 3. Water content of sensors at 10, 30, 60, 90, 120 and 150 cm. in wine grapes from 3/30 through 6/25/96.

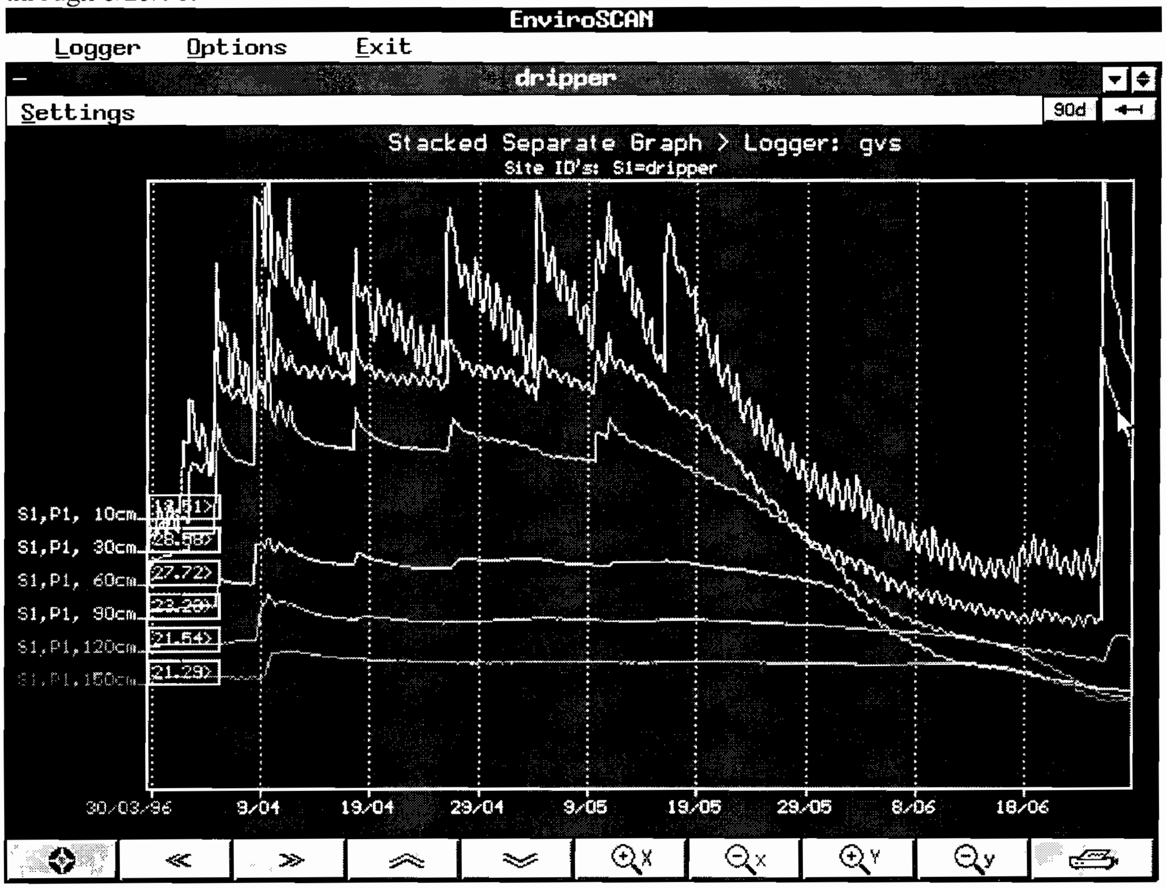
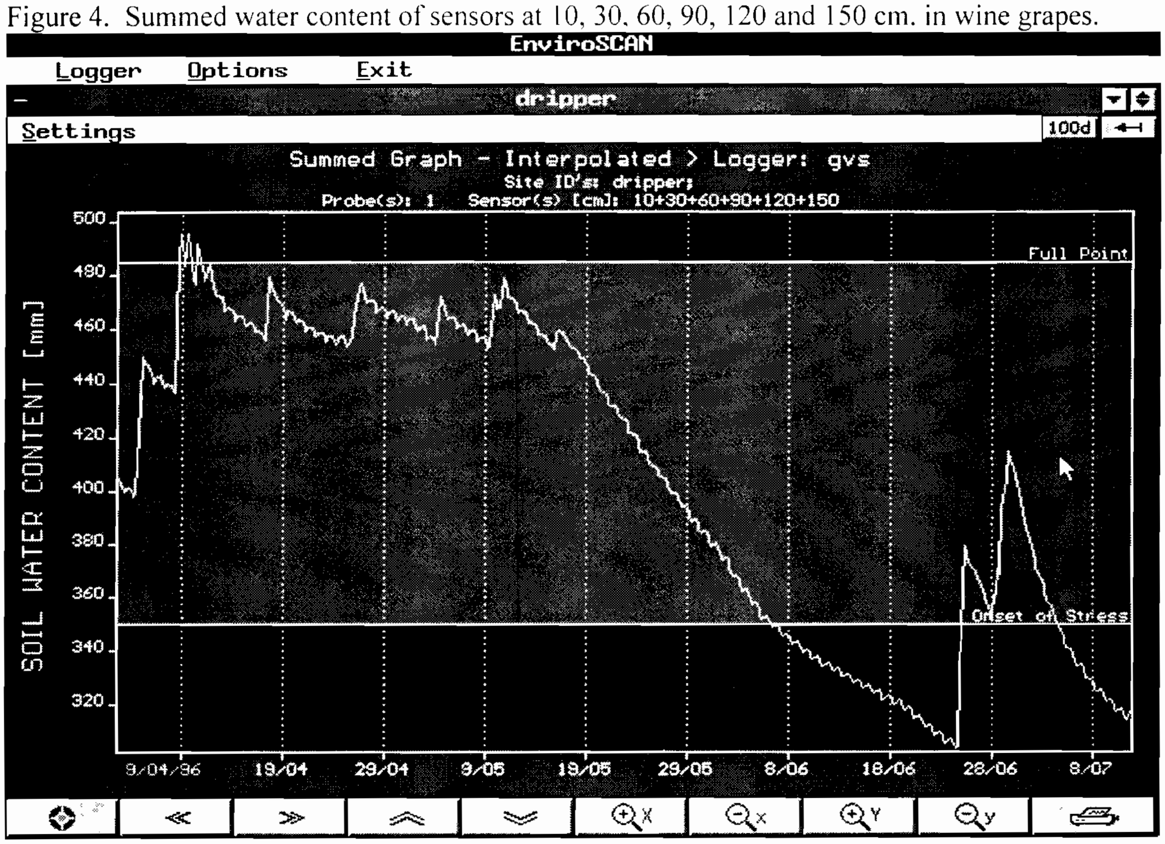


Figure 4. Summed water content of sensors at 10, 30, 60, 90, 120 and 150 cm. in wine grapes.



Strategic Uses of Continuous Soil Moisture Monitoring

Continuous soil moisture monitoring data, has two unique attributes, which are very valuable in particular cropping situations. These are the ability to :

1) determine the water content at which extraction slows down ("onset of stress"), and to monitor the magnitude of the decrease in extraction and the duration of the decrease in extraction.
2) monitor the duration of infiltration below the root zone, and potentially, the amount of water infiltrated below the root zone.

In the course of working with 45 EnviroSCAN systems during the last 5 years, our observation has been that when one of these two attributes is critical to crop production, the value of the system is greatly increased. We found three cropping systems in which use of system was very successful.

1) Avacadoes in Southern California. (See Oltman, 1998). Avacadoes in southern California are irrigated with saline water from the Colorado river, which is very expensive due to high pump lifts. Avacadoes are also very susceptible to phytophora root rot, which increases under saturated conditions. Growers tend to under-irrigate due to the high water cost, which results in build-up of salts in the lower part of the root zone. During periods of high evaporative demand, water and salts are extracted from this lower part of the root zone, with detrimental effects to tree health. We developed the practice of installing 50 cm. probes, with sensors at 10, 30 and 50 cm. Our strategy was to manage the irrigations to maintain a high water content at the 10 and 30 cm. sensors, and **to achieve infiltration of water below the 50 cm. sensor on a regular basis**, based on daily evaluations of the data. This strategy led to improved tree health, with minimal increase in water use. The ability to continuously monitor the infiltration past the 50 cm. sensor is critical to this system.

2) Drip-irrigated strawberries on the Central Coast. High frequency drip irrigation (2-3 irrigations per day) is used to maintain optimal water content in the entire strawberry bed. We installed 50 cm. probes with sensors at 10, 20, 30 and 50 cm. Our strategy was to manage the irrigations to maintain a high water content at 10-30 cm., and to minimize infiltration past the 50 cm. sensors. This strategy was successful. Theoretically, this strategy could be implemented with periodic measurements of tensiometers. However, the continuous data removes any doubt about the water status between periodic measurements. Also, the convenience of downloading data from 16-32 sensors at one time, as opposed to reading and maintaining 16-32 tensiometers several times per week, is very important.

3) Deficit irrigated premium wine grapes on the Central Coast. In recent years, research has indicated that the wine quality from red grapes can be improved by early season deficit irrigation. We installed 150 cm. probes. with sensors at 20, 40, 70, 110 and 150 cm. in a number of blocks with several growers. Our strategy was to achieve sufficient water stress during or after berry set, through veraison, to stop shoot growth. Post-veraison we experimented with different levels of water stress. **We have learned that the slow-down in extraction measured with continuous soil moisture monitoring in the drip zone, does not necessarily correlate with plant water stress.** Our observation is that in deep soils, water is extracted preferentially from the upper root zone in the dripzone, but when that water is gone, extraction from other areas of the root zone, is sufficient to maintain the vine without water stress for long periods. Therefore, multiple deep probes per vine would be required to adequately estimate the onset of stress. We feel that it is

more practical to measure plant water stress directly, until the reserve water from outside the drip zone is depleted. From that time on, a good correlation between the decrease in extraction indicated by continuous soil moisture data in the drip zone and actual plant water stress should exist, so that scheduling based on the continuous data should be correct.

Areas of Concern

Continuous monitoring of soil moisture offers potential for improving irrigation management of high valued agricultural crops. Particularly in the areas of deficit irrigation management, and management of infiltration of water below the root zone, this technology offers significant advantages. However, there are areas of concern:

1) It is important that the probes be installed in representative sites in a field. This requires a survey of soil variability and irrigation system variability.
2) How can we use continuous soil moisture data to quantify leaching of water below the root zone? Fares and Alva (1999), have initiated research in this area, but additional research is necessary. The ability to quantify the amount of water leached below the root zone will have far-reaching environmental impacts.
3) How well does continuous soil moisture data predict crop water stress? Goldhamer, et al. (1999) have initiated research in this area, but much more work is required.
4) How can the installation of sensors be simplified and improved, in order to guarantee reliable data?

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Effect of Partial Rootzone Drying on Vineyard Water Use, Vine Water Relation, Yield Components, and Fruit Composition in Field-Grown Mature Sauvignon blanc Grapevines – A Preliminary Evaluation in California

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Partial rootzone drying (PRD), derived from split root research, is an irrigation technique which modifies the vine growth and development by keeping part of the rootzone dry and the rest of the rootzone well watered. PRD offers a way to produce a vine with a better balance between vegetative and reproductive development, holding the promise of significantly reducing vine water use, controlling vine vigor and canopy density, and maintaining crop yields when compared to standard vineyard irrigation practices. Experiments have also shown that when the wetting and drying sides are alternated periodically, usually every 10-14 days, the drying roots are maintained in a healthy condition by water supplied from the well-watered roots.

PRD stimulates physiological responses associated with water stress while maintaining an adequate water status in above ground tissues of the vine, resulting in a significant reduction in water use and vine vegetative growth. Consistent reduction in pruning weight, node number, leaf area especially those on lateral shoots, and increase in amount of light reaching the fruit zone are found in vines subjected to PRD treatment. Because of less shoot growth, the canopy is more open and fruit exposure is improved. PRD improves fruit quality such as lower pH, higher anthocyanins, phenolics, and glycosyl-glucose, possibly related to reduced canopy density. Maturity is also advanced by PRD treatment. However, PRD treatment did not induce a significant reduction in yield and berry size, indicating PRD offers an advantage over regulated deficit irrigation (RDI) which usually causes a significant decrease in berry size and yield in response to a substantial reduction in the amount of water applied.

It is demonstrated that an increase in abscisic acid (ABA) content derived from the drying roots is responsible for the decrease in stomatal conductance, photosynthesis, and vegetative growth and the improvement in water use efficiency. The decrease in vegetative growth is due to the reduced photosynthesis and the inhibition by elevated ABA content.

There is no information available in the technical literature on PRD in California vineyards. It is possible to expose the fruiting zone to excessive levels of sunlight causing sun burn if there is too much reduction in leaf area, especially in the San Joaquin Valley of California where the sunlight level can be very high during the growing season. Influence of PRD in water uptake may also affect mineral nutrition status which may alter the growth and development of the vines vegetatively and reproductively.

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The objective of this research was to investigate the feasibility and effect of PRD on vineyard water use, vine water relation, vegetative growth, mineral nutrition, yield components, and fruit composition in field-gorwn mature Sauvignon Blanc grapevines (*Vitis vinifera* L.) grown in the San Joaquin Valley of California.

Materials and Methods

Experimental Design. This study has being conducted in a 15-acre bilateral cordon trained mature Sauvignon Blanc/Freedom vineyard on Hanford Sandy Loam in the California State University, Fresno Agricultural Laboratory. The experiment is designed as a randomized complete block with four replications. Treatment factors include irrigation methods, PRD vs. conventional drip irrigation (CDI) and amount of water applied, 0.4 and 0.8 evapotranspiration (ET), resulting in 4 treatments, CDI-0.4, CDI-0.8, PRD-0.4, and PRD-0.8. Viticulture data have being collected from three representative vines located in the middle row of each irrigation treatment plot.

Irrigation System Design. Drip irrigation system for PRD and control was designed, installed, and tested in May 1999. Each vine is serviced by two emitters spaced 48 inches apart down the row between trunks except CDI-0.4 which is serviced by one emitter at the trunk during the period of PRD experiment. The PRD treated blocks were designed with two-polyethylene (PE) tubes. Odd numbered vine spacings of 1, 3, 5, etc. are serviced by emitters on one PE tube and the other PE tube supplies water to even numbered vine spacings of 2, 4, 6, etc. with emitters. This allows for alternate wetting and drying of either side of the vine, depending on the tube selected for irrigation and cycle time. Different amount of water was achieved by using emitters with a flow rate of either 0.6 or 1.2 gallon per hour. All the emitters are pressure-compensated (Netafim Irrigation, Inc., Fresno, California).

Irrigation Schedule. The vines have been irrigated daily since March 23 this year. PRD was applied during May 25 and August 31. The wetting and drying sides of PRD treated vines were alternated on May 25, June 22, July 9, July 24, August 7, and August 21. Conventional drip irrigation applying 0.8 ET was used for all the treatments prior to and after PRD treatment.

Water Use. Amount of water applied was calculated by multiplying the hours of irrigation system run time and flow rate of the emitters.

Vine water relations. Stomatal conductance (g) and transpiration rate (E) of recently-matured healthy leaves were measured with a porometer (LI-1600; LI-Cor, Inc., Lincoln, Nebraska) during June 21 and July 19 and again during August 9 and August 19 every 1 to 7 days.

Canopy microclimate. The canopy radiation in fruiting zone were assessed in July between veraison and harvest.

Yield components. Cluster number and yield were collected at harvest on August 26, 1999.

Fruit composition and maturity. Samples were taken on August 10, 17, and 25. Berries were analyzed for berry weight, % soluble solids (Brix), titratable acidity (TA), and pH.

Data analysis: Data analysis was conducted with variance analysis and correlation and regression procedures of selected variables according to experiment design to reveal the effect of PRD on the parameters measured.

Results and Discussion

Water use of vines irrigated with 0.4 ET (CDI-0.4 and PRD-0.4) is only 50% of that for vines irrigated with 0.8 ET (CDI-0.8 and PRD-0.8) during the PRD treatment. Amount of water applied was the same for all the treatments at the level of 0.8 ET prior to or after PRD treatment. Water use efficiency was much high in vines irrigated with 0.4 ET compared to that with 0.8 ET. Water saving of CDI-0.4 and PRD-0.4 was about 30% over CDI-0.8 and PRD 0.8 (Table 1).

The g and E were reduced when less water was applied in PRD-0.4 and CDI-0.4 or with the same amount of water applied on one side of the vine in PRD-0.8, compared to CDI-0.8. CDI-0.4 showed the most decrease in stomatal conductance and transpiration rate, lower than PRD-0.4 with the same amount of water applied. The g and E of PRD-0.8 is lower than CDI-0.8 but higher than PRD-0.8. An over-recovery of g and E was observed after alternating the drying and wetting sides with PRD-0.4 and PRD-0.8 (Fig. 1).

Neither irrigation methods nor amount of water applied affected cluster number or yield significantly. The decrease in cluster and berry weight caused by PRD or CDI-0.4 did not result in significant yield reduction (Table 1). Yield was related to cluster number but not to cluster weight (Fig. 2).

PRD and amount of water applied only affected total acidity (TA) at early stages of fruit maturation. TA was higher in CDI-0.8 and PRD 0.8 than in CDI-0.4 and PRD-0.4. The significant difference diminished later during the fruit maturation towards harvest. Soluble solids content and pH were not influenced by either PRD or amount of water applied (Fig. 3).

Vine mineral nutrition and vegetative growth is under evaluation. The same experiment will be conducted again in 2000 and a more comprehensive report will be presented at a later date.

Preliminary experiments conducted so far demonstrated that PRD offers a way to produce a vine with a better balance between vegetative and reproductive development, reducing vine water use, controlling vine vigor and canopy density, and maintaining crop yields when compared to standard vineyard irrigation practices. PRD stimulates physiological responses associated with water stress while maintaining an adequate water status in above ground tissues of the vine, resulting in a significant reduction in water use and vine vegetative growth. However, PRD treatment did not induce a significant reduction in yield. Partial stomatal closure due to PRD resulted in a decrease in g, E, and in turn an improvement in water use efficiency. It holds potential to be one of the very useful vineyard practices in the San Joaquin Valley of California.

Acknowledgement

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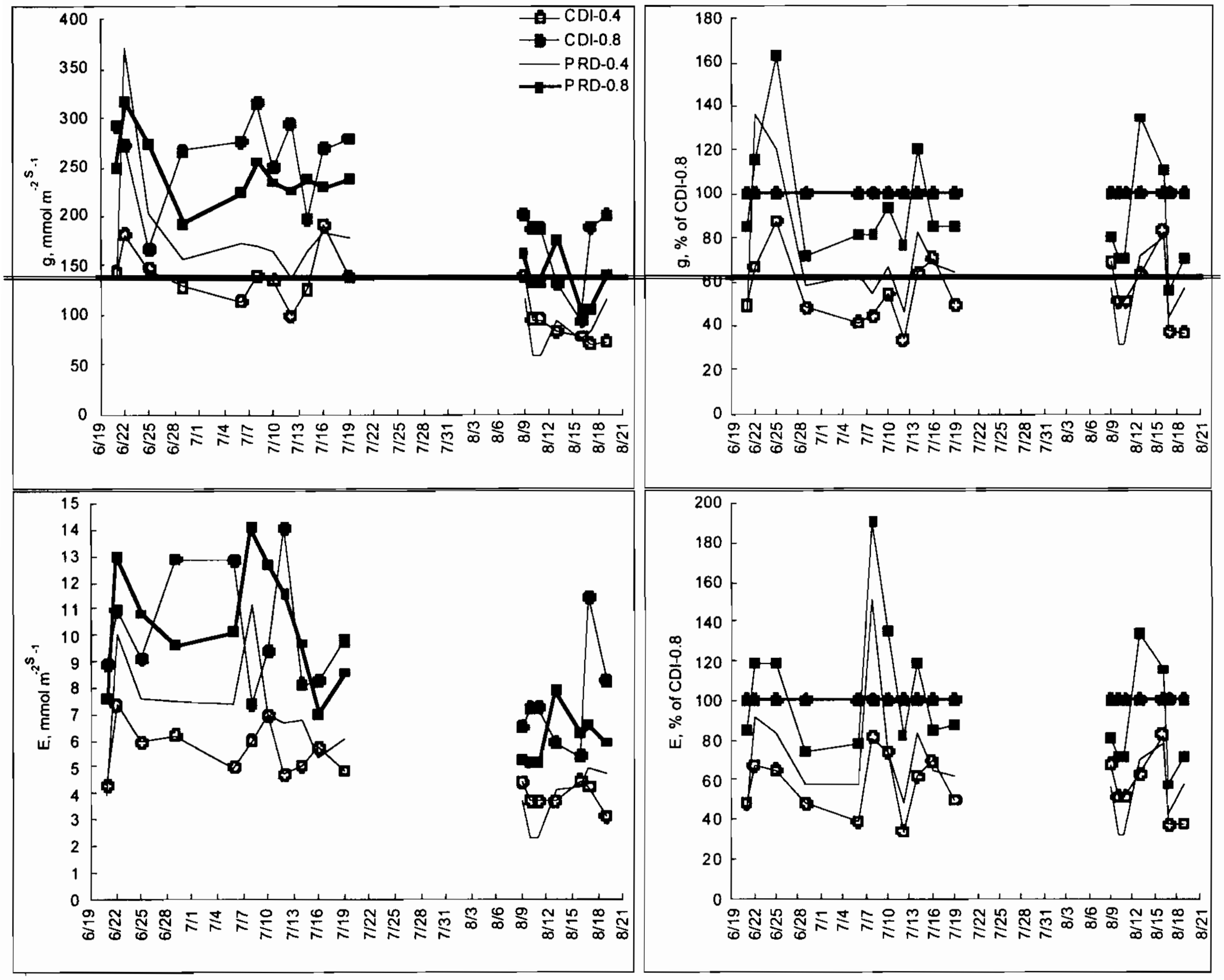

Fig. 1. Effect of partial rootzone drying (PRD) and conventional drip irrigation (CDI) at 0.4 or 0.8 ET on mature leaf stomatal conductance (g) and transpiration rate (E) in Sauvignon blanc grapevines.

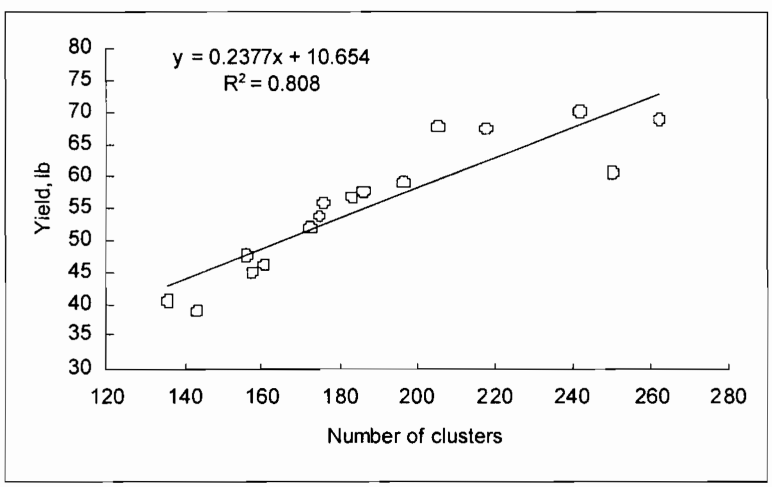

Fig. 2. Relationship between yield and cluster numbers in Sauvignon blanc grapevines watered with partial rootzone drying (PRD) or conventional drip irrigation (CDI) at 0.4 or 0.8 ET.

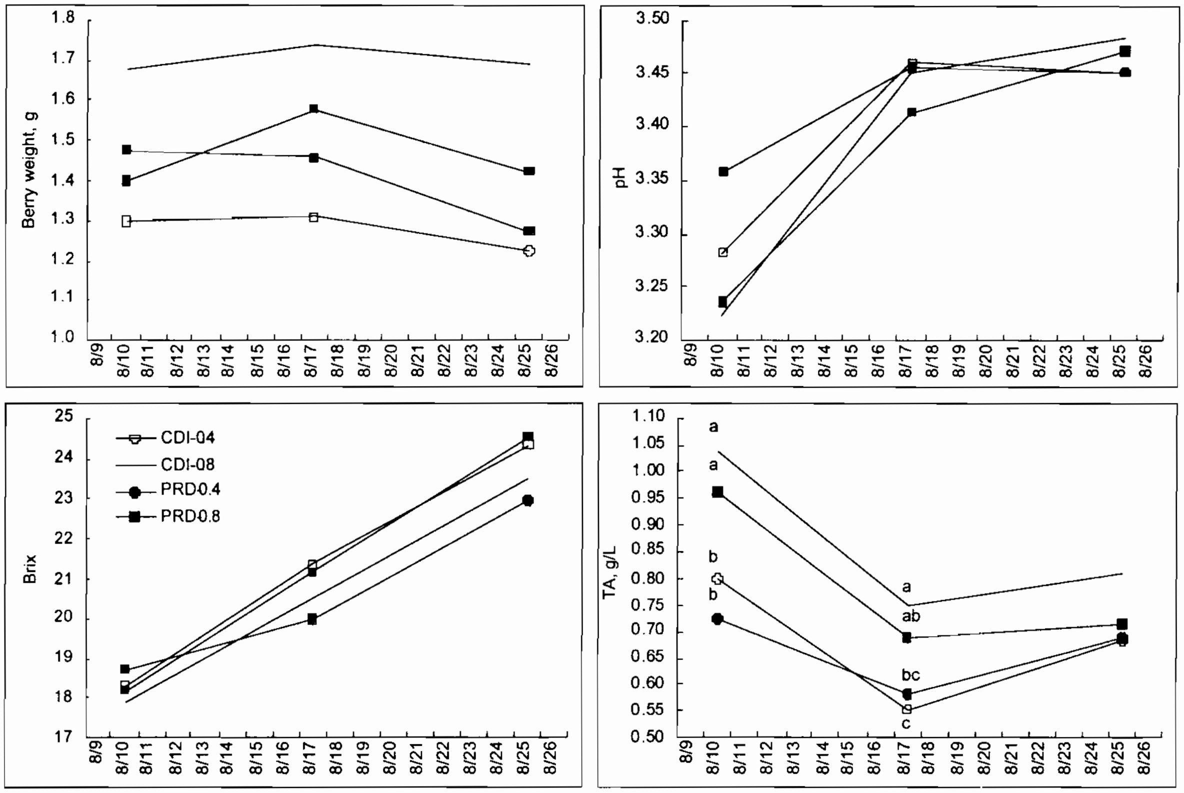

Fig. 3. Effect of partial rootzone drying (PRD) and conventional drip irrigation (CDI) at 0.4 or 0.8 ET on berry weight and fruit composition in Sauvignon blanc grapevines. Different letters for each sampling indicate a significant difference by Fisher's LSD at p=0.05 level.

Table 1. Effect of partial rootzone drying (PRD) and conventional drip irrigation (CDI) at 0.4 and 0.8 ET on yield components and water use efficiency in Sauvignon blanc grapevines

Treatment	Clusters /vine	Yield (lb/vine)	Cluster weight (lb)	Berry weight (g)	Water applied (gal)	Water use efficiency (gal/lb)
CDI 0.4	177	47.8	0.27 b[z]	1.22 b	1128	24
CDI 0.8	184	57.1	0.31 a	1.69 a	1696	30
PRD 0.4	213	61.2	0.29 ab	1.27 b	1172	19
PRD 0.8	180	56.0	0.31 a	1.42 b	1652	30

[z]Means within columns followed by different letters are significantly different by Fisher's LSD at

Uses of N-15 in rice cropping systems to determine the fate fertilizer N

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Residue management impacts on soil organic matter (SOM) and long-term fertility is becoming more relevant in the context of soil quality. Open-field burning has been used traditionally to dispose of crop residues and sanitize agricultural fields against pests and diseases (Ponnamperuma, 1983). Because of air pollution concerns, this practice is now unpopular in many regions of the world. Alternative rice residue management practices that incorporate rice straw into paddy soils and winter flooding are currently being adopted in California due to the legislative restriction of open-field burning mandated by the California Rice Straw Burning Reduction Act (AB 1378, 1991). In rice cropping systems, the restriction on open-field burning can result in 7 to 12 Mg of residues per hectare being left on soils (Kludze and Delaune, 1995). The rice residues can impede seedbed preparation and contribute to disease and weed problems. There are currently few options for rice straw because of its poor quality for forage, bioconversion, and engineering applications (Jenkins *et al.*, 1997). Rice growers are therefore seeking alternative disposal options, such as incorporation of the straw into the soil. Soil incorporation of residues and winter flooding has been shown to enhance rice straw decomposition and N availability. These rice residue management changes may alter the sustainability of rice production systems unless producers are able to adequately manage for soil N combined with winter flooding and incorporation of rice residues.

Previous studies have shown that the incorporation of rice straw can negatively affect rice yield through N immobilization (Rao and Mikkelsen, 1976) or N availability (Cassman et al. 1997). Other studies have shown positive residual effects on rice yield after straw incorporation (Cassman et al. 1996). However, a dearth of information exists for flooded rice residue management and its effect on long-term N availability (Mikkelsen 1986; Cassman et al. 1996).

Nitrogen use optimization must achieve both efficient utilization of fertilizer N inputs and soil organic N. The influence of the soil organic fraction on soil fertility in rice cropping systems is rarely considered; yet soil organic matter (SOM) has been identified as the single most important indicator of soil quality in agricultural systems. Previous studies indicate that soil organic nitrogen is the most important source of plant-available nitrogen for rice in California, representing 50-80% of total nitrogen assimilated by the crop (Broadbent, 1979; Mikkelsen, 1987). The effect of plant residues and winter flooding on nitrogen immobilization into organic fractions of rice systems has received little attention, especially in California. The implementation of residue incorporation with winter flooding has been found to reduce straw waste for seedbed preparation and provide needed habitat for migratory waterfowl. Incorporation of 7 to 12 Mg ha^{-1} of rice straw each year to soils with virtually continuous flooding may alter the composition and nature of SOM fractions; this in turn may have important agronomic implications with respect to N availability by affecting the rate of N sequestration by SOM.

The impact of long-term winter flooding on nutrient cycling and rice production remains unknown, as winter flooding only recently became a common practice in California. Long-term studies have been initiated to examine retention versus removal of rice straw combined with winter flooding. The overall objective of this study was to determine the impacts of alternative rice straw management practices and winter flooding on yield, N uptake, and N use efficiency.

MATERIALS AND METHODS

Two field sites were established on different rice growing soils in northern California. The 28 ha site on a commercial rice farm near Maxwell, Colusa County was established in the fall of 1993 and the 10 ha site at the Rice Research Station near Biggs, Butte County in the fall of 1994. Some key differences between the soils of the two sites were higher clay content at Maxwell (51% vs. 35%), higher pH at Maxwell (6.6 vs. 4.7), and higher exchangeable K at Maxwell (305 vs. 72 mg kg^{-1}). Treatments were laid out in a split plot design with the main plots arranged in a randomised complete block design replicated four times. The main plot treatments were winter flooding and no winter flooding. Subplot treatments were four post-harvest straw management practices (burn, incorporate, roll, and bale/remove). With the exception of the rolled treatment, which was flooded before rolling, all winter-flooded plots were flooded near the end of October after the fall straw treatments, then drained in late March for seedbed preparation. Following seedbed preparation and application of fertilizer the fields were flooded in the beginning of May and rice variety M202 aerially seeded. Draining for harvest occurs about mid September.

^{15}N microplots were established at both sites using fertilizer labeled with ^{15}N. Use of ^{15}N fertilizer allows for the precise tracking of N as it cycles through the soil, plant and residue. At the Maxwell and Biggs sites, microplots were established in the following four treatments: 1) residue incorporated and winter flooded, 2) residue burned, winter flooded, 3) residue incorporated, non-winter flooded and, 4) residue burned, non-winter flooded in all four repetitions of the main field study. These four residue management treatments were chosen as they represent the most diverse residue management options that are currently been tested. Microplots were established in May 1997 at Maxwell and in May 1998 at Biggs. Both sites received the added subplots prior to the 5th growing season of the straw management trials. The Maxwell microplots are 12 m^2 , while those at Biggs were 1.83 m^2 in size. In addition, microplots were established within each main plot that either received no fertilizer N or different rates of fertilizer N.

Plants were sampled and analyzed for yield and ^{15}N content. Grain yield was corrected to 140 g kg^{-1} water content. The dried samples were coarse ground with a Wiley mill, then ground into a fine powder using a ball mill. Samples were analyzed for total C and N by complete combustion with a Carlo Erba and an isotope ratio mass spectrometer. Analysis of variance (ANOVA) was performed and repeated measure analysis of variance over years evaluated treatment effects over time.

RESULTS AND DISCUSSION

The research was specifically intended to examine the factors that control the rate and extent of nitrogen immobilization (tying up of fertilizer nitrogen by soil and rice residue) and long-term nitrogen availability in rice soils subjected to winter flooding and straw incorporation. Our results have shown that previous year's rice residues contribute a minor amount of N to the next rice crop. However, the cumulative effect of residue incorporation has shown a substantial nutrient benefit. In other words, the N in rice residue and roots becomes available to the rice crop after 3 to 5 years following incorporation leading to a build up of SOM. This nutrient benefit is of considerable importance since we have shown that fertilizer-use efficiency is low, (Fig. 1 and 2). Fertilizer use efficiency based on ^{15}N studies averages 36% at the Maxwell and 30% at the Biggs research sites. The N difference method (comparing fertilized versus unfertilized plots) showed higher fertilizer use efficiency at both sites. The difference between the ^{15}N and difference methodologies can be attributed to soil N processes showing that rice N uptake comes from both fertilizer and soil sources. The ^{15}N method provides data on the contribution from both sources, while the N difference method can not differentiate between sources of N in soil. The ^{15}N data show the importance of soil N in supplying N for rice uptake and of the importance of fertilization in maintaining soil nitrogen pools. As mentioned earlier, soil N can account for up to 80% of rice N requirements. These finding demonstrate the importance of soil N as an additional source of nitrogen for uptake by rice in fertilized systems.

The effect of straw incorporation on N availability can be seen from the results from a fertilizer N rate trial at the Maxwell site (Fig. 3). The trial consisted of N rates ranging from 0 to 160 kg. ha^{-1}. We found that residue incorporation treatments at the 0 kg nitrogen rate had a yield increase of 1500 kg ha^{-1} over that found on burned treatments. Maximum economic yield was achieved at 90 kg N ha^{-1} in the residue incorporated plots. In the burned treatment, maximum economic yield was achieved at 120 kg N ha^{-1}. These results clearly show the benefit of residue incorporation in building soil N pools to sustain N availability.

The results of this research show clearly the value of residue incorporation in increasing soil N availability and that fertilizer applications could be reduced under straw incorporation and winter flooding. Further studies are required to determine the effects of rice straw incorporation on long-term rice yield. Estimates of relative costs of different options must be developed, as the most attractive choices might have significant impacts on environmental quality through their effect on microbial processes that determine the magnitude of C storage in the soil, methane emission into the atmosphere, and long-term soil fertility.

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Figure 1. Fertilizer use efficiency (FEU) at the Biggs's site. Results are expressed by the ^{15}N and N difference methods. Flood implies winter flooding. Line bars denote standard error of the mean, n=4.

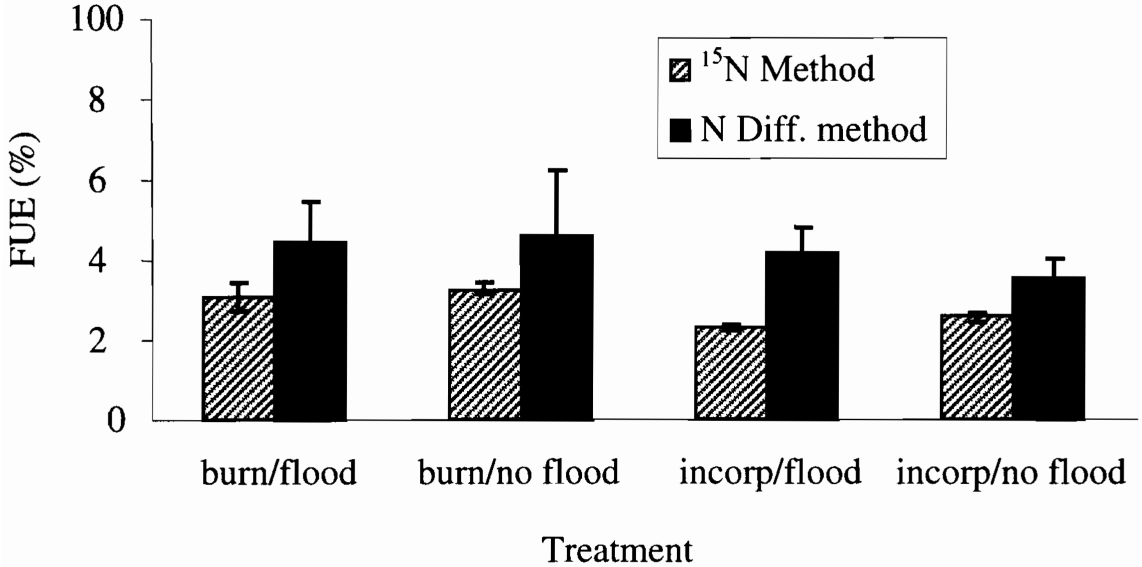


Figure 2. Fertilizer use efficiency (FUE) at the Maxwell site. Results are expressed by the ^{15}N and N difference methods. Flood implies winter flooding. Line bars denote standard error of the mean, n=4.

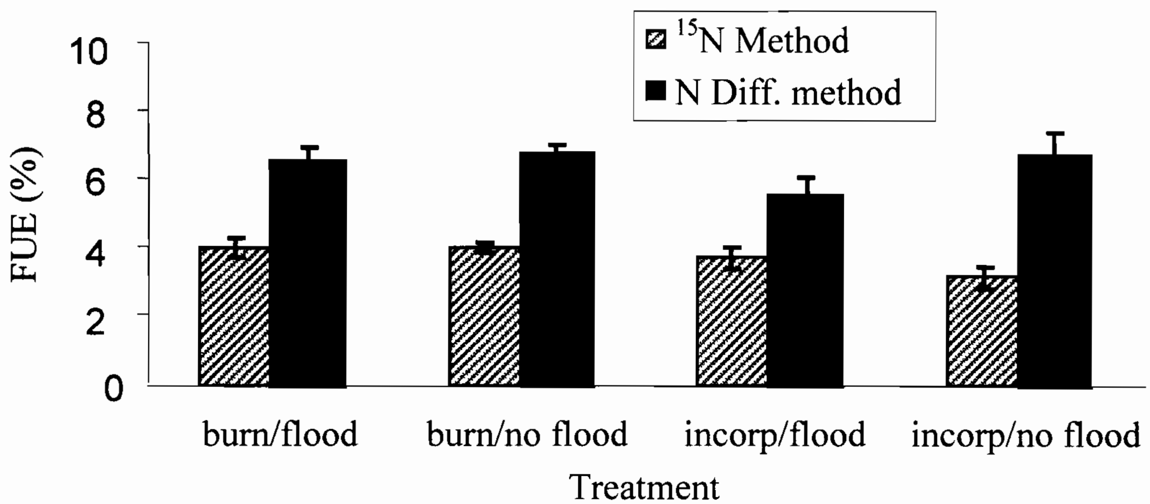
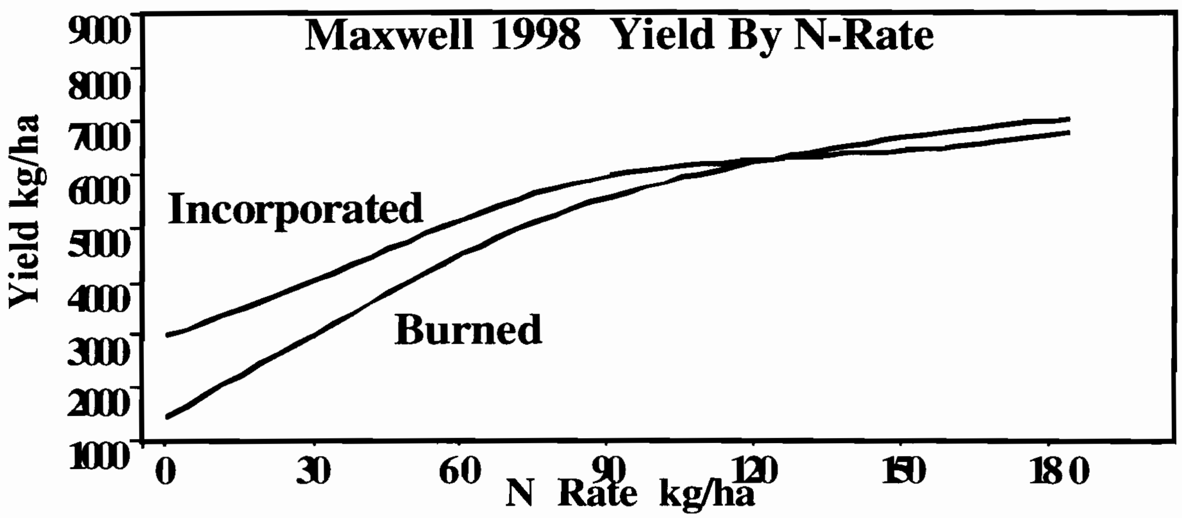


Figure 3. Results from the fertilizer rate trail done at the Maxwell rice residue study during 1998. This study will be done again at Maxwell in 1999 to verify the 1998 results. The same study will be initiated at the Biggs rice residue study in 1999.



NITROGEN BUDGET FOR CALIFORNIA COTTON PRODUCTION

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Introduction

Cotton has been an important crop in the San Joaquin Valley for many years. Approximately one million acres of cotton are grown in California every year. While this indicates that cotton production has been successful in California, producers have been and are continuously facing new challenges such us a volatile market as well as changing production conditions. Modern cotton varieties, for example, are more determinant, earlier maturing, set and fill bolls over a shorter period of time, and respond more strongly to nitrogen applications than obsolete varieties (Meredith et al., 1997). Many of the production guidelines for cotton, including those for nitrogen (N) fertilization, were developed in the 1960's based on different cultivars and management practices than those employed today. Cotton cultivars currently grown in California produce lint yields approaching 3 bales per acre - among the highest in the world. To obtain these yields, nutrient, water and other inputs need to be managed with great care.

Nitrogen nutrition is known to affect the development of cotton plants, particularly the balance between vegetative and reproductive growth. Thus, N fertilization represents a valuable management tool for producers to control cotton development. The critical role of N in cotton management warrants a reevaluation of its application guidelines tailoring its management to new cultivation practices and recognizing widespread environmental concerns. Nitrogen fertilization in cotton may be in one application, or in split applications and depending on soil type and previous cropping history generally varies between 150 and 200 lb per acre but may exceed 200 lb per acre in some cases. Hence, assuming an average annual cotton production of one million acres, cotton accounts for nearly 20% of all agricultural N use in California. Nitrate concentrations in well water from the Central Valley of California increased over the past ten years mostly due to non-point sources, indicating possible involvement of agricultural production (Water-Resources Investigations, Report 98-4040). This is critical for cotton producers since management of nitrate contamination in groundwater is increasingly regulated in California. In addition, it has been reported that high N application rates increase the likelyhood of aphid infestations (Cisneros and Godfrey, 1998), and decrease the efficiency of defoliation (Johnson-Hake et al., 1996).

Reevaluation of the N fertilization guidelines is needed in light of the above noted changes in the production system and to optimize management practices for environmental concerns, insect control, and defoliation efficiency. Based on ongoing studies very small or no yield responses to N were observed at several locations throughout the San Joaquin Valley. In order to understand this occurrence better and since cotton varieties and management practices are likely to keep changing in the future, the focus of the project discussed here is to understand the N dynamics in the cotton production system over the course of a growing season as well as cropping cycle. Better understanding of the underlying mechanisms controlling N dynamics in a cotton field will facilitate adaptations of fertilization practices to new production requirements.

Methods

A field study was initiated in spring 1998 at two sites in the San Joaquin Valley, on a farmers field (Kings County) and on the Westside Research and Extension Center (Fresno County). Four treatments (four replications), 50, 100, 150, and 200 kg N ha^{-1} were established at each location. In the 50 and 150 kg N ha^{-1} treatments microplots were established using ^{15}N enriched urea. Over the course of the season a number of measurements were carried out in the microplots, including dry weight determinations of leaves, stems, and fruiting structures, leaf area measurements and plant growth characteristics (i.e. number of nodes). All treatments were analyzed for yield. Subsamples of plant materials collected throughout the season were analyzed for total N and for atom % ^{15}N.

Soil samples were collected at the beginning, in the middle and at the end of the season and analyzed for total N and ^{15}N atom %. In addition, end-of-season soil samples were taken from the 50 and 150 kg N ha^{-1} treatments in order to analyze mineralization rates for cotton residues under controlled conditions. Soil samples were sieved through a 5 mm screen and subsamples of 100 g were incubated either directly or with 0.4 g ground cotton residue at 10°C or 25°C. Evolution of CO_2 and the appearance of NO_3^- and NH_4^+ was measured in intervals.

Results and Discussion

A large amount of data were obtained during the first year of this project. Analysis of this information is in progress. Only selected data will be presented here.

Lint yields were not different between the treatments at WSREC. At the Kings County site the difference was significant only between the 100 and 150 lb $acre^{-1}$ treatments (Figure 1). Only small differences in lint yield between the two locations were observed. In contrast to lint yield, a positive response to additional nitrogen fertilizer was found for above ground biomass present at defoliation (Figure 2). The amount of biomass accumulated at defoliation was higher at WSREC than at Wisecarver farms. Similar to data from other sites, these results suggest that N fertilization rates could potentially be lowered without significant reduction in lint yield. This may be particularly true for cotton grown in rotation with other crops after which high residual soil nitrate levels can be found. Evaluation of the ^{15}N data will aid in the interpretation of these results. Tissue analyses from early season plant samplings indicate high amounts fertilizer N being taken up in the 150 lb per acre treatment and low amounts in the 50 lb per acre treatment (data not shown). Evaluation of ^{15}N analyses from plant samplings conducted later in the season is in progress and will allow calculations of the fertilizer-N uptake efficiencies for the first year and the different treatments.

Figures 3a and b show the rate of CO_2 evolution from the two soil types indicating the amount of organic matter being decomposed. At both locations soils incubated at 10°C (50°F) evolved roughly 50% less CO_2 than those incubated at 25°C (77°F). The addition of plant material (0.4 g per 100 g of soil) at least doubled the amount of CO_2 evolved over time. While all treatments were the same relative to each other for the two soil types, the absolute amounts of CO_2 evolution were higher in the lighter soil than in the heavier one. The rate of CO_2 evolution as a function of time gave expected results. Treatments without the addition of plant material exhibited only small changes in the rate of CO_2 evolution over the first 120 days of the experiment. Treatments with added plant material had about two to three fold higher CO_2 evolution rates during the first 14 days than over the next 100 days. This suggests a readily decomposed fraction of soil organic matter (added plant material) which is broken down initially followed by a soil organic fraction that is more difficult to decompose.

In order to construct a N budget for California cotton production and to understand the N dynamics in the current production system more data are being collected and those obtained need to be analyzed further. Collectively these data will serve as source of information based on which researchers, extension agents, and producers can make sound decisions.

The authors acknowledge the cooperation and assistance from Wisecarver Farms Kings County and UC WSREC, Five Points.

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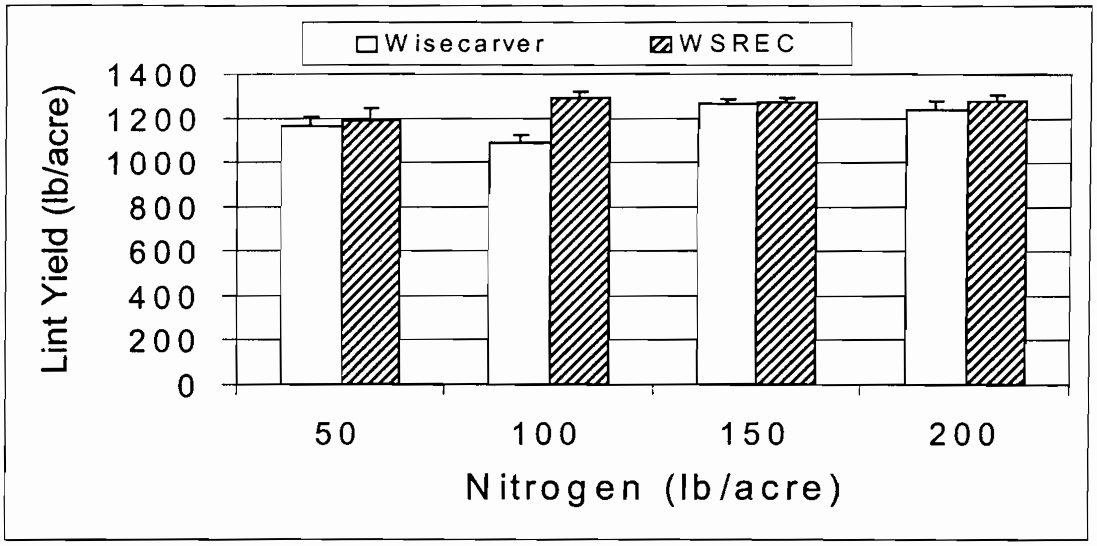

Figure 1. Effect of N fertilization on cotton lint yield at the Kings County site and the West Side Research and Extension Center in 1998.

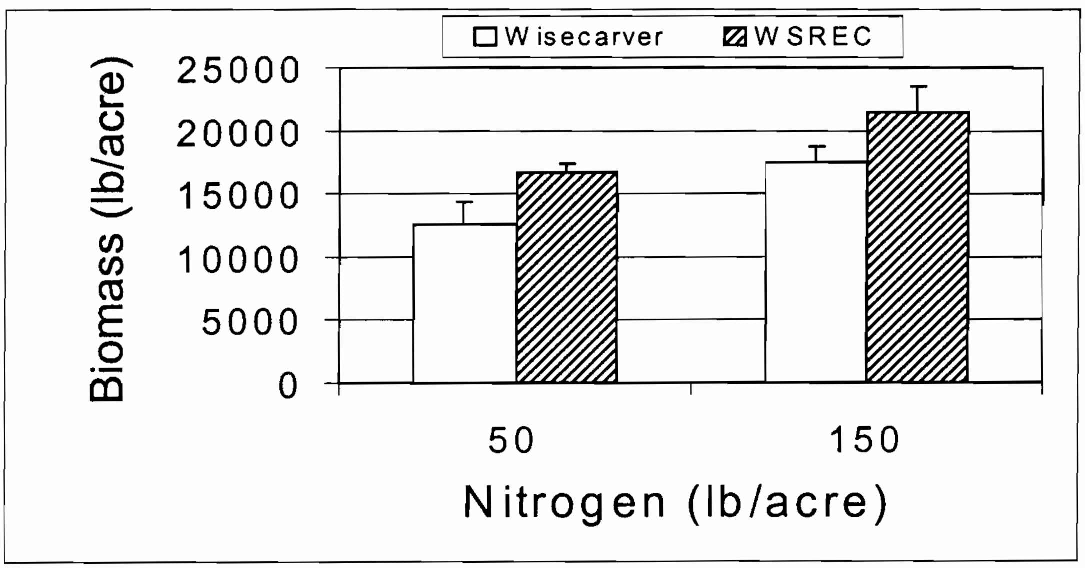

Figure 2. Effect of N fertilization on above ground biomass at the time of defoliation at the Kings County site and the West Side Research and Extension Center in 1998.

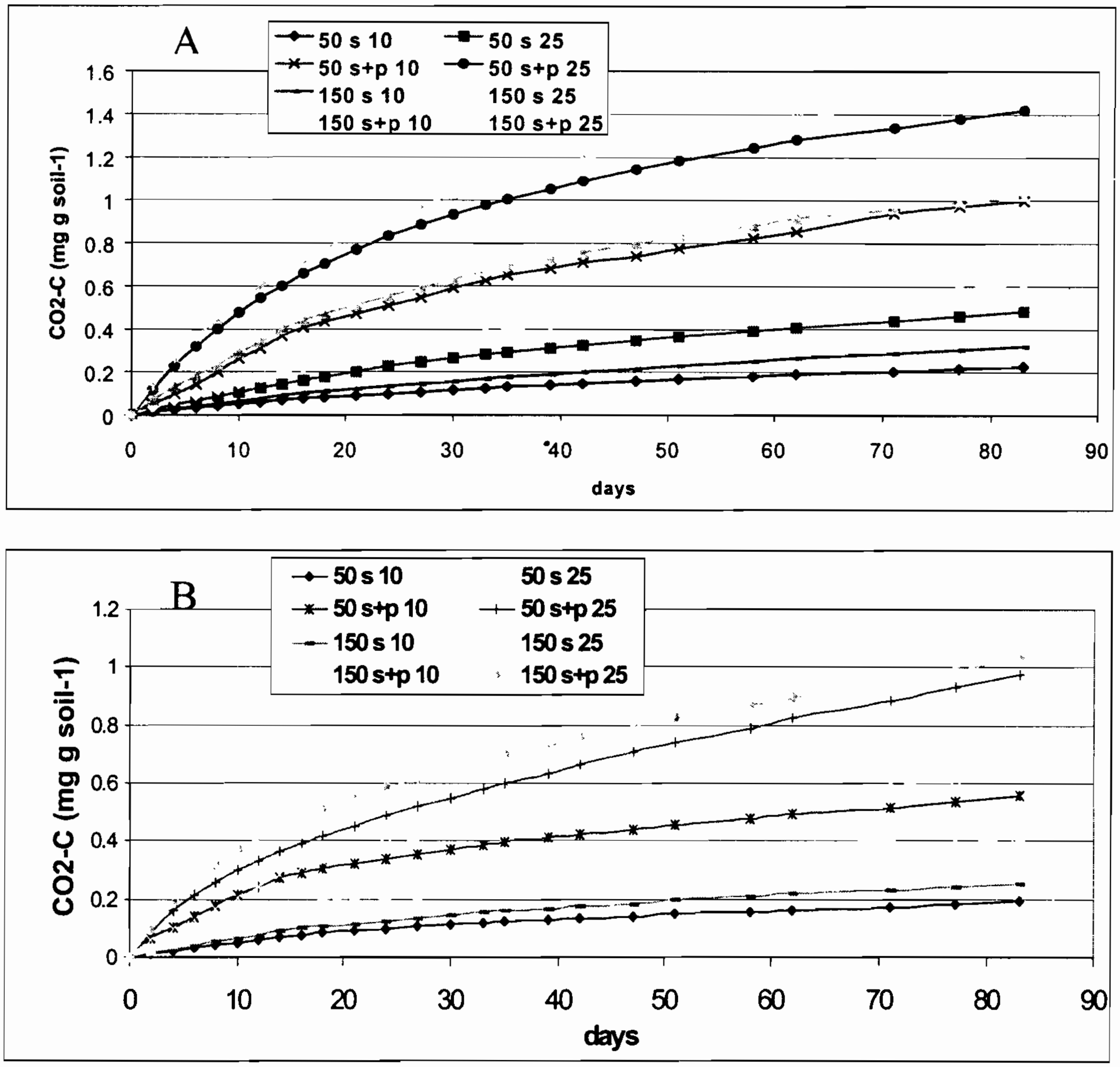

Figure 3. Effect of soil type, temperature and cotton residue addition on CO_2 evolution. Soil was incubated at 10°C (10) or 25°C (25) without additional plant material (s) or with 0.4 g cotton residue per 100 g soil (s + p). Soil was collected from the 50 and 150 lb N per acre fertilization treatments, respectively. A) West Side Research and Extension Center, B) Kings County site.

Plant and Microbial Utilization of Cover Crop Nitrogen in a Vegetable Field

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ABSTRACT

The ability of microbes and plants to assimilate and retain N from cover crop residue was studied in a sandy loam soil in a field under intensive vegetable production in the Salinas Valley. Although it is well-established that non-leguminous winter cover crops can assimilate up to approximately 100 kg N ha^{-1} (89.2 lbs $acre^{-1}$), thereby reducing the leaching of nitrate during winter rainfall periods (Jackson et al., 1993), the contribution of cover crop N to the subsequent vegetable crop is less well-understood. A successful cover crop strategy is to synchronize the release of inorganic N from the cover crop with N demand by the subsequent cash crop so that cover crop-derived N is retained in the system, and N losses via leaching and denitrification of mineralized cover crop-derived N are minimized. In this study, we examined the fate of N in cover crop residue using typical field management practices for lettuce in the Salinas Valley.

Fresh residue (478 g m^{-2}, i.e., 4264 lbs $acre^{-1}$) of ^{15}N-labelled *Phacelia tanacetifolia* (C/N of 19) was incorporated into the soil of large cylinders (25.4 cm (10 in.) dia. and 60 cm (23.6 in.) deep) *in situ* in a vegetable field near Chualar, CA. Crisphead lettuce (*Lactuca sativa* L. 'Target') was planted in the cylinders 45 days later. A total of 8.43 g N m^{-2} (75 lbs $acre^{-1}$) was added as inorganic N fertilizer to the crop, and total water input was 41.9 cm (16.5 in.). Fertilizer applications were split so that more N was available in the last weeks prior to harvest, which is the period of highest demand of N by lettuce. Also, irrigation was applied to match crop demand based on tensiometer readings. Microbial biomass C and N were measured by the chloroform fumigation-extraction method (Brookes et al., 1985; Wyland et al., 1994; Vance et al., 1987). Ammonium and nitrate were measured in 2N KCl extracts. Anion exchange resin bags were placed at the bottom of the soil columns to trap leached nitrate (Wyland et al., 1993). To prepare KCl extracts and Kjeldahl digests of the fumigated and control MBN extracts for ^{15}N analysis, the diffusion technique of Brooks et al. (1989) was used. Analysis of N, ^{15}N, and C in plant material, soils, and extracts was with a Europa Scientific ANCA Mass Spectrometer.

Microbial biomass and nitrate increased rapidly after incorporation of plant residue, then began to decline two weeks later (data not shown). Microbial biomass C declined faster than microbial biomass N. Only a small amount of ^{15}N was ever found in microbial biomass, but nitrate was enriched with substantial ^{15}N. Microbes may have assimilated C from the plant residue, met their N demand mainly with soil-derived N, and released cover crop-derived N that was rapidly mineralized and nitrified. The resulting inorganic N was either taken up by plants, leached, or denitrified.

As is typical for direct-seeded lettuce, N in shoots and roots accumulated slowly for the first 6 weeks after planting, then rapidly increased during the last month before harvest (Table 1).

Lettuce head formation and size was normal, and mean plant dry weight in the cylinders, was 44 g $plant^{-1}$ (0.097 lbs $plant^{-1}$), a typical value for crisphead lettuce. Fertilizer N can account for at most one-third of the lettuce N uptake. Mineralized N derived from sources of soil organic matter other than the cover crop must have been the major source of crop N.

Percentage recovery of the added ^{15}N after four months was: 60.7 as soil organic N; 20.1 in plants; 1.4 as inorganic N; 1.4 in microbial biomass; 4.7 in ion exchange resin bags and thus leached below 60 cm (23.6 in.) depth; and 11.7 as unexplained loss (Figure 1). Losses of ^{15}N during the first lettuce crop after the cover crop were relatively low, most likely due to low rainfall and appropriate scheduling of fertilizer and irrigation. Total soil ^{15}N at 0-30 cm (0-11.8 in.) depth declined for the first seven months, and thereafter cover crop N was apparently no longer readily mineralizable.

Low rainfall in the spring contributed to the high recovery of ^{15}N. In regions with higher spring rainfall, greater proportions of cover crop-derived N can be lost (Bremer and van Kessel, 1992). Although most of the cover crop-derived nitrate was retained within the rooting zone, approximately 4 g nitrate-N m^{-2} (35.7 lbs nitrate-N $acre^{-1}$) that was derived from soil and fertilizer was leached during the first crop of lettuce. Most of this leaching occurred within a month of seeding, when lettuce plants had low N demand. Proper management of water and fertilizer inputs after incorporation of low C/N plant material is important for avoiding N loss before plants are established, especially since nitrate becomes readily available, and microbes do not retain much of the cover crop N in this intensively managed soil.

ACKNOWLEDGMENTS

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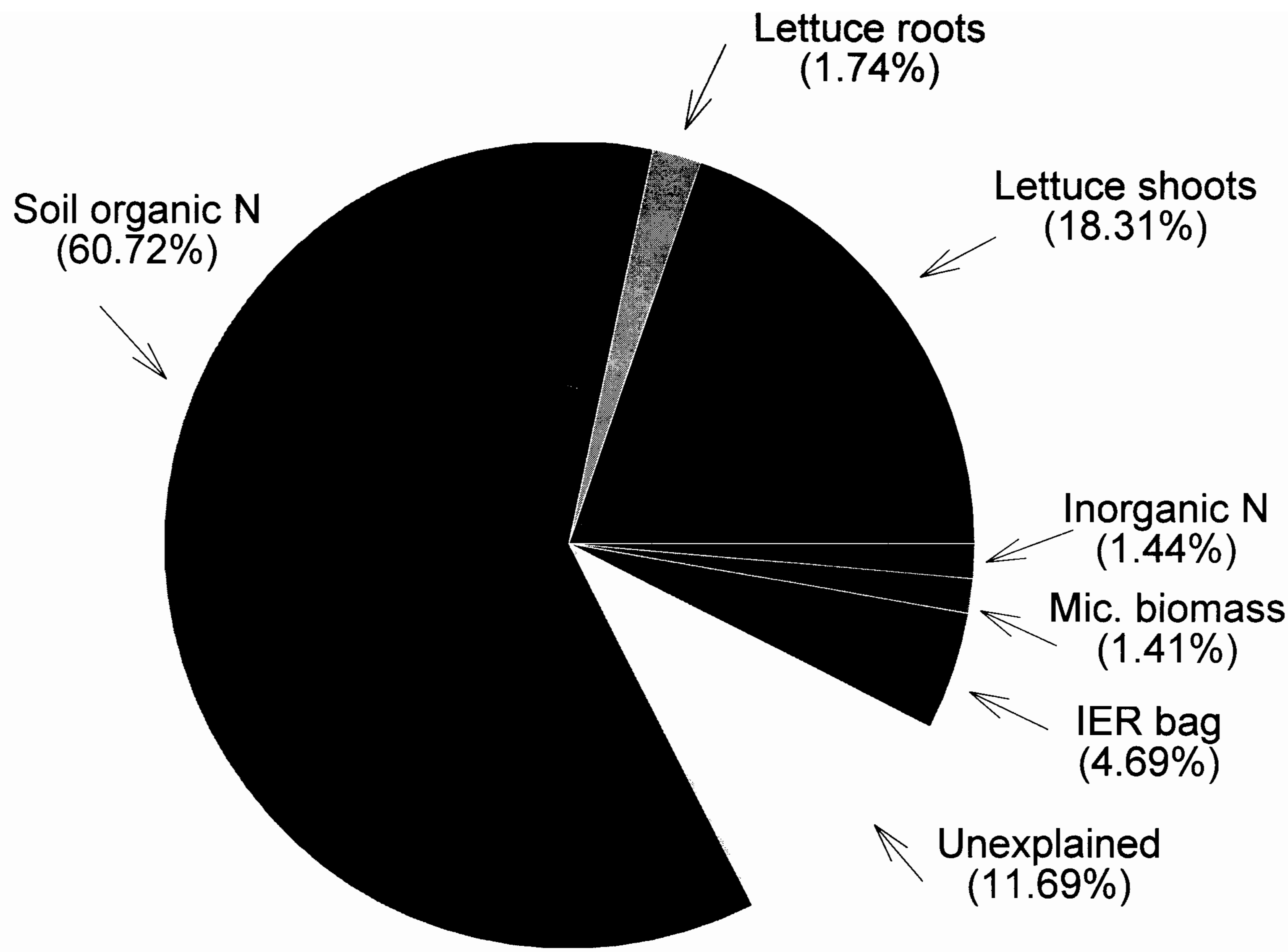
Table 1. Nitrogen pools in the lettuce crop after cover crop incorporation, and the percentage of the nitrogen in the lettuce that was derived from the nitrogen in the cover crop residue, as calculated from ^{15}N concentrations.

	Lettuce crop in the middle of the growing season	Lettuce crop at harvest
Days after incorporation	72	116
	N pools (g N m^{-2})* mean ± SE	
Lettuce shoots	0.625 ±0.123	23.35 ± 3.333
Lettuce roots	0.168 ± 0.024	2.48 ± 0.254
	Derived from cover crop residue (%) mean ± SE	
Lettuce shoots	9.70 ± 0.605	9.20 ± 0.768
Lettuce roots	9.19 ± 0.601	8.25 ± 0.599

* Convert g N m^{-2} to lbs N $acre^{-1}$ by multiplying by 8.9. Note that the land surface area per lettuce head in the soil cylinders was less than half that in a lettuce field with typical field spacing.

Figure 1. (next page) Proportion of the added ^{15}N in *Phacelia tanacetifolia* residue that was recovered in different plant and soil components at harvest of the first lettuce crop, which was four months after residue incorporation. Means ± SE.


Lettuce roots
(1.74%)
Soil organic N
(60.72%)
Lettuce shoots
(18.31%)
Inorganic N
(1.44%)
Mic. biomass
(1.41%)
IER bag
(4.69%)
Unexplained
(11.69%)

Development of an N-Fertilizer Recommendation Model to Improve N-Use Efficiency and to Alleviate Nitrate Pollution to Ground Water from Almond Orchards

Patrick H. Brown[1]

Summary: The aim of this research was to determine the seasonal patterns of N demand in mature almond. To this end sequential whole tree excavations were conducted at 1/21, 3/20, 5/20, 7/28, 1/10 at the Delta college orchard, Manteca, CA. At each harvest date five entire mature trees were excavated and partitioned into leaves, root, trunks, and branches. Samples were then analyzed for total nutrient content, differences in nutrient content between sequential harvests represents tree nutrient demand and tree nutrient uptake. The trees usedinthis experiment were 22 years old and had an average three year yield of 2800 lbs/acre.

Weight of individual trees excavated ranges from 570 kg to 799 kg dry, with corresponding total N content of 4 to 6 kg N. The highest proportion of total N was present in root and root stock in January and March. Fruit and canopy had the largest proportion of total N in May. Nitrate and total soluble N represented only a small proportion of total N presented in the whole tree.

We have completed analysis of seasonal N uptake dynamics and total yearly N demand. This information has now been integrated into a user friendly interactive computer program that is available for distribution. The details of this program will be discussed. In summary, the determination of N fluxes in almond demonstrates that the majority of N uptake and demand occurs from late February through to early September and that the primary demand for N is for nut fill and nut development. N demands can therefore be predicted by estimating yield and can be applied during the periods of greatest N uptake from the soil which occurs during nut development.

The relative demand for N has been integrated with the estimated N inputs based upon the research conducted by CDFA-FREP program and the BIOS program of the Californian Association of Family Farmers. By entering yield data and information on N inputs (manures, cover crops etc) and management systems (irrigation method) growers can obtain a recommended fertilization program.

By timing N applications with periods of greatest demand, and matching N application rates with crop load we provide growers with a tool that will encourage maximum efficiency of use of N fertilizers. Maximum efficiency of use will result in a minimization of N loss from the orchard system. Copies of the computer program screen are attached to this document.

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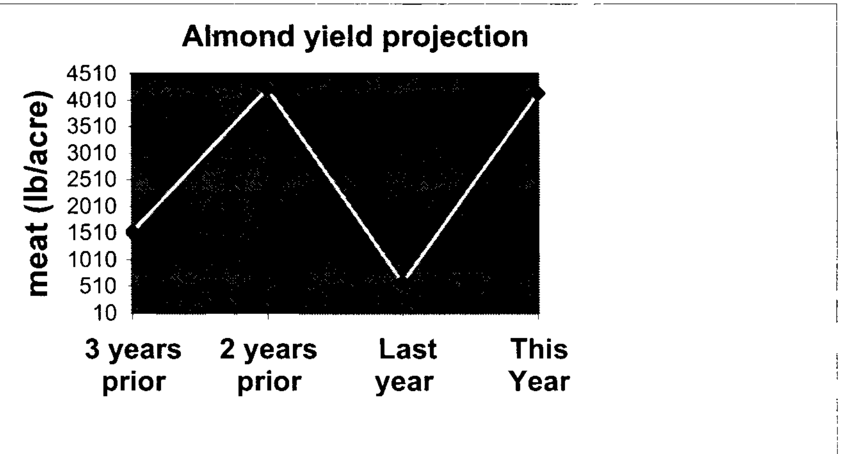
Basic Information Sheet

	(lbs./acre)
Your projected almond meat yield	4132.1
External N contribution	(lbs N/acre)
Irrigation Water	89.1
Soil N	0.0
Manure, Compost and Cover crop	50
Leaf Tissue Adjustment	-10.0



The following result is our fertilizer recommendation for location:

West Ranch1999

Fertilizer Application Method.	**Fertilizer needs total for season lbs. N/acre**		**Best time to apply N** Feb. ---March	March -- May	June ---July
Fertigation through low volume irrigation	not chosen		not chosen	not chosen	not chosen
Several split broadcasts	not chosen		not chosen	not chosen	not chosen
Single broadcast application	315.9				

This program provides recomendations only and is not intended to be used as the sole source of information for making N fertilization decisions. Local environmental conditions can have a profound effect of fertilizer demands. CDFA-FREP and the University of California are not responsible for the accuracy of this model under all conditions.

Enter orchard location and year here: West Ranch1999

(1) History of Almond meat yield in your orchard

Please enter previous years' yield information below

	Almond Nut Meat Yield (lbs/Acre)
3 years prior	1530
2 years prior	4220
Last year	580

(2) Best Estimate of Current Years Crop Load

Excellent — Scale from 1 to 5: 5

(3) Irrigation water used before nut harvest

Acre feet of well water applied per year — feet/acre: 3.3

choose only one

Nitrate-N (NO_3-N) concentration in units of ppm or mg/liter — ppm or mg/l: 10

If you don't know your NO_3-N ppm level, select here. Unknown — 0

Scroll down

More below

(4) Soil type of orchard

Choose one

- Fertile loam or clay (selected)
- Sandy loam
- Sand

1

(5) Last July leaf total N level

% of dry weight: 2.40

(6) Fertilizer application method

Choose one

- Fertigation through low volume irrigation
- Several split broadcasts
- Single broadcast application (selected)

3

Your Choice: **Single broadcast application**

(7) Do you apply Manure, Compost, or a Cover Crop?

choose one

Yes (selected) No

choose one or more

	Amount (Tons/Ac)		Manure type	Application Year
Manure	1.0		Chick Manure	Last year
	Amount (Tons/Ac)	**% N in compost**	**Compost type**	
Compos	3	1.3	Fresh, incorporated	
Legume Cover Crop	Poor crop	Mow or disc in?	Discing in	

Total N requirement

Water and Fertilizer Management for Garlic

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Summary

Garlic is a cool season vegetable crop with a long growing season – approximately October to July. The potential nutrient and water needs are, therefore, high. Compared to onion, garlic has a more extensive root system that can access and uptake water and nutrients to a depth of at least 3 _ feet, thus garlic is more efficient than onions. Research trials conducted during the 1980's and 1990's were inconsistent in optimum fertilization rates and irrigation timing and amounts. These experiments have, however, increased the knowledge about water and nutrient management of garlic in California.

Irrigation Timing and Amounts. Highest yields are probable with soil moisture depletion of as little as 25-30% depletion, certainly lower than 50%. Starting the season with the soil profile full of moisture is essential to reaching optimum production. Subsequent irrigation with as little as 12-15 acre inches of water is frequently sufficient. Irrigation frequency, with furrow or sprinkler, of 7-10 days on soils with approximately 2 – 2 _ inches of available water per foot of soil provided highest yields. Drip irrigation of 0.4 – 0.8 inches per application provided equal yields.

Evapotranspiration can also be used as a guideline for irrigation timing and amounts. In 1998-1999 a sprinkler line source experiment was conducted to determine the crop coefficient for garlic. Irrigating at either 110% or 130% of ET gave approximately equal yields. Garlic extracted water deeper than the 42 inches, the maximum depth depth of soil moisture measurements in this experiment. Results from the first year of this line source experiment were as follows:

1. Garlic yield was independent of applied water for conditions where a deep fine textured soil is, initially, at field capacity. Applied water varied from about 4 inches to 13 inches, yet no yield response was found.

2. Garlic is capable of extracting considerable water in a fine textured deep soil at depths deeper than 3.5 feet as shown by plots of the neutron probe data with time. The sum of the seasonal change in soil moisture content and applied water was nearly equal with distance from the sprinkler line until near the edge of the wetted area of the sprinkler, where much extraction appeared to occur at the deep depths.

3. Little change in crop canopy occurred with distance from the sprinkler line except at the last sample site, 38 feet from the sprinkler.

Irrigation cutoff date, or date of last irrigation, has a great influence on garlic yield. Yields increase with later cutoff dates. This effect is lower if higher levels of irrigation are used during the season, providing a full soil profile for the crop to gradually deplete. Quality can be reduced, however, with late irrigation. The most serious is the potential for stem/root plate rot. Plant population at harvest can be significantly decreased with increasingly later irrigation cutoff dates. Storageability is also decreased.

Fertilization. Response to fertilizer depends on soil type, past cropping, and the yield potential of the variety or strain planted. "Virus-free" garlic, for example, responds to higher rates of nitrogen than non-virus free seed lots, because the yield potential is significantly higher and maturity is generally later.

Garlic rarely responds to phosphorus, potassium or zinc when grown on the heavy deep soils of the West Side of the San Joaquin Valley. Similar results were obtained in Kern County and Salinas Valley experiments.

Optimum nitrogen rates in the numerous experiments conducted by the University of California over the past 20 years have varied from 100 to 400 lbs. N per acre. Nitrogen, as well as moisture, availability early in the growing season is essential for optimal growth. Late applications of nitrogen may be deleterious to both yield and quality. Growth is slow during the first four months after planting. Thus, the greatest nitrogen needs are when growth begins in late winter and early.

Response to phosphorus fertilization has been infrequent and poorly correlated to soil test levels. When response was measured, 50 lbs per acre was adequate for maximum yield. Response to potassium fertilizer has been rare. Zinc response was measured at the rate of

20 lbs/acre when soil test levels were approximately 0.5 ppm. No response was measured at soil levels of 2.0 ppm.

Leaf nitrate and total nitrogen are directly related to nitrogen fertilizer but do not appear to be affected by irrigation. Total N is a better indicator of adequacy, with levels of 4-5% at early season (pre-bulbing), 3-4% at mid-season (bulbing) to pre-cutoff date, and 2-3% at late season (near irrigation cutoff) correlating well with yield response.

Garlic Quality. Fertilizer and water management influences harvest quality and postharvest quality. Both nitrogen and irrigation affect soluble solids, or dry matter content. In general, dry matter is reduced as nitrogen fertilizer rates increase, particularly at rates higher than optimum for yield. However, in some cases dry matter was lower at nitrogen levels sub-optimum for yield. Water stress also results in lower dry matter content. Cutoff date is again important; dry matter content increases during the season. Thus, if irrigation cutoff is too early, dry matter can be reduced. The risk of late cutoff date was discussed above.

Preliminary results indicate that cloves in storage sprouted earlier if they had been subjected to higher soil moisture regimes. Nitrogen fertilization did not affect sprouting. Pungency increased with length of time in storage for all field and storage treatments. Yellowing of cloves also increased with time. Storage conditions have a much greater influence on garlic bulb and clove quality than does the fertility and water management during production. Phosphorus and potassium fertilizer, while not having any effect on yield, may positively influence dry matter percent, percent soluble solids, firmness and white color at harvest. Phosphorus, without potassium, however, resulted in the poorest clove color and the highest pungency.

A sprinkler line source experiment with nitrogen rates is again being conducted this year at the UC Westside Research and Extension Center to further study the objectives of determining the relationships of water management, fertilizer management, garlic productivity and garlic quality.

Appreciation is expressed to Rogers Food, CDFA Fertilizer Research and Education Program, and American Dehydrated Onion and Garlic Association for financial and research support of these studies.

OBJECTIVES

1. Relate fertilizer and irrigation management of garlic to yield and to the efficiency of water and fertilizer use.
2. Determine garlic leaf tissue concentrations of nitrogen in relation to fertilizer and irrigation practices and relate to crop quality at harvest and postharvest.
3. Develop crop coefficients relating garlic evapotranspiration to CIMIS reference crop evapotranspiration.
4. Relate postharvest quality of intact and fresh peeled garlic to different fertilization and irrigation practices.

5. Determine if slow release nitrogen fertilizers are equal or superior to more soluble nitrogen forms.

EXPERIMENTS

1. Nitrogen rate experiments, ranging from 0 to 500 lbs./A.
2. Nitrogen timing experiments – pre-plant, side-dress, water-run.
3. Nitrogen source experiments.
4. Phosphorus rate experiments.
5. Potassium rate and timing experiments.
6. Irrigation rate experiments based on soil moisture depletion.
7. Irrigation rate experiments based on evapotranspiration.
8. Irrigation timing experiments based on calendar.
9. Irrigation timing experiments based on cutoff dates.
10. Irrigation method experiments – furrow, sprinkler, drip.
11. Sprinkler line source experiments.
12. Postharvest controlled atmosphere storage treatments.

MEASUREMENTS

1. Yield (tons per acre).
2. Bulb size (weight)
3. Soluble Solids of cloves.
4. Leaf Total N and Nitrate N.
5. Leaf Total P and Total K.
6. Soil moisture content with neutron moisture meter throughout the season to depth of 4 feet.
7. Soil moisture content with Enviroscan system throughout the season to depth of 4 feet.
8. Canopy coverage with digital near-infrared camera.
9. Depth of water applied.
10. Respiration rates of stored peeled and intact cloves.
11. Storageability – weight loss, decay, sprouting, rooting, firmness, color
12. Pungency
13. Sugar content

Tables 1–4 and Figure 1 list some of the recent research results. Additional results will be presented during the Conference.

Table 1. Results of the 1997 irrigation treatments*.

Treatment	Time between irrigation	Date last irrigation	Applied Water (inches)	Bulb Count	Yield (pounds per plot)
T1	1 week	May 9	13.8	340a	29.0a
T2	1 week	May 16	17.2	342a	31.1b
T3	1.5 weeks	May 9	11.8	327a	26.1c
T4	2 weeks	May 16	14.3	334a	26.2c

* Averaged across N fertilization treatments

Table 2. N fertilizer treatments and yield data for 1997*.

Treatmen t	Preplant	Sidedress	Water-run**	Total lb. N/acre	Bulb Count	Yield (Pounds/plot)
F1	70	30	0	100	332a	25.6a
F2	70	90	40	200	332a	28.1b
F3	70	170	60	300	334a	29.2c
F4	70	250	80	400	344b	29.4c

* Averaged across irrigation treatments.
** Applied in four applications

Table 3. Irrigation treatments applied in 1998. Data are averages of 6 field replications.

Treatment	Date last irrigation	Bulb Count	Bulb Weight*	Piece weight*	Total Yield*	Solids (%)
T1	May 12	615a	36.0a	2.8a	38.7a	37.2a
T2	May 19	545b	31.4b	6.6b	38.0a	36.8a
T3	May 25	447c	24.9c	8.9c	33.8b	36.1a
T4	June 4	390d	21.9c	9.5c	31.4b	36.1a

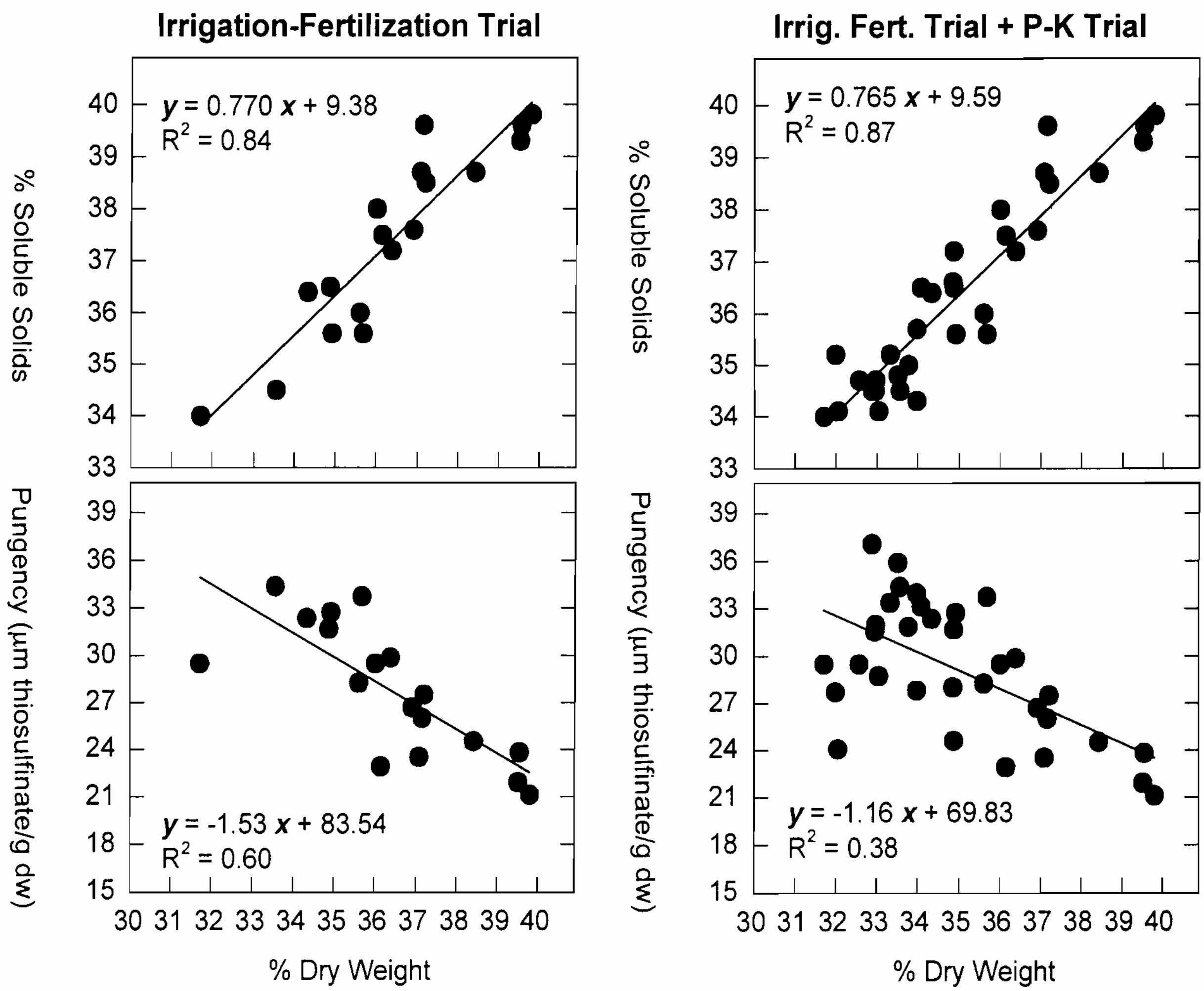
* Weights are pounds per plot
** Data averaged across fertilization treatments.

Table 4. Nitrogen fertilizer treatments applied in 1998. All plots received 70 lb N/acre pre-plant. Data are averages of 6 field replications.

Treatment	Side-dress*	Water -run*	Total*	Bulb Count	Bulb Weight*	Piece weight*	Total Yield*	Solids (%)
F1	30	0	100	565a	31.3a	2.9a	34.3b	38.1a
F2	65	40	175	527ab	30.9a	5.9b	36.8a	37.2ab
F3	140	40	250	486bc	28.4b	7.2c	35.7ab	36.6bc
F4	175	80	325	465c	26.9bc	9.1d	36.0ab	35.5c
F5	250	80	400	451c	25.1c	9.4d	34.5b	35.3c

* Pounds per plot

Figure 1. Relationship between soluble solids and dry weight (top panels) and pungency and dry weight (lower panels) from garlic fertilization and irrigation experiments.



Fall planted cover crops may improve tomato yields

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Planting fall cover crops in fields that will later be planted to processing tomatoes is a departure from the goal among many tomato growers of minimizing weed vegetation prior to seedbed preparation. Vetch cover cropping attempts to maximize the vetch's vegetative growth to exclude weed competition, increase plant biomass for soil incorporation, fix atmospheric nitrogen and reduce winter runoff. Incorporating the green manure crop can be a challenge for tomato growers, with uncertain rainy weather conditions and planting schedules that for tomatoes are defined by calendar days.

In the first year of our test the previous year, we were encouraged by a 5% increase in both tomato fruit yield and °brix with our cover crop planting compared to the conventional fallow bed practice.

We repeated the field test in the southern Sacramento Valley near Woodland with a 1998 fall planting of common vetch-pea mix in another field setting, which was also cropped with back-to-back tomatoes. The trial was a 3-acre planting in a commercial field, with cooperator Blake Harlan of Harlan and Dumars. The soil type was a Yolo silt loam series. The cover crop was drilled into dry beds, germinated after late fall rains, established well and grew vigorously during March despite a very dry and cold December. The peas were able to grow and develop during the cooler temperatures, compared to vetch, which grew more rapidly during late February and March. Ideally, vetch should be allowed to reach its maximum growth, normally by early April in the Sacramento Valley, before incorporating the plant biomass to maximize the benefit.

Analysis of the cover crop estimated a nitrogen contribution of ~200 pounds/acre, twice the previous year's level. The relative growth of the cover crop species was also different between test years. In 1998, the cover crop biomass composition was roughly 50% peas and 50% vetch. In 1999, vetch dominated the cover crop biomass at a ratio of nearly 5:1. No major disease or pest problems were noted in the cover crop, although some large weeds grew through the dense cover in spots. The rest of the field, including the "fallow" trial plots, were treated with Roundup® herbicide. Gopher activity was greater in the cover cropped area.

In February and March 1999, we compared rainfall runoff from grouped sets of field-length (~1000') rows of cover crop and fallow beds using various devices including flow meters. Seasonal runoff from the cover crop furrows was 60% or less compared to the fallow furrows.

In 1999, a Wilcox Performer® bed mulcher was used to incorporate the cover crop. The ground driven rotary cylindrical bladed, bed mulcher chopped & incorporated the cover crop in two passes and repeated a week later in a single pass prior to final incorporation and bed shaping.

Prior to incorporation, soil was sampled in cooperation with and consultation from Louise Jackson of the UC Davis Vegetable Crops Department. About two weeks after cover crop incorporation, tomato variety Halley was transplanted commercially by the grower on April 18, 1999.

Our plot design was a randomized complete block with 6 replications with each plot 3 beds wide by 100 feet long. We evaluated two factors: 1) fallow vs. cover cropping with a vetch-pea mix and 2) spring-applied sidedress nitrogen rates of either 0, 50, 100, or 150 pounds of N per acre. Sidedressed N, as urea, was applied soon after transplants were well established. Sprinkler irrigation was used initially to establish the plants, followed by furrow irrigation thereafter. All other cultural practices were those commonly used by growers in our local area.

We monitored growth of the tomato plants throughout the season. Plant tissue samples, petiole as well as whole leaf, were collected at 3 separate growth stages and sent to a UC lab at

Davis. Although we calculated the cover crop fixed over 200 lbs. of N per acre, tomato yields suffered when grown solely on the nitrogen fixed by the vetch-peas and without benefit of supplemental applied N. We did not see a substantial fertilizer N benefit from the cover crop nor detect large N differences from lab analysis of tissue samples.

Yields were increased 7% to 41.6 tons in the cover cropped beds compared to 38.7 tons/acre in the fallow beds (Table 1). The leguminous biomass incorporation enhanced yield over the conventional fallow treatments except when applied N was withheld, where yields were the lowest. In the fallow bed treatments, tomato crop yield did not respond to spring time applied N.

Fruit quality was reduced with the cover crop. °Brix was decreased substantially from 5.7 to 5.3 with the cover crop treatment (Table 2). Fruit color was reduced from 22.7 to 23.6 using the Processing Tomato Advisory Board's measurements. Peeling quality was reduced. The fruit disorder yellow eye was increased from 0.7 o 2.1 fruit per 50 fruit sample. Defects with only internal white core remained unchanged. Fruit with both yellow eye and white core defects were increased from 4.5 to 7.0 fruit per 50 fruit sample.

Plant tissue samples of nitrate-N from petioles or per cent N from whole leaf samples indicated either no difference between fallow or cover cropped practices, or reduced N tissue levels with the cover cropping (Table 3). The reduction in tissue N indicates tie up of N in the soil, which made the leguminous N unavailable to the tomato crop.

In summary, we remain optimistic cover cropping between successive years of tomatoes in the rotation can provide a yield benefit. The reduction in winter run-off may be attractive to reduce down-stream flooding. We are uncertain of the influence of cover cropping on brix levels, as quality was inconsistent with improvement the previous year compared to a substantial reduction this year. Irrigation may have to be adjusted with perhaps an earlier irrigation cut-off with the cover cropping to raise brix levels. Indices of peeling quality indicated peelability was reduced.

We are continuing our testing into the 3rd year in a different field with similar soil texture with cooperator Blake Harlan.

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Table 2. Influence of vetch-pea cover crop on tomato peelability, Harlan & Dumars, Woodland, CA, 1999.

treatment		per 50 fruit # yellow eye	per 50 fruit # white core	per 50 fruit # yellow eye with white core
Fallow		0.7	5.3	4.5
Vetch/peas		2.1	4.6	7.0
Probability		0.06	NS	**
Sidedress N rate/A				
None		2.5	4.0	7.4
50 lbs		2.2	5.9	5.3
100 lbs		0.7	3.9	5.3
150 lbs		0.3	5.9	5.0
Probability		0.10	**	0.10
Interaction				
Cover X N (Probability)		NS	NS	NS
Fallow X N rates				
none vs		1.0	4.8	6.3
some		0.6	5.4	3.8
	probability	NS	NS	*
linear		NS	NS	*
quadratic		NS	NS	NS
Cover X N rates				
none vs		4.0	3.2	8.5
some		1.5	5.1	6.6
	probability	*	*	0.12
linear		**	0.11	NS
quadratic		NS	NS	0.14

Table 1. Influence of vetch-pea cover crop on tomato fruit yield, Harlan & Dumars, Woodland, CA, 1999.

treatment	Yield tonsA	% #1 reds	% pink	% green	% sun burn	% mold	% BER	Kg per 50 fruit
Fallow	38.72	84.2	3.68	7.59	1.44	2.91	0.24	3.78
Vetch/peas	41.58	85	4.58	4.22	2.73	3.46	0.21	3.99
Probability	*	NS	NS	**	*	NS	NS	*
Sidedress N rate/A								
None	37.22	86.2	3.4	5.22	2.04	2.85	0.34	4.03
50 lbs	42.18	84.2	4.32	6.63	1.25	3.37	0.24	4.01
100 lbs	40.48	84.2	4.28	5.79	2.24	3.35	0.15	3.72
150 lbs	40.73	83.7	4.51	5.98	2.81	3.17	0.17	3.78
Probability	0.07	NS	NS	NS	NS	NS	NS	*
Interaction								
Cover X N (Probability)	NS	NS	NS	NS	NS	NS	NS	NS
Fallow X N rates								
none vs	38.2	84.3	4.0	7.7	0.9	2.7	0.4	4.0
some	38.9	84.1	3.6	7.5	1.6	3.0	0.2	3.7
probability	NS							0.1
linear	NS							**
quadratic	NS							NS
Cover X N rates								
none vs	36.2	88.0	2.8	2.7	3.2	3.0	0.3	4.1
some	43.4	83.9	5.2	4.7	2.6	3.6	0.2	3.9
probability	**							NS
linear	*							NS
quadratic	**							0.15

Table 3. Influence of vetch-pea cover crop on tomato tissue N levels, Harlan & Dumars, Woodland, CA, 1999.

treatment	6.02 Petiole nitrate-N	6.02 whole leaf %N-Total	6.17 Petiole nitrate-N	6.17 whole leaf %N-Total	7.09 Petiole nitrate-N	7.09 whole leaf %N-Total
Fallow	7283.8	4.2	8542.5	4.6	617.1	3.4
Vetch/peas	6393.8	4.1	6729.6	4.4	421.7	3.4
Probability	*	0.12	**	**	0.06	NS
Sidedress N rate/A						
None	3307.5	3.8	4973.3	4.2	107.5	3.1
50 lbs	8151.7	4.4	8087.5	4.5	366.7	3.5
100 lbs	7952.5	4.2	8753.3	4.6	712.5	3.3
150 lbs	7943.3	4.3	8730	4.7	890.8	3.6
Probability	**	**	**	**	**	**
Interaction						
Cover X N (Probability)	NS	NS	**	0.06	NS	NS
Fallow X N rates						
none vs	4433.3	3.9	7160.0	4.5	170.0	3.3
some	8233.9	4.4	9003.3	4.7	766.1	3.4
probability	**	**	**	0.14	**	NS
linear	**	*	**	*	**	NS
quadratic	**	0.06	NS	NS	NS	NS
Cover X N rates						
none vs	2181.7	3.6	2786.7	3.9	45.0	3.0
some	7797.8	4.3	8043.9	4.5	547.2	3.5
probability	**	**	**	**	**	**
linear	**	**	**	**	**	**
quadratic	**	**	**	*	NS	NS

PHYTOCHEMICALS: NATURALLY OCCURRING BIOACTIVE AGENTS ARE CREATING VALUE ADDED SPECIALTY CROPS

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INTRODUCTION

A new diet-health paradigm may be evolving that acknowledges the nutritious and healthful aspects of food. The paradigm goes beyond the role of food constituents as essential nutrients for sustaining life and growth to one preventing or delaying premature onset of chronic diseases. The key change in the new health paradigm is prevention rather than treatment (Bidlack, 1998).

As a complex mixture of chemicals, food provides essential nutrients, requisite calories, and other physiologically active constituents needed for life and health. Except for a few nutrients, most of these dietary chemicals remain uncharacterized, including the level and frequency of human consumption. Many of these chemicals are inert, while some are toxic or carcinogenic (Bidlack and Omaye, 1995), and others may have positive effects on physiologic function acting as protective agents countering the risks of acute toxicity and diminishing the onset of disease. Further evaluation of the mechanisms of action of these chemicals is essential to our understanding of why certain phytochemicals seem to be beneficial at low concentrations within our general food supply (Bidlack et al., 1998, 1999).

Epidemiological surveys continue to provide positive correlations between diets, and specific foods, and apparent positive health benefits. Diets rich in fruits, vegetables and grains have been associated with the prevention of several chronic diseases, including reduced risk of a variety of tumors, especially epithelial cancers of the respiratory and gastrointestinal tract. The effect of whole fruit and vegetables appears to be more pronounced than that of the individual dietary constituents they supply. Perhaps, it is the combination of nutrients and other dietary constituents in fruit and vegetables that is etiologically relevant. From these results, recommendations have been made that Americans should consume at least two servings of fruit and three servings of vegetables daily. Although the majority of adults fall well short of meeting these guidelines, as well as the need for grains and fiber, recent reports indicate a dramatic increase in vegetarianism, vegetarian requests at restaurants, and fresh cut fruits and vegetables in the supermarkets.

There has been no evolutionary pressure exerted on plants to develop food components that protect man from diseases and cancer; yet, diets rich in fruits and vegetables appear to do just that. Most likely, the active plant constituents developed as a part of their own defense mechanisms and only fortuitously contribute to man's health.

PHYTOCHEMICALS AS BIOACTIVE AGENTS

The number of identified physiologically active phytochemicals has increased dramatically in the last decade, although there has not been a systematic approach to either categorization or documentation of their role in health promotion or disease prevention (Bidlack and Wang, 1999). Initial identification of these agents was made by epidemiological surveys that correlated a positive health benefit with specific food groups and then focused on specific dietary components. Further evaluations have been developed using chemical analyses, test tube reaction systems, cell culture, animal studies and in a few cases human intervention studies. To date, most research related to phytochemicals has focused on cancer prevention, although recent experiments have been expanded to include atherosclerosis, heart disease, immune response, osteoporosis, and others.

Although some of the phytochemicals have shown positive biological activities, which may participate in disease prevention, most of them will be determined not to be magical silver bullets. These agents may work through specific individual or multiple mechanisms or in synchrony with each other to enhance health. Some of the desirable bioactive-chemical properties of these phtochemicals include: 1) antioxidants, modifiers of oxidative damage and defense mechanisms related to oxidative stress, 2) antimutagens, anticarcinogens, and inducers of enzymes of xenobiotic metabolism, 3) antimicrobial and antiviral substances, 4) enhancers of GI function, 5) immunomodulators and anti-inflammatory agents, 6) phytoestrogens, and 7) hypocholesterolemic agents. It might be noted that just because an agent is determined to have one activity does not prove that it is the primary biologic activity of that agent.

The promise of functional foods, food products, and supplements that deliver a possible physiologic benefit in the management or prevention of disease represents an opportunity for production of selected crops that contain bioactive phytochemicals, as well as enhancement of future new product growth in the food and beverage industries (Bidlack and Wang, 1998, Fjeld and Lawson, 1999).

PHYTOCHEMICALS OF INTEREST

From the beginnings of recorded history, plant components (leaves, flowers, roots and bark) have been identified and used in the treatment of specific diseases. Hippocrates, the father of medicine, included food as a basic part of treatment to cure disease. Taken from many cultures, herbs and plants commonly used for treatment of specific disorders have been carefully identified. The use of modern analytical methods have enabled identification of numerous physiologically active constituents, many of which have been developed into pharmaceutical agents.

Researchers are examining these foods, isolating and characterizing their chemical components, and identifying their structures and physiologic function. To date, very few phytochemicals have been examined as thoroughly as needed (Bidlack and Wang, 1998). Unlike the essential nutrients, food composition data for most nonessential phytochemicals either do not exist or are limited. Similarly, epidemiological data for most bioactive plant constituents are sparse. It will be many years before these agents are determined to offer health benefits as either natural ingredients, food additives, or as dietary supplements. Decisions must be based on efficacy, assessing the lowest possible dose to provide the benefit, and in all cases safety must be assured.

Some of the phytochemicals that appear to have significant physiological activity and provide positive health potential include:

- Phytoestrogens may decrease osteoporosis, offset menopause symptoms, and decrease estrogen enhanced carcinogenesis. Genestein and daidzein, commonly found in soy foods (soy flour, texturized soy protein, tofu and tempeh), and coumestan (alfalfa, clover and soybean sprouts, split peas, pinto beans) are phytochemicals of interest. Theoretically phytoestrogens bind to the estrogenic receptor and either compete with or antagonize estradiol action. The health effect would depend on the exposure level of the phytoestrogen, the binding constant relative to estradiol, and the selectivity of different tissue receptors. Reservatol is another phytochemical having phytoestrogenic activity. It occurs in purple grapes, grape juice and red wine.

- Tea catechins, may inhibit initiation and promotion of the carcinogenic processes. Using either green tea infusion or isolated tea catechins, these polyphenolic compounds have proven to express a broad spectrum of anticarcinogenic activity in multiple animal models, including the inhibition of the development of tumors at different sites and affecting a wide array of enzymes involved in cell proliferation. Importantly, the results of animal experiments consistently indicate the effective concentrations of these phytochemicals equal the levels found in brewed green tea. Unfortunately, human studies have not been as impressive. Grape seeds and skins also contain catechins.

- Polyphenolic phytochemical derivatives include aromatic compounds such as flavonoids, anthrocyanins, tannins and lignins. Flavonoids, such as quercetin and kaempferol, found in almonds cause strong suppression of lung and prostrate tumor cell growth. Similar flavonoids, as well as myricetin and apigenin, are also found in tea. Anthocyanins are reddish phytochemicals found in strawberries, cherries, cranberries, blueberries, black currants and red grapes. These compounds appear to decrease platelet aggregation, decrease heart disease and lower cholesterol synthesis.

- Natural antimicrobial phenolic-compounds found in hot peppers and spices, such as benzoic acid, caffeic acid, catechin, catechol, rutin, eugenol, and thymol, have historically protected foods from spoilage. Many of these compounds have demonstrated antiviral and anticancer activities as well.

- Alpha-tocopherol (vitamin E), which is rich in grains and vegetable oils, has been shown to inhibit free radical reactions in biological membranes. The family of tocopherols includes the tocotrienols, which also has an excellent antioxidant profile in food and biological systems. However, tocotrienols exhibit properties different from those of α-tocopherol. For example, γ-tocotrienol is much more effective than α-tocotrienol in lowering cholesterol synthesis (through specific modulation of HMG CoA reductase protein degradation), while α-tocopherol has no effect. In addition, tocotrienols have been shown to delay the onset of tumorigenesis and/or reduce the proliferation of a range of tumors.

- Carotenoids are a large family of terpene compounds. In excess of 40 carotenoids have been identified in fruits and vegetabes, but only 13 appear to be absorbed, metabolized, and utilized by humans (Omaye et al, 1997). Carotenoids, such as alpha and ß-carotene, are absorbed intact and converted to vitamin A. In contrast, metabolic transformations of other major carotenoids, such as lutein, zeaxanthin, and lycopene, involve a series of oxidation-reduction reactions. Several dietary carotenoids have been detected in significant mounts in human organs and tissues such as liver, lung, breast, and cervix. Their potential role in prevention of cancer and age-related macular degeneration has been described.

- Organosulfur compounds found in garlic and onions clearly demonstrate antioxidant functions, a decrease in metabolic activation of carcinogens and adduct binding to DNA, and a decrease in platelet aggregation and serum clotting mechanisms. It should be noted that the doses used to test these agents have been very high for many of the experiments reported. The chemical changes induced by cutting garlic and onion, and subsequent changes caused by cooking or processing used in the manufacture of commercial garlic nutritional supplements, must be considered when examining the molecular basis for the biological activity attributed to these plants, or the commercial supplements produced from the plants.

- Prebiotic enhancement of intestinal function. oligosaccharides, such as fructose oligosaccharides and inulin, produce specific physiologic effects on immune function, tumorigenesis and regulation of serum cholesterol. Some of these agents have already been incorporated into commercial products.

A shift in paradigm from food quality to include consideration of specific constituents that may promote health requires new thinking and new strategies across all segments of the food production system. It is abundantly clear that if phytochemical research is to develop and succeed, better interdisciplinary linkages are needed between experts in plant biology, human nutrition and food science, as well as the role of agriculture through crop science, soil science and horticulture. Further research needs to be implemented on specific molecules, mechanisms of action, biomarkers of their status and functions, efficacious delivery, and means to improve the food supply in order to realize the full value of the bioactive agents. Importantly, agricultural practices must be established for each plant that will select specific agents, protect and enhance these constituents to be carried into the food supply.

SEED TECHNOLOGY AND PLANT PHYSIOLOGY

Species selection and identification of individual cultivars will initiate the process. Use of traditional breeding and marker assisted breeding methods, and potentially biotechnology, to enhance the desired traits will increase the value of these specialty crops. If the physiologically active compound gene is present, it is possible to increase its expression to enhance the accumulation of these compounds or molecules. If the gene is not present, biotechnology and breeding methods are employed to introgress the gene(s) into elite germplasm.

In addition, characterization of the growing conditions that optimize plant production of these phytochemicals will optimize the yield and stabilize production quality from field to field. The screening of these plants for bioactive agents will include various plant parts and types of extracts. The isolates will then be evaluated in a variety of biological animal and cell model systems.

These value-added products, sometimes referred to as nutraceuticals, have been developed cooperatively between seed industry and pharmaceutical laboratories. The merging of these two industries has come about as a result of the realization that seeds are the ideal delivery device for this new technology. Seeds are a convenient and economical way in which to store and transport the genetic information that ultimately yields plants of higher nutrient and / or phytochemical value.

Seeds have evolved primarily as a device to establish a plant. The altered expression of certain phytoactive compounds, however, might interfere with the normal functioning of the seed. The Cal Poly Pomona Seed Technology Laboratory (STL) has been actively engaged in developing methods to ensure that value-added seeds retain their primary function of establishing the next generation. High quality seed is characterized by the ability to germinate quickly and uniformly, germinate under conditions of environmental stress, and retain long shelf life. As value-added technologies are developed, the STL laboratory will identify and select for key genes that allow production of seed from genetic lines that expresses both high seed vigor and increased expression of physiologically active compounds in the plant.

MARKET POTENTIAL

Traditionally fortified foods and nonherbals have an existing market in excess of $100B. As of 1998, the healthy food/dietary supplement market exceeded $60B, and the expected increase during the next three years could add another $16B. In recent years the population has accepted the message that fruits and vegetables are not only nutritionally good for you, but provide other health benefits. Seventy-one percent of the population has increased their individual consumption of fruits and vegetables. The fresh cut market in grocery stores will reach $20B by 2001.

The areas of growth will include grains and more grains, soy products, fish oil/omega 3 fatty acids, cultured products, inulin and fructose oligosaccharides (prebiotic), energy aids, anthrocyanin and lectin and lycopene. Agricultural production of many crops, such as grapes and wine, almonds, soybeans , onions and garlic, peppers, and tomatoes, will all take on new characteristics of value added products, if indeed their bioactive constituents are found to provide health benefits.

CONCLUSION

Only a few examples of bioactive phytochemicals have been presented here to represent their exciting potential as future physiologically active agents that may be incorporated into the food supply. "Natural products" are not a cure-all. A decision on efficacy must look at the lowest doses needed for producing their effects, since higher doses increase the risk for toxicity. In all cases, the question of safety must be assured.

As a new paradigm in nutrition, perhaps some of these non-essential compounds will prove to be beneficial to health. However, too many programs are promoting the marketing potential of these agents before they have been determined to function in the human system. Basic research must delineate many of these factors before phytochemicals can be further promoted as benefiting health. Evaluation must be based on the best scientific evidence available as provided by cellular biology, animal studies, clinical trials, and epidemiological surveys. The interpretation must consider the quality, strength, and consistency of the data, and the biologic plausibility of the hypotheses. Confirmation that these agents may prevent human disease is eagerly awaited; however, it would be unfortunate if over-promotion of potential health benefits created unrealistic expectations that could never be realized. The result might be a decrease in the research effort and support needed to identify those bioactive agents that could provide health benefits (Bidlack, 1998).

An understanding of the basic principles of formulation, food technology and processing, and new biotechnologies provides ample opportunity for development of functional foods, which will utilize phytochemicals having bioactive components to create products to prevent disease and maintain a healthy life throughout our existence. The future of science and product development in this area will be an exciting adventure for years to come.

Perhaps our grandmothers were right and we should eat everything on our plate, but there may be important health benefits derived from specific foods. Thus, the potential for increased agricultural profits for the self-initiated producer may be readily approaching in the very near future.

ACKNOWLEDGEMENT

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Quality Indicators in Lettuce Seed

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The objective of every seed producer is to produce and sell seed of the highest possible quality. The concern of growers is that the seed they plant will produce a stand, even if weather conditions are not ideal. It is well known that high quality seed are more likely to germinate and establish a seedling than are seed of low vigor under environmentally stressful conditions. Each seed lot must be tested, but it is difficult, time consuming and expensive to determine seed quality. The simplest method in which to test a seed lot is to conduct a field emergence test. These tests, when replicated over time, can give conflicting results because different planting dates and fields often create a different physical environment at each planting. The field emergence test gives the likelihood of germination of a seed lot at that point in time under "real world" conditions. It does not, however, provide any benchmark as to the physiological status of the seed lot by measuring, for example, thermo- and osmoinhibition, skotodormancy or potential longevity of the seed lot.

A seed producer is concerned about seed quality at two specific times in the seed producer-to-grower chain: 1) when assessing seed quality after production, and 2) when managing inventory of stored seed. Seed producers often contract with seed technology companies to provide seed enhancements such as priming or pelleting. Similarly, the seed technology company is concerned about seed quality at two specific times: 1) when assessing seed quality to determine suitability of the seed lot to be enhanced, and 2) when assessing the effects of the seed enhancement. Each company is likely to perform a standard germination test, as well as numerous other tests, which may be proprietary in nature. The common feature of each seed company with these tests is the need to obtain the physiological assessment information as quickly and efficiently as possible. Because of the enormous volume of seed lots that must be tested, low cost tests are desirable.

The germination process is initiated with a complex set of physical, cellular and molecular events and is influenced by water availability, air composition, and temperature during imbibition. Most seed lots will have high germination percentages under ideal conditions. If an environmental stress is included in the germination test, discrimination can be made between seed lots of higher or lower quality. For a number of different species, germination tests that measure the overall speed of germination are sensitive indicators of the physiological status of the seed lot, as germination rate often declines before viability (Powell and Matthews, 1984; Ram and Weisner, 1988; Still, 1999). However, all seeds in a sample do not germinate at the same time, and these differences in time are even greater under stress. Further, this sensitivity to abiotic factors during germination is normally distributed within a seed population, which enables the use of population statistics to describe and quantify vigor for a seed lot.

Hydrotime tests

Our laboratory has been developing hydrotime (Bradford, 1990, 1995; Dahal and Bradford, 1990; Still and Bradford, 1998) vigor tests for lettuce to assess the sensitivity of germination to reduced water potentials (Fig. 1). By imbibing seeds in a series of progressively lower water potential solutions and obtaining germination time courses, the threshold sensitivity distribution to reduced water potential (ψ_b) has been obtained for a number of cultivars and lettuce types. Every seed differs in its sensitivity to stress, which in this case is an osmotic stress. The sensitivity is due to natural physiological variation and is likely to have a genetic component as well. All seeds do not germinate simultaneously in water and under an osmotic stress the differences in time to germination are exacerbated. The relative difference in germination times under stress is the basis by which discrimination is made between seed populations of different physiological maturity or quality using hydrotime analysis. The hydrotime characteristics of a seed lot are characterized by three variables: θ_H, the hydrotime constant that is related to the speed of germination, $\psi_b(50)$, the water potential that just prevents 50% of the population from germinating, and the standard deviation of the threshold distribution, σ_{ψ_b}. A seed lot is comprised of seeds with each seed having a different $\psi_b(g)$ value. If a sample from a given seed lot has a greater proportion of seeds with low $\psi_b(g)$ values (able to germinate under water stress), that lot will have a lower $\psi_b(50)$ value compared to a seed lot comprised of seeds with high $\psi_b(g)$ values (not able

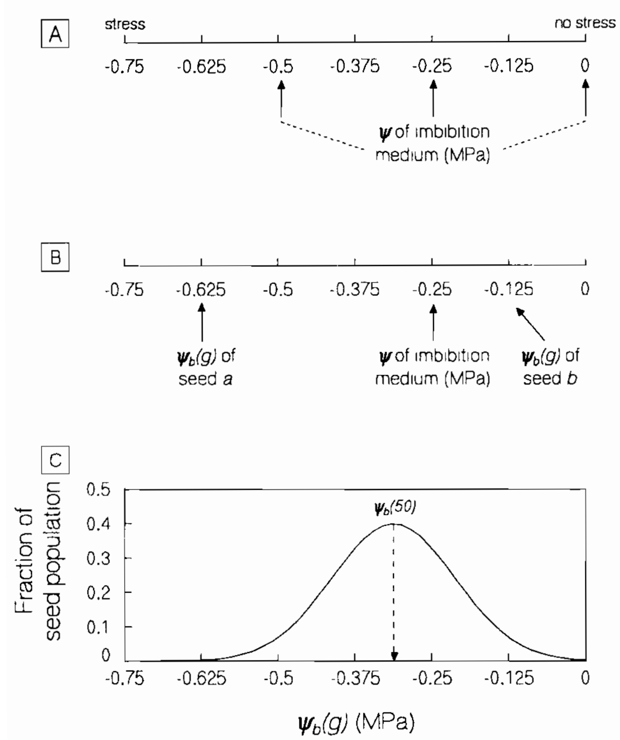

Figure 1. Overview of hydrotime vigor test. (A) Seeds are imbibed in water (0 MPa) or polyethylene glycol solutions (-0.25 or –0.50 MPa). (B) Seed *b* will not germinate whereas seed *a* will because its water potential threshold is more negative than the imbibition medium water potential. (C) Data from the hydrotime germination time courses can be expressed as a normal distribution curve with a median value of $\psi_b(50)$ and a variance of $\sigma\psi_b$. These two parameters, in addition to the hydrotime constant (θ_H), are used to quantify seed vigor in lettuce.

to germinate under water stress. We have hypothesized that a good seed lot will have a relatively low $\psi_b(50)$ (more negative) and a small σ_{ψ_b} value. This would allow uniform germination under low moisture or high salinity conditions. Seed lots with low σ_{ψ_b} values indicate a greater uniformity in germination, that is, less time has elapsed between the first seed to germinate and the last seed to germinate, which is another indication of a high quality seed lot.

We have found a good correlation between hydrotime characteristics and field emergence. Further, we have found that the hydrotime vigor test is sufficiently sensitive to detect effects of priming on hydrotime as well as pellet effects on hydrotime. These data will be presented as well as a discussion on how hydrotime can be used to set benchmarks for seed quality in lettuce.

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PRODUCING QUALITY COTTON FOR TOMORROWS MARKETS

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Changes in the Market Place

We often observe a recurring phenomenon in which a new product or a new technology replaces the old. A classic example is the automobile and the horse and buggy. As the sale of automobiles increased, the sale of buggies decreased until a point was reached where the numbers were equal, probably sometime between 1910 and 1920. From this crossover point the future demise of the buggy was inevitable in spite of some who questioned at the time whether the automobile was here to stay.

We have experienced, to a degree, a similar phenomenon in the cotton industry as synthetic fibers made rapid inroads throughout the sixties and seventies. In U.S. mills this crossover point in fiber usage was reached in 1968. Within another 5 years the ratio of synthetics to cotton had increased to 70/30, exactly the reverse that prevailed in 1960, scarcely a dozen years before. Part of the man made fibers success was undoubtedly due to aggressive advertising and promotion (most of us remember the popular plaid polyester slacks and polyester suits of the period). But much of it has to do with the highly competitive nature of the textile industry. To be cost competitive the successful companies have gone to automated high-speed equipment. In today's modern mills the various processing machinery from carding, to spinning, to weaving, operate at many times the speeds that were common in 1960, and increases continue to be made. This places added stress on the fiber, increasing the susceptibility to breakage and other processing interruptions. The synthetics with their long, strong, uniform fibers were well adapted to this processing environment.

However, in one respect fabric made from cotton has an inherent advantage, and this is related to the unique nature of the fiber. An individual cotton fiber is in reality a singe, highly elongated cell, not too different from an ordinary cell in diameter, but an inch or more in length. In the process of a fibers development, successive layers of cellulose are laid down daily inside the primary cell wall. This is somewhat analogous to annual tree rings except that the layers proceed from the outside to the inside. At maturity, after about 40-50 days of development, an individual fiber consists of a relatively thick cell wall of nearly pure cellulose with a hollow central core. It is this characteristic, unique among all fibers, natural or manmade, that gives cotton fabric the exceptional ability to absorb moisture and perspiration, and hence, comfort.

With this highly desirable characteristic built in, the challenge to breeders and to producers is to deliver to the mills a cotton that can be efficiently and profitably spun into a high quality product. As the raw material of an incredibly complex manufacturing process, cotton has not just one or two, but an array of characteristics that determines how it will perform in the mill, and measuring these traits can only be done using sophisticated instruments. In contrast, many or most agricultural products in the marketplace can be described and measured relatively simply; some produce may be adequately described by nothing more than size. Aided by the development of instrumentation, there has come to be recognized three basic fiber quality parameters. These are (1) fiber length and length distribution or uniformity, (2) strength and elasticity, and (3) micronaire, which is a combination of fiber fineness and fiber maturity. Attempts to bring about quality improvements involve changing one or more of these characteristics. The ideal for a fine count high end yarn is a uniform long, strong, fine fiber. The cotton plant may be unique in that the component of primary interest provides little or no obvious contribution to the plants survivability. In fact, some wild ancestors of cultivated cottons have little or no lint on the seed. It could be said that, in effect, the breeders efforts are unaided by the plants natural inclination. Nevertheless, significant improvements have been made in the past 20 years in both yield and quality as we shall discuss later.

To return to the time period up to the 60's and 70's that was discussed earlier, the primary breeding emphasis in most parts of the Cotton Belt had been to improve yield, with quality considerations secondary. With successive variety releases most quality parameters showed no consistent trends in either direction. The San Joaquin Valley has always been somewhat of an exception in that quality aspects have received much more emphasis; as a result of its higher quality much of the domestic usage of SJV cotton has gone into blends with other cottons to upgrade the quality of the mix, particularly with regard to strength. Nevertheless, it is apparent that overall failure to keep up with the more stringent demands of changing manufacturing technologies contributed to the rapid decline in market share described earlier.

As we have seen, by the early 70's this had reached crisis proportions. Had the losses continued at the same rate, cotton would have been relegated to nothing more than a minor niche market long before now. In an attempt to stem the losses, the industry created a new entity known as Cotton Incorporated. Supported by a grower paid assessment on each bale, its charge was to turn the tide—through advertising and promotion, research and technical support for mill customers. Within a few years the downtrend had been turned around, and throughout much of the 80's and 90's many of the previous market losses had been recaptured. It is generally acknowledged that CI's highly successful advertising campaigns and changing consumer preferences have largely brought this about, but, for reasons discussed earlier, it is highly unlikely that this could have come about had it not been for an improved product to deliver to the mills. That these quality enhancements have occurred, especially in fiber strength, is evident from USDA market reports since 1980. This is true not only of SJV Acalas, but for other parts of the Cotton Belt as well.

These improvements have been spurred by the development of High Volume Instruments (HVI), around 1980. This allows a rapid and inexpensive measure to be made on every bale for length, uniformity, strength, and micronaire, something heretofore not possible except in a laboratory setting. As an example, when HVI was instituted in official classing offices the average fiber strength was 24 to 25 grams per tex, and this was set as the base standard by the USDA. Anything below this was considered to be in the discount range and anything above it in the premium range. By 1998 the average fiber strength in the mid-south was 27 to 28 grams per tex. In effect, what once would have been considered to be well into the premium range had now become the de facto standard. Relatively little cotton now produced anywhere in the Cotton Belt is at the official standard, and almost none below it. In a similar manner, SJV cotton has increased from 28 grams per tex to 32 grams per tex during this same period.

SJV Quality Cotton Program

Mention has been made of the high quality tradition of SJV cotton. This goes back to a unique "One-Variety" law passed in 1925. For several years prior to this the USDA had been advocating the formation of voluntary one-variety gin committees to prevent varietal mixing at the gin and also to take economic advantage of marketing a uniform fiber type. California producers, in a still fledgling enterprise, carried this idea a step further and supported the state legislation making it a requirement throughout the San Joaquin cotton growing area. The law in its original form mandated that only high quality "Acala" types could be commercially grown in the district, with the USDA as the sole breeder. Since that time, the San Joaquin valley has established and maintained its reputation in the world marketplace as the premier area of uniform high quality cotton.

In 1978 the USDA announced its intent to discontinue applied breeding. To fill the void new legislation was enacted that, among other things, gave approval for the private sector to assume breeding responsibilities formerly carried out solely by the USDA. The revised law called for a 17-member Board to, among other responsibilities, set the industry standard, commission a continuing testing program, and approve new varieties for commercial production. By its nature and scope, the testing program, carried out by the University of California, is not a variety testing program in the ordinary sense. Except for the "standard variety" used for comparison, almost none of the entries are commercial varieties; rather they are experimental lines submitted by the participating breeders. In a sense, the testing becomes a part of the selection process. Since the 1978 law change, more than 600 lines have entered this testing program. Most of these are destined to drop out after the first year. To receive ultimate approval a cotton must undergo increasingly rigorous evaluations of many agronomic and quality parameters over a 3-year period. Besides a wide array of fiber quality measurements, the testing continues through actual spinning and other manufacturing processes. This goes far beyond what is carried out in typical breeding and testing programs. This ensures that any entry receiving approval will indeed perform as expected. Once a cotton is determined to have met the standard and has been approved, it becomes by definition "Acala". It is then dropped from the program to make room for new experimentals. At this point U.C. Cooperative Extension picks up the newly approved variety and continues to yield test it, along with previously approved varieties, further enlarging the database.

Of the 600 entries previously mentioned, more than two dozen have ultimately received approval over the years. Breeders are currently maintaining ten or so of these varieties, thus forming a pool from which growers can choose. At the time of the law change some feared that opening up the valley to private breeders and a possible proliferation of varieties might lead to a loss of confidence by mill customers. This has not been the case. Mention has been made of severe stresses put on the fiber by increasing operating speeds. In response to this, there have been several upgrades in the Acala quality standard since 1978. Consequently current varieties have a longer, stronger, finer and more uniform fiber that is most desired by the mills that customarily produce the fine count yarns into which most SJV cotton is spun. Acala SJ-2, the variety standard at the beginning of the eighties and considered a premier cotton at the time, clearly would not meet current Acala standards.

Management Practices for Quality Cotton

With the above in mind, from a strictly fiber quality standpoint, the individual SJV Acala grower ordinarily need not be overly concerned with his choice of a variety since all approved varieties have been shown to have a high level of quality built into them by the breeder. His choice will hinge mainly on yield factors and how a given variety fits in with his production system. However there is a catch. He still must preserve the inherent quality that is already there. There is sometimes a tendency to think that high production and high quality do not go together, but this is not necessarily so. By and large the same inputs that produce optimum yields also promote high quality.

Good seedbed preparation, planting when temperatures are favorable, close insect monitoring, timely irrigations, adequate but not excessive fertilizer, especially nitrogen, maintaining a favorable vegetative/fruiting balance—in short, all things making for a good fruit load also leads to a well defined cut-out which in turn sets up the plant for a timely and efficient defoliation. All of these things are easier said than done, but we now have better tools to accomplish this than we used to have, e.g. plant growth regulators such as Pix, the use of plant mapping to better control growth and fruiting, nodes above cracked boll to make better defoliation decisions, and improved harvest aid chemicals to promote leaf drop and rapid boll opening.

A field of well defoliated cotton when picked at a desirable moisture content does not require a lot of drying and cleaning at the gin, and the inherent quality is thus preserved. Poorly defoliated fields suffer in two ways: (1) with the excess trash grades are reduced and, (2) with extra drying and cleaning to try to improve the grade, fibers are broken and neps (very small tangled clumps of immature fiber) are produced. The breakage may or may not be sufficient to reduce the staple length significantly, but the short fibers and neps that are produced lead to processing difficulties and reduced quality of yarn and fabric.

In light of the above observations on yield and quality, one other interesting observation can be made. For nearly two decades prior to 1980 relatively few quality improvements were made in most parts of the Cotton Belt, as was alluded to earlier. This was also a period when yields were generally stagnant. In what might seem like a paradox, yields along with quality since 1980 have been improved throughout the Belt, demonstrating on a broader scale that advances in both yield and quality are not incompatible. Sometimes we can have our cake and eat it too.

Uplands and Acalas – New Legislation

Though not a part of the regular trials, from the inception of the testing program the performance in the San Joaquin Valley of leading out of state varieties have been monitored in small scale plots on a regular basis. Before now, none of them - with one minor exception - had exceeded either the yield or the quality of the standard Acala variety. However in the most recently completed 3-year testing cycle that these varieties undergo, two of them, though of lesser quality, did significantly out-yield the Acalas. Because of interest generated from recent reports on several of the newer non-Acala types, both here and in the Sacramento Valley, a greatly expanded program was put in place for 1998 to more fully explore the yield potential of some of these cottons in the San Joaquin Valley. A total of nine varieties were entered in these tests, six "Upland"varieties originating from both in state and out-of-state, together with three approved Acalas for comparison. These were tested in replicated field length plots either adjoining the regular Acala tests or in a nearby field. As with the Acala tests, the full array of measurements was made with respect to yield, and fiber quality and spinning characteristics.

Unfortunately varietal yields were reduced and distorted by the most disastrous weather problems in memory. The abbreviated season worked to the advantage of the shorter season non-Acala types and this was reflected in the yields. On the other hand fiber and yarn quality measurements were not adversely affected. Though below the Acalas, as expected, HVI measures of length, strength, uniformity and micronaire of the six non-Acalas were well within what would be considered to be a very acceptable range for most end uses. However, when spun into finer yarns the disparity between the two types increases. For example the Upland fiber strength, the best single predictor of yarn strength, averaged 91% of the Acalas. However, when spun into 22's, 36's, and 50's, count yarn representing increasing fineness, the relative yarn strength of the Uplands compared to the Acalas decreased to 87, 78 and 75% respectively. This is a manifestation of what experience has shown, viz. that when cotton is processed into finer counts, fiber quality factors become more critical. Some of the samples were unable to be spun into the finest count because of excessive yarn breakage. This would not necessarily have been predicted by the fiber data alone. These observations should be born in mind in the discussion to follow.

The past year has seen some dramatic developments in the San Joaquin Valley cotton industry. A combination of high production costs, depressed worldwide markets, and weather and insect related problems several years in a row had put producers in a financial bind. Since the majority of the San Joaquin Valley production now goes to Pacific Rim countries, the financial and economic problems there have been particularly damaging in the marketplace. On top of all of this the unprecedented El Nino related weather problems of 1998 forced many growers to the brink. In an attempt to salvage what little season was left, an emergency exemption was obtained permitting shorter season non-Acala varieties to be planted. After much discussion and debate a decision was made to implement legislation permitting any variety to be grown on a permanent basis. The legislation finally put in place provides for both the Acala and the Pima testing programs to continue as in the past, with only the mandatory aspects relating to commercial plantings no longer in force. Regulations were adopted to properly identify the approved varieties as distinguished from all other Upland and Pima varieties. The approved Acalas and Pimas will be known as "SJV Acalas" and "SJV Pimas"; bales from other varieties grown in the valley will be designated and tagged as "California Uplands" and "California Pimas". So long as this differentiation is successful and the mill customers have confidence in the process it may well be that approved Acala and Pima growers will benefit from an even greater premium brought about by a finer balance between supply and demand, while at the same time giving all producers greater flexibility in their planting decisions. From past experience, substantial changes in the operation of the law have been followed by a period of uncertainty, but in the end the industry has benefited and been made stronger. One can expect this will continue to hold true.

PRODUCING HIGH QUALITY ALFALFA:
Factors that Influence Alfalfa Forage Quality

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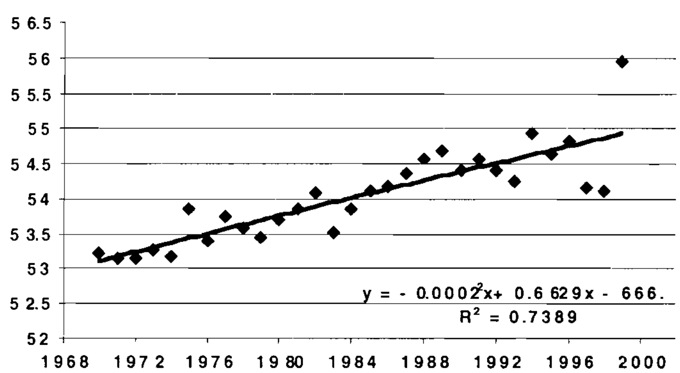
INTRODUCTION

Alfalfa is California's most important forage crop and has been worth between $800 million and $1 billion annually in recent years. Depending upon the year, alfalfa rivals cotton, tomatoes and lettuce for the state's second most important crop behind grapes. Statewide average yields have increased significantly over the years, with current average yields of between 7 and 7.5 tons/acre, approximately 25% more than in 1970. There are over 1 million acres of alfalfa in California, which is the primary feed for the state's $4 billion dairy industry.

Perhaps the largest change in the industry during the past 30 years has been an increased emphasis on forage quality. A dataset from Petaluma labs in Northern California has shown an average increase of about 1.5 points TDN[1] of samples received by that lab from 1970 through 1999 (Figure 1). This is a function primarily of grower's response to demands for higher quality hay by dairy producers.

Figure 1. Change in Total Digestible Nutrients (TDN) over 1
Petaluma Hay Testing Lab, Petaluma, CA



It is estimated that at least 20% of the value of California's alfalfa crop is determined by quality factors. This may be greater than $200 million annually. About 15% of California's alfalfa crop was tested by labs for quality factors in the early 1970s; but today that number is likely greater than 75% and many lots of hay are tested 2-3 times. Producing high quality alfalfa is often the key determining profitability of alfalfa hay production for the farmer. This article reviews the major and minor factors that determine alfalfa forage quality.

WHAT IS FORAGE QUALITY?

This answer to this question is complex, since the rumen-forage system is complex. Species and types of animals differ significantly in their forage quality requirements. In California, forage quality is defined primarily for the purposes of dairy production, since most of the crop is

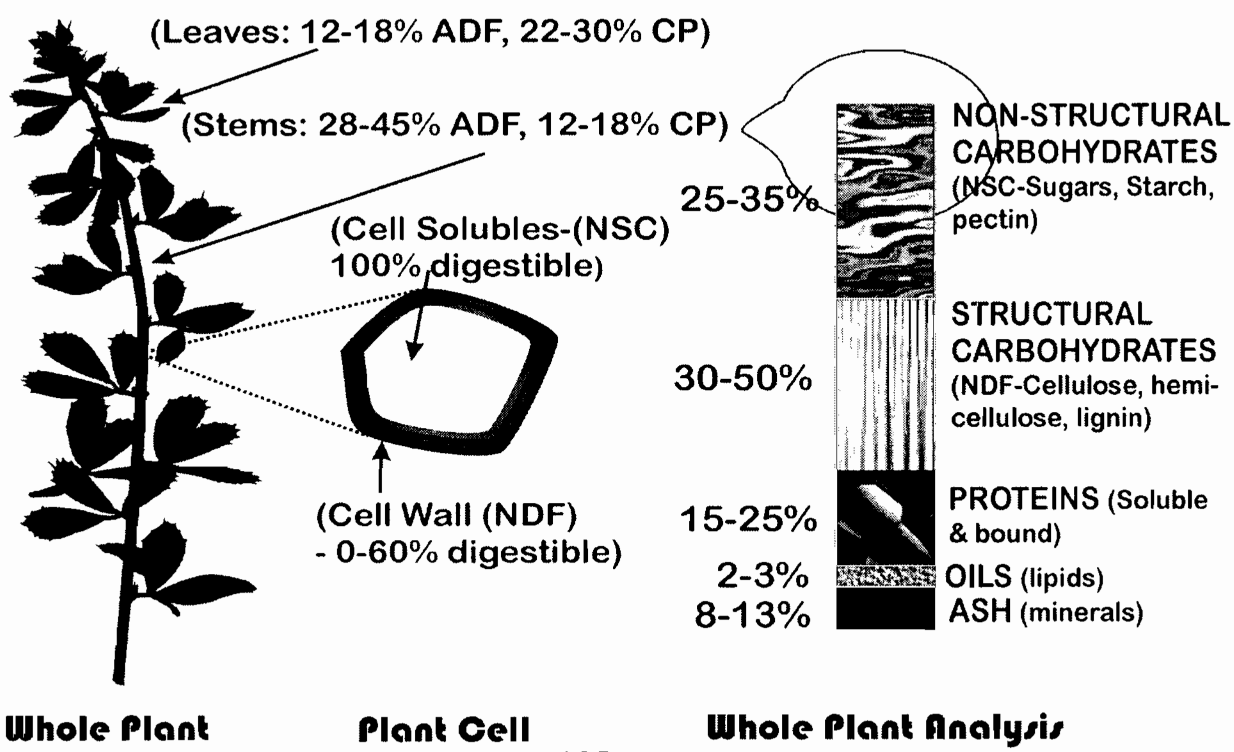
[1] Abbreviations: ADF=Acid Detergent Fiber, NDF=Neutral Detergent Fiber, CP=Crude Protein, TDN=Total Digestible Nutrients calculated from ADF, DM=Dry Matter, RFV=Relative Feed Value, NEL=Net Energy of Lactation.

destined for that use. The primary consideration for dairy producers is a high total yield of digestible energy per ton of hay. Other factors such as the rumen-degradable protein concentration, palatability, the amount of rapidly fermented non-structural carbohydrates, the speed of fermentation of the fiber fraction, anti-nutritional compounds, and the mineral content of the hay are also quite important. A complete review of the nutritional aspects of forage quality is beyond the scope of this article. However, it should be understood that many factors contribute to the potential feeding value of alfalfa, and forage quality is a multi-faceted characteristic.

Unfortunately, the most important aspect of forage quality (content of energy actually utilized by the animal) cannot be measured directly but is instead estimated or predicted. Most energy estimates (TDN or NEL) are calculated directly from a fiber measurement (ADF or NDF). In many areas of the USA, Relative Feed Value Index is calculated from ADF and NDF, but this is used only for marketing purposes, nutritionists do not use this to balance rations. There are also several lab measurements of fiber digestibility (In Vitro Digestible Dry Matter, or NDF digestibility) that have been shown to be valuable in predicting feeding value, but these are not widely used for the purposes of hay trading.

High quality forage in the California marketplace is defined primarily as having a low fiber (ADF or NDF) concentration, with a correspondingly high TDN value (calculated from ADF). As fiber (ADF) is reduced, TDN increases. California dairy markets have traditionally defined this as <29% ADF or about 54% TDN (90% DM basis, using the Western States Equation of Bath &

Figure 2. Alfalfa forage consists of structural components that differ dramatically in forage quality Leaves are much more digestible and lower in fiber than stems, and can have 2-3 times the protein. Within the cell, soluble components are 100% digestible whereas the cell wall is only partially digestible. Since cell wall is the most difficultly digestible plant component, it is the focus of chemical analysis. NDF approximates total cell wall and ADF approximates the most difficulty-digested portions of the cell: cellulose and lignin. Total plant quality is determined to a large extent by leaf-stem components, and development of the cell wall; both are affected by plant maturity.



Marble, 1989), but 'dairy hay' in recent years has been defined as closer to 54.5, 55%, or greater (<27 or <28% ADF). Both the 'cutoff level' for dairy quality and the price premium are functions of the supply and demand situation in a given year. Additional considerations in the marketplace are the Crude Protein content, as well as cutting and location of where the hay is grown, condition of the hay, and subjective quality factors.

Although low fiber hay is highly valued by dairies, there is a practical nutritional limit to reducing fiber in forages. Since there is an animal requirement for long plant fiber for chewing, salivation, and proper rumen function, extremely low fiber hays become difficult to feed, leading to physical problems like displaced abomasums or runny stools. Low-forage diets can lead to low milk fat (Mertens, 1999). Low fiber is important, but the digestibility of the fiber fraction is perhaps more important. Alfalfa hay is particularly valued for its highly digestible fiber content. The digestibility of the fiber fraction becomes more important with higher productivity dairy animals.

WHAT'S IN AN ALFALFA PLANT?

The primary constituents of plants from a nutritional perspective are listed on the right side of Figure 2. These are the ash, or mineral content, which is about 6-13% of the dry matter; lipids or fats, which are an insignificant portion (2-3%) of forages, total protein (typically 16-25%), the non-structural carbohydrate (NSC) component, primarily sugars, starches and pectin (about 25-35%), and the structural carbohydrates or fiber fraction, which is about 30-50% of the plant dry matter (Robinson, 1999). The fat component and the NSC as well as protein are very highly digestible and contribute directly to the energy feeding value (TDN) of the plant. The cell wall or fiber fraction, approximated by the NDF measurement, is only partly digestible. It yields some energy in ruminants through fermentation in the rumen by microorganisms. The amount and rate of digestion of fiber is highly variable, and will depend upon many factors, particularly the age of the plant. Thus the fiber fraction is the focus of lab analysis of forages. Both the amount of fiber and the rate of its digestibility are important. The ADF measurement (which predicts TDN using the current system), measures a fraction of the NDF or cell wall component. The acid in the solution leaves only the very indigestible cellulose and lignin fractions of the plant-thus it has been widely used to predict total potential energy (TDN). However, the ADF-TDN system has been criticized, since NDF is a better indicator of forage intake per unit time, is more widely used for balancing rations, and may be superior for comparing the multiple feedstuffs used in modern dairies (Robinson, 1999).

FACTORS WHICH INFLUENCE FORAGE QUALITY

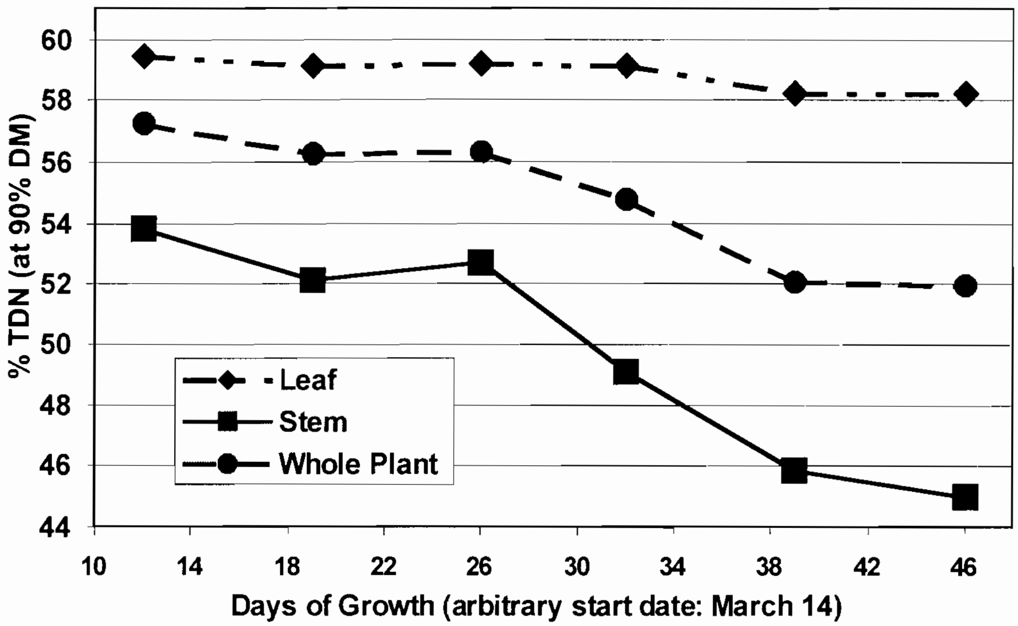
There are a number of factors that may impact the quality of harvested alfalfa. These are divided these into Major Factors and Secondary Factors. The main criteria for dividing these into two groups include both their degree and of impact upon forage quality, and the importance and breadth of the mechanism in determining overall forage quality.

Primary Factors

Plant Maturity and Plant Development at Harvest. It is a universal axiom of alfalfa forage production that as a plant grows and develops, forage quality declines. This is due to at least two major mechanisms. First, after approximately 14 days of growth during the early bud development, leaves do not significantly increase in yield. Continued growth takes place primarily in the stem component after early reproductive development. Secondly, the quality of the stem fraction declines precipitously as the plant continues to grow. This is due to what is happening on the cellular level, as the young, tender primary cell wall is strengthened by the more highly lignified secondary cell wall. These fibrous components of the stem greatly increase the ADF and NDF of the whole forage as the plant grows and develops.

This second principle is illustrated in Figure 3. The TDN (calculated from ADF) of the leaf fraction remains at 58-59 percent, and varies only slightly from 12 days of growth through 46 days of growth. The stem fraction, however, is approximately 54% TDN in a very immature stage (12 days), but rapidly drops in quality, reaching TDN of less than 45% by 46 days. This brings the overall plant TDN from 57% down to 52% as the plant develops (Figure 3).

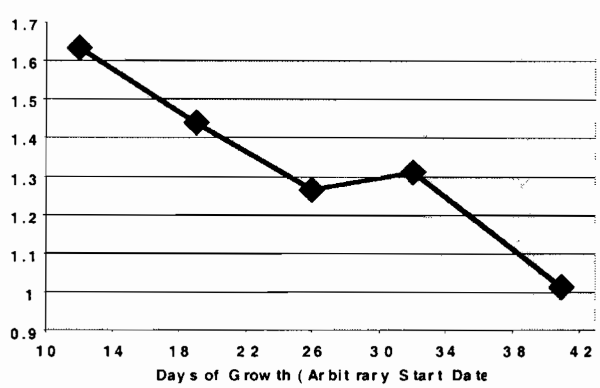
Figure 3. Changes in TDN of Leaf, Stem, and Whole Plant-- First Harvest, Davis, CA 1999 (T. Ackerly, 1999)



Staging the growth of the plant according to vegetative and reproductive development is an important predictor of potential feeding value. Stages include vegetative, early bud, late bud, early flower, late flower, and seed production. Most growers in recent years have found it necessary to harvest alfalfa in early to late bud to meet the demands for low fiber, high TDN hay by dairies. There are methods, including the UC Intermountain Alfalfa Quality Stick, available to help predict the forage quality of standing alfalfa crops for harvest decisions.

Leaf Stem Ratio. Leaves and stems of alfalfa differ dramatically in forage quality. Leaves tend to be very low in ADF and NDF, and high in CP (Figure 2). Even in an immature stage of development, alfalfa leaves are significantly higher in feeding value than stems. Leaves may have two to three times the protein content of stems (Marten et al., 1988), and in some forages consist of 2/3 of the feeding value, though may consist of 50% of the DM or less.

Figure 4. RATIO OF LEAF TO STEM, First - Davis, CA, 1999 (T. Ackerly)



Perhaps as importantly, stem quality declines very rapidly in alfalfa as the plant grows (Figure 3), whereas the leaf forage quality declines only a small amount. Stems decline in digestibility about _ percentage point per day (Marten et al., 1988), whereas leaves decline only very slightly. Thus, any agronomic practice that impacts leaf-stem ratio will also affect forage quality. Many agronomic factors may affect leaf-stem ratio, including plant maturity, variety, pest damage, and harvesting procedures.

Weeds. Weeds can have neutral, positive, or negative effects on alfalfa forage quality, depending upon many factors. The primarily considerations are the species of weed and when it is harvested. However, most weeds, especially grassy weeds, have a negative effect on alfalfa forage quality, and in practice, weeds are a major detriment to alfalfa forage quality. Even in cases where weeds do not reduce the analytical feeding value, they may reduce the marketability of the hay due to perception of the buyer. Some weeds like common groundsel and fiddleneck are toxic to animals and thus significantly lower the feeding value, even if TDN or CP is not affected. In practice, inability to control weeds is one of the most common causes of low forage quality of alfalfa.

The effect of harvest schedule, plant maturity at harvest on yield, quality, weeds and stand life is illustrated in Table 1. This classical dataset shows the dramatic and powerful effect of cutting schedules on forage quality. It should be pointed out that yield is also dramatically affected by harvest interval, as is weed infestation and stand (the forage quality data in this table does not reflect the weed component of the sward). The tradeoff between yield, quality, and stand life is a major issue for forage producers, and is of tremendous economic importance. The optimum profitability point as determined by cutting schedule is rarely is the point where maximum quality is obtain, nor at the point where maximum yield is obtained. This is a complex relationship, and one that has challenged forage producers for decades.

Table 1. Effect of Maturity at harvest and harvest interval on alfalfa yield, quality, and leaf percentage weeds and stands life.

Maturity at Harvest	Harvest Interval (days)	Yield T/acre	TDN	ADF	CP	Leaf	Weeds	Stand
			----------	----------	%	----------	----------	----------
Pre-Bud	21	7.5	56.3	26.3	29.1	58	48	29
Mid-Bud	25	8.8	54.2	29.5	25.2	56	54	38
10% Bloom	29	9.9	52.4	32.2	21.3	53	8	45
50% Bloom	33	11.4	52.0	32.7	18.0	50	0	56
100% Bloom	37	11.6	50.1	35.5	16.9	47	0	50

Source: V.L. Marble, 1974. Proceedings, 4th CA Alfalfa Symposium, Dec. 4-5, 1974. UC Cooperative Extension.

Secondary Factors Affecting Forage Quality

These 'secondary factors' may be very important determinants of forage quality, depending upon the situation. However, when each individual situation is analyzed, it may become apparent that these secondary factors are important primarily because they influence either the leaf-stem ratio, plant maturity, or weed composition, which are the major factors listed above.

Environment/Temperature. Most alfalfa growers and dairy producers understand the variations in forage quality that occur over the season. Alfalfa forage quality is generally highest in the spring (first and second cuttings) and late fall, and lowest in the summer, but forage quality will also change depending upon temporary weather patterns. One hay grower jokingly remarked that the easiest way to get high quality hay was to harvest it all in the late fall and early spring! Seasonal variations have their effect primarily through temperature, but day length is also important. The high temperatures of summer have the effect of increasing growth rates (primarily stem growth), hastening plant maturity, and increasing lignification of the cell wall. Thus, the primary effect of season and temperature is on the primary factors of leaf-stem ratios and plant maturity. High temperatures primarily hasten biological processes that decrease forage quality.

High temperatures can also hasten respiration rates, which in turn reduce the quantity of soluble carbohydrates in the stem and leaves (see Figure 2). Respiration turns sugars and starches into CO2 and produces energy to produce other compounds in the plant, such as cell wall material. Thus, high rates of respiration have the dual effect of lowering the 'sugar pools' in the plant (which are highly digestible) and hastens growth and maturity.

Daily Changes in Forage Quality. Observations from the 1940s have shown changes in soluble carbohydrate levels in alfalfa due to time of day. More recent data from California (Putnam et al, 1998) and Idaho (Mayland, 1998, Shewmaker, 1999) have mostly confirmed a forage quality advantage of harvesting alfalfa in the late afternoon, to take advantage of temporary accumulation of soluble carbohydrates associated with bright sunshine. As the alfalfa plant rapidly photosynthesizes in the late morning, sugars and starches may accumulate in plant tissue. At night, these compounds are respired and utilized by the plant, slightly increasing the fiber level (by difference). If hay is cut in the afternoon, and respiration in windrows is minimal, then the higher concentration of soluble carbohydrates may contribute up to 1-1.5% to the TDN of the forage. These effects will not always occur, however. It is likely that the advantage of afternoon harvest would be greatest under cool, bright sunshine conditions, and under conditions where the forage is highly conditioned to increase drying rates and minimize respiration in the windrow after harvest.

FACTORS AND PRINCIPLES THAT INFLUENCE ALFALFA QUALITY:

PRIMARY FACTORS:

- Leaf-Stem Ratio
- Maturity of the Forage
- Mixture with Weeds

SECONDARY FACTORS:

- Environment/Temperature
- Daily Changes in Quality
- Rain Damage
- Harvesting Effects
- Cultivar
- Stand Density
- Soil type and fertility
- Irrigation
- Pest Interactions

Rain Damage. Rain reduces the level of available carbohydrates or available energy by leaching soluble components from the plant material, and decreases forage quality by increasing leaf shattering. Since soluble components are 100% digestible, leaching decreases TDN value significantly, as well as protein content. Table 2 indicates the effect of simulated rain on total dry matter losses due to leaching. The extent of leaching is influence by stage of maturity, forage moisture at the time of the rain, amount and intensity of rain, and condition of the hay during the rain event. Rain can increase dry matter losses due to leaching and leaf shatter from about 10% up to over 50%, depending upon the amount of rainfall (Table 2).

Table 2. Effect of rain on dry matter losses in bud stage alfalfa and red clover as a percent of initial dry matter (% loss)

Loss	No Rain	1 inch	2.5 inches
	---% loss in Dry matter---		
Leaf Shatter	7.6	13.6	17.5
Leaching & respiration	2	6.6	36.9
Total Loss (%)	9.6	20.2	54.4

* Source: Rohweder, 1983

Harvest Effects. The skill of harvesting has long been known to affect forage quality. Since leaves dry faster than stems, often growers need to wait past the point where leaves can be harvested to completely dry the stems. Therefore, hay is often harvested at a point where leaf shatter is a hazard. Leaf shatter, as illustrated above, can greatly affect forage quality by reducing leaf-stem ratio. The greatest risk for leaf shatter is probably in the raking process, not baling, though any field operation may increase leaf shatter depending upon conditions. Any field operation (intensive conditioning, wide windrows) that hastens drying of stems in the field may help preserve forage quality. Baling at a more moist condition or with dew will help preserve the leaf component of the forage. Some hay preservatives may enable growers to bale under more moist conditions, thereby conserving leaf material. Some growers have found ways of allowing the stems to dry, and then re-wetting windrows to soften leaves just before baling. However, skill in the harvest procedure remains a major challenge to growers to maintain forage quality.

Switching to haylage can have a very positive effect on leaf retention, which approaches 100%, since the forage is wilted, not dried, before pickup. A major advantage of haylage is the ability to get the crop off the field rapidly in the spring when rains are threatening, and in some cases, an additional harvest is possible. However, production of haylage may entail DM losses during the ensiling process that are equal or greater than those present in the baling process. Although feeding value of haylage may be better in some circumstances than hay, many agronomists feel that there is no clear advantage to either methods when all the plusses and minuses are considered.

Maceration Effects. Maceration, or intensive conditioning, may have dramatic effects on forage quality (Putnam & Orloff, 1998). Since commercial-scale macerators are not currently available, this discussion will be short, but this aspect deserves mentioning. Maceration is the 'pre-chewing' or cell rupture of forage, not just crushing or conditioning. Drying rates are reduced to as little as a day, and a 'mat' is produced which can then be picked up and baled or cubed. Maceration has the effect of changing micro-particle size and making the cells more available for rumen fermentation. The immediate availability of the soluble fraction of forage, as well as the rate of fermentation of the NDF fraction, and milk production have been shown to be dramatically affected by maceration in studies at USDA and at UC Davis. If commercialized, this technology may have a major effect on forage production and quality (Putnam & Orloff, 1998).

Variety. Cultivars of alfalfa can differ in forage quality. Research from California and other locations have show differences between varieties, when placed under the same cutting schedule. Varieties may differ primarily due to changes in leaf percentage, or due to slower growth rates (often a function of fall dormancy), or due to more subtle changes in cell wall structure. Multifoliolate varieties (varieties which produce more than three leaflets per leaf) can in some cases result in higher quality, but this is not always so. The key issue is leaf percentage, as illustrated by Table 3. Some varieties may be called 'multi-leaf' or 'multifoliolate', but have no greater percentage of leaves than traditional trifoliolate varieties. Some trifoliolate varieties have also been developed to have a superior quality (Table 3).

It is important to judge the quality of a variety in relationship to the yield of that variety. In Table 3, the yield of the varieties in that trial did not differ. However, it can be shown that some varieties with supposedly higher quality, are also lower in yield. Their growth rates may be significantly below that of other adapted varieties in a region. Although there may be some economic conditions where growers must sacrifice some yield for forage quality, studies have shown that yield is the predominant economic factor for alfalfa growers, and forage quality secondary. Furthermore, quality of alfalfa is the subject of numerous claims by seed companies, and glossy ads and brochures are the norm. When considering forage quality of cultivars, it is important to ask for data that proves the point, and to evaluate the quality claims in relationship to the yield potential of that cultivar.

Table 3. Effect of multifoliolate (MF) and trifoliolate (TF) varieties on yield, CP, and ADF, average of 2 years (MN Study, Juan et al., 1993).

Entry	Multileaf Expression	Leaf Percentage	Yield	Protein	ADF
	------------------%--------------		t/acre	-------------%--------------	
Multi-7 (MF)	58	59	4.7	19.7	30.5
MulitKing (MF)	16	57	4.6	19.3	29.5
EXP (MF)	9	5	4.8	19.3	33.6
Legend (MF)	3	52	4.6	19.0	32.5
WL322 (TF)	0	56	4.5	20.6	30.0
SaranacAR (TF	0	53	4.5	19.5	32.6
LSD ($P<0.05$)	3	2	n.s.	0.4	0.8

Stand Density. Leaf percentage, percent CP, ADF, and lignin are not largely affected by stand density per-se. This is due to the fact that at higher plant densities, the numbers of stems per crown is greatly reduced, so that the numbers of stems per unit area actually does not differ very much between very high and moderately low densities. However when stand densities fall below a certain number (between 4 and 10 plants/square foot, depending upon the age of the stand), open spaces are made available for the growth of weeds. The weeds, in turn, can have a significant impact upon forage quality.

Soil Type and Fertility. It has long been known that alfalfa produced on certain soils, primarily heavy clay or salty soils, produces a higher quality than that produced on sandy or loamy soils (Marble, 1992). This has been attributed to a greater stress on those soil types, perhaps due to lack of oxygen in the roots or salt effects. The stress seems to produce a shorter, finer stemmed, leafier alfalfa at the same harvest interval than alfalfa harvested at the same harvest interval on sandy or loamy soil. Soils such as those in the Imperial Valley, Tracy, Pos Palos areas in California have gained that reputation (Marble, 1992). It should be noted, though, that climatic influence may be important in some of those areas, as well as the soil type.

There have been a number of claims of fertilizers improving alfalfa forage quality. However, unless these can be clearly demonstrated through well-replicated field trials, they should be looked on with some suspicion. Most fertilizers have the effect of improving yield of alfalfa when those elements contained in the fertilizer are in short supply in the soil. Thus, if potassium, phosphorus, sulfur, or micronutrients are low in the soil or tissue tests, yields of alfalfa will improve with application of those fertilizers. This has been clearly demonstrated in field trials spanning more than 50 years. In most cases, however, the improvement in yield that results from application of fertilizers will result in more rapid growth rates, which works against forage quality, and will not improve quality of the forage. There may be exceptions to this, but those exceptions must be clearly demonstrated in field trials, replicated over time and space, before they are accepted.

Several years ago, there were claims of improved quality with applications of potassium sulfate, even if K was present at high levels in the soil. Subsequent trials conducted by UC Cooperative Extension clearly showed no forage quality advantage with K fertilizers in California, though yields were improved (Meyer and Mathews, 1995). A similar study in Wisconsin showed a decrease in forage quality due to K fertilization (not surprising considering the effect of K on growth). Additionally, nutritionists have emphasized the importance of low K hay for close-up cows (pregnant cows nearing birth), to prevent problems with Calcium nutrition and Milk Fever. When K is added to the soil when already in ample supply, 'luxury consumption' occurs, and the K concentration of the forage increases without an increase in yield. This is clearly not desirable either from the grower's point of view (an expense is incurred without an increase in yield or value), or from the nutritionists point of view (danger of excess K in the forage).

Irrigation Management. Irrigation management is probably the most important yield-limiting factor in California. Over-applications of water or water stress (especially during the harvest period) are a major problem with alfalfa production—mostly due to the requirement for dry down for frequent harvests. Water stress often has the effect of actually increasing forage quality, since the leaf-stem ratio is improved due to lack of growth of the stem component. However, it is not likely a good practice to stress plants to improve forage quality, since yields are linearly related to water availability, and yields are dramatically reduced by water stress. Excess water that does not kill the plant also may improve forage quality, since the stress may also improve leaf: stem ratio. However, areas of the field killed by excess irrigation or irrigation mistakes or poor leveling become a problem for production of quality hay, since weed invasion is the most likely result. The best strategy is to irrigate for full yield and health of the whole plant (including the prevention of oxygen depravation to the root), and attain high quality through some other method.

Insects and Diseases. Insects and disease pests can have either a positive or a negative effect on forage quality. Most insects have a negative effect since their feeding habits include chewing of leaves and decreasing leaf:stem ratio. Sucking insects, such as aphids, may have the effect of reducing soluble carbohydrates, therefore reducing forage quality. However, some insects and diseases may actually improve quality, since they create plant stress, which tends to improve leaf:stem ratio. Insects which intensively suck plant sap (such as the Sweet Potato Whitefly in the Imperial Valley) cause widespread stickiness on the plant surface, which is in turn causes a fungus to develop (sooty mold), which lowers palatability and consumer acceptance.

CONCLUSIONS

Forage quality is a multi-faceted aspect of modern alfalfa production. It is defined primarily in terms of low fiber (low ADF or NDF), and high CP and TDN. Growers have been under intense pressure to produce high quality alfalfa, and in recent years quality factors have had a large impact on profitability. The primary determinants of alfalfa forage quality are plant maturity at harvest, leaf-stem ratio, and weed composition. Secondary factors include Environment and temperature, daily changes in forage quality, rain damage, harvest effects, cultivar, Stand Density, Soil type and fertility, and irrigation. These 'secondary' effects may be very important depending upon the situation, but may have their effects primarily through affecting plant growth and maturity, leaf-stem ratio, or weed composition. Early harvest has the most powerful effect on forage quality, but excessively early harvests significantly reduce yields and stand, leading to weed invasion and reduced stand longevity. 'Staggered' cutting schedules may have the affect of allowing high quality of some harvests, while allowing recovery of the root reserves for improved growth later in the season. Since forage quality is attained often at the expense of yield, growers should strongly consider the tradeoff between yield and quality as economic factors in management decisions that affect forage quality.

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EFFECTS OF BROADSCALE USE OF PEST-KILLING PLANTS

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More than 20 million acres of transgenic insect-resistant crops, including cotton, corn, and potatoes were planted in the United States in 1999 — and growers are on the verge of much more extensive plantings. Genetically engineered to produce insecticidal proteins of the bacterium *Bacillus thuringiensis* (Bt) these plants provide effective, environmentally safe pest control. First generation crops may encounter insect resistance, partly because they have been engineered to produce only single Bt insecticidal proteins, and partly because plant senescence can result in lower production of Bt proteins as crop plants age. Australia cotton growers, for instance, found they had good control for the first half of the season, but required insecticide treatmemts in the latter half. Resistance avoidance strategies and crop varieties in the pipeline that produce two or more insecticidal proteins are planned to provide long-term resistance management. If successful, this new technology promises high crop yields as well as benefits to most non-target arthropods and biological control insects by reducing the use of broad spectrum chemical insecticides.

In the 1999 growing season, U. S. growers planted approximately 15 million acres of transgenic corn and 3.5 million acres of transgenic cotton, genetically engineered to produce insecticidal Bt proteins. This acreage is expected to grow to about 30 million acres of corn and 6 million acres of cotton within 5 years, representing, respectively, about a third of the corn and half of the cotton acreage in the United States. Bt crops offer advantages over conventional crops in that the insecticidal proteins are produced by the plants continuously, reducing the material and application costs of using a synthetic chemical insecticide. Growers have reported improved profit margins averaging $30 to $50 per acre during the first few years of Bt-cotton plantings in the Southeast. About 60,000 acres of Bt-potatoes are grown in the U.S. and Canada, and demand is increasing.

Transgenic Bt Crops. In 1981, scientists cloned the first Bt toxin gene, which led quickly to the development of the first transgenic Bt plants in the mid-1980's. Since then, many major crops that suffer substantial economic damage from caterpillar and beetle pests have been genetically engineered to produce Bt toxins to control these insect pests, though only a few of these are available commercially. In the United States, the available crops are cotton, corn, and potatoes. Numerous others under development include rice, soybeans, broccoli, lettuce, walnuts, apples, and alfalfa. The largest plantings so far have been in the mid-West with Bt-corn from Monsanto and Novartis, and Monsanto's Bt-cotton (Bollgard) in the southeastern United States. Within the next few years, however, these and other companies plan to plant millions more acres of Bt-corn, and plantings of Bt-potatoes are likely to grow to at least several tens of thousands of acres. Moreover, if these crops prove to be economic successes, many others, including minor crops, will eventually be engineered to produce Cry proteins to control their major insect pests.

Resistance Development Concerns. While Bt crops would appear to be on the verge of major agronomic successes in several crop systems, minor failures have occurred in the first three growing seasons [1996-1998]. In the United States, corn earworm (*Helicoverpa zea*) populations invaded limited acreages of Bt-cotton in Texas, virtually destroying the crop due to their high tolerance to the Bt toxin (Cry1Ac) produced by transgenic plants. In 1998 in Australia, where the principal cotton pests are bollworms (*H. armigera* and *H. punctigera*), which are also quite tolerant to this toxin, the efficacy of the Bt-cotton lasted for only one-half the season. Applications of other pesticides, including Bt-based insecticides, were needed to control these pests. The lack of control resulted not only from the lower sensitivity of the bollworms to the toxins, but because the levels of the toxin (Cry1Ac) decreased gradually in the cotton plants over the growing season. A danger of decreasing toxin levels is that this could prime target populations for the development of resistance to the toxin used in the plants and to other related Bt toxins to which these populations may initially be quite sensitive. This is because low doses of toxin eliminate the most sensitive insects, leaving a more toxin-tolerant population, in which resistance can develop much faster. Moreover, because most Bt toxins have a similar mode of action, once resistance develops to one toxin, it can confer reistance to other related toxins. This is known as "cross-resistance" and has already been demonstrated in laboratory studies of Bt Cry toxins.

One reason resistance could develop is that transgenic cotton and corn varieties marketed each currently produce only one toxic Bt protein, compared to the principal Bt strain used in insecticides to control caterpillars, which contains four major toxins in addition to other factors that increase insect moratlity. Although early successes of the transgenic cotton and corn are impressive, resistance strategies will become increasingly important as total acreage expands. Were resistance to occur, the value of microbial insecticides based on Bt proteins could be diminished owing to the target insect's lower sensitivity to the Cry proteins contained in these. The environmental impact could be serious as well, because farmers would return to broad spectrum chemical insecticides. The potential for the development of resistance to Bt proteins is not only of concern to environmentalists, but to most scientists in academia, government, and the Bt insecticide and transgenic plant industry. Failure of Bt-crops in the field after more than a decade of high development costs would result in significant financial losses to companies. Monsanto has estimated that it invested $30 million in 10 years of testing and development of Bt-resistant cotton.

Other concerns involve the safety of Bt transgenic crops to non-target organisms. Safety studies show that vertebrate stomach juices rapidly inactivate Bt wild-type proteins. Most Bt proteins are insect-specific and become active only in the insect gut, which in most target insects is alkaline, rather than acidic as in most verberates including humans. Despite their general safety, Bt transgenic plants and the bacteria from which these proteins are derived have some harmful effects on nontarget insect species. These effects are much less than those of chemical pesticides.

Bt Insecticides. Understanding the reasons for resistance, and placing these concerns in perspective, requires knowledge of Bt's basic biology, mode of insecticidal action, and Bt products used as insecticides. Insecticides based on Bt have been used in many regions of the world for more than 30 years to suppress lepidopteran pests of forests, vegetables, and field crops, and more recently to control beetle pests and the larvae of many species of vector and nuisance mosquitoes and blackflies. Bt's success is due to the high efficacy of its insecticidal proteins, the existence of a diversity of proteins that are effective against a range of important pests, its relative safety to non-target insect predators and parasites, its ease of mass production at a relatively low cost, and its adaptability to conventional formulation and application technology.

Bt's Mode of Insecticidal Action. Bt consists of more than 60 spore-forming bacterial subspecies found commonly in soil, grain dust, on plants and in insects. Under field conditions, the subspecies used in commercial bacterial insecticides typically have a restricted insect spectrum, being toxic to the larvae of either lepidopterous (moths and butterflies), dipterous (flies and mosquitoes), or coleopterous (beetles) insects. The insect spectrum and specific toxicity of a subspecies is due to one or more insecticidal proteins, referred to as δ-endotoxins, produced during sporulation and assembled into a crystalline parasporal body. More than 100 different Cry (for crystal) proteins have been isolated over the past 20 years. All are encoded by genes carried on plasmids, circular pieces of DNA that can be transmitted from one Bt subspecies to another. Plasmid transmissibility and mutations arising during evolution are responsible for the widespread occurrence and diversity of Bt proteins that occur naturally in the environment. The role of these proteins is to kill certain insects, thereby providing Bt with a rich resource for its reproduction.

Bt toxins are not contact poisons like most synthetic chemical insecticides; instead, they must be eaten to be toxic (Schnepf *et al.*, 1998). When a sensitive insect such as a caterpillar ingests the parasporal body containing the crystalline toxins, they dissolve upon encountering the alkaline (pH 8-10) juices of the midgut. Most Cry toxins contain an active "core" about one-half the size of the total toxin; the core is released in the midgut by cleavage of the molecule. These activated toxin molecules bind to specific receptors on the surface of the insect's gut. Binding is an essential step of insecticidal action; in susceptible insects the toxicity of a particular Bt protein is correlated with the number of receptors on stomach cells. After binding, it is thought that the toxin molecules insert into the microvillar membrane and form pores. These pores cause leakage and swelling of the cells due to an influx of positive ions and then water. The swelling continues until the cells lyse, allowing the alkaline gut juices to leak into the insect's blood, raising the blood pH, which causes paralysis and insect death. In insects with low sensitivity to Bt proteins, other components are required to kill the insect including the spore, which produces a variety of enzymes in the stomach after germination, and zwittermicin, a compound that increases Cry protein toxicity.

Bacterial Insecticide Products. More than 30 Bt formulations are on the market in the U.S., and most of these are complex mixtures based on sporulated cells, produced by large-scale fermentation, containing the spores and array of toxins found in either *B. t. kurstaki*, which is used to control a wide range of moth pests, or *B. t. israelensis*, used to control the larvae of numerous mosquito and blackfly species. Both owe their success to their broad spectrum of activity and the absence of any widespread insect resistance after many years of use. These characteristics are due to the complex composition of the parasporal body, which in each case contains four major proteins, and to the moderate frequency of use.

The first commercial formulations of Bt marketed over 30 years ago, such as Dipel and Thuricide, still in common use, are those based on *B. t. kurstaki*. The parasporal body of HD1 consists of four Cry proteins, Cry1Aa, Cry1Ab, Cry1Ac, and Cry2A. These vary in their insect spectrum and specific toxicity, and in combination give this isolate a broad spectrum of activity against a wide range of caterpillar species attacking field (cotton, corn, soybeans), vegetable (tomatoes, broccoli, lettuce, cabbage), fruit (strawberries, grapes, peaches) and forests (deciduous and fir trees). This complexity probably accounts for the lack of economically important resistance after more than 30 years of use in all but a very few species of lepidopterans, the notable exception being larvae of the diamondback moth, *P. xylostella*. Parasporal body complexity can delay resistance because there is usually at least one different receptor for each of the Cry proteins, even though some can share the same receptor. Whereas insects in a target population are unlikely to be sensitive to all four Cry proteins, moderate to high sensitivity to two or three reduces the probability that a substantial number of insects within the population will be resistant to all toxins. Thus under conditions of moderate Bt usage, i.e. low selection pressure, the frequency of individuals containing a full set of resistance genes remains low, which translates into little or no Bt resistance.

Concerns about Bt transgenics. All first generation transgenic Bt-crops are based on plants that produce only a single Bt protein, lacking the complexity of conventional Bt-based bacterial insecticides. For example, current lines of Bt-cotton produce the Cry1Ac protein, and are targeted to control the tobacco budworm, the most important cotton pest in the southeastern U.S. Cry1Ac was selected for engineering into cotton because it is the most toxic to the tobacco (Table 1). Similarly, in the case of corn, most lines have been engineered to produce only the Cry1Ab or Cry9A toxin to control the European cornborer (*Ostrinia nubilalis*), and in potatoes to produce only the Cry3A toxin to control the Colorado potato beetle.

In addition to the lack of complexity in comparison to bacterial insecticides, each of these toxins is produced continuously by the plant. While perhaps an advantage from the standpoint of saving application costs, continuous toxin production places insects under heavy selection pressure. Actually, over the past two growing seasons, studies of Bt cotton in the U.S. and Australia have shown that Cry1Ac production is continuous, but can decrease over the growing season, in some cases leading to sublethal doses for budworm larvae near the end of the season. This was the reason that growers in Australia experienced control problems with their caterpillar pests. Aside from problems during a particular growing season, as noted above, sublethal doses can prime populations for resistance because it is the most tolerant individuals in the population that survive.

Table 1. Toxicity of Bt Cry proteins to first instars of three lepidopteran pest species*

	LC_{50} in ng/cm^2 of diet		
Cry protein	Tobacco Hornworm	Tobacco Budwrom	Cotton Leafworm
Cry1Aa	5.2	90	> 1,350
Cry1Ab	8.6	10	> 1,350
Cry1Ac	5.3	1.6	> 1,350
Cry1C	> 128	> 256	104

*Tobacco hornworm (*Manduca sexta*), Tobacco budworm (*Heliothis virescens*), Cotton Leafworm (*Spodoptera littoralis*).

Because first generation Bt crops generally target only a single pest species, another problem they present is lack of adequate control of insects not very sensitive to the toxin produced by the crop. It is important to realize that lack of or low sensitivity is not resistance. Resistance is defined as a statistically demonstrated decrease in sensitivity to a toxin by a population in response to use of the toxin as a killing agent. Thus, if there is little or no susceptibility to begin with, this can not be resistance, but nevertheless can lead to control problems. For example, the Cry1Ac protein is not very toxic to species of armyworms (*Spodoptera* species), or bollworms (*Helicoverpa* species). Already problems have been encountered in the U.S. and Australia in Bt-cotton with bollworms. In the U.S., corn earworm (*Helicoverpa zea*) populations invaded limited acreages of Bt-cotton in Texas, virtually destroying the crop due to their high tolerance to Cry1Ac. In 1998 in Australia, where the principal cotton pests are bollworms (*H. armigera* and *H. punctigera*), which are also moderately tolerant to Cry1Ac, the efficacy of the Bt-cotton lasted for only approximately half the season. Applications of other insecticides had to be made to control these pests. The lack of control resulted not only from the lower sensitivity of the bollworms to Cry1Ac, but because the levels of toxin decreased gradually in the cotton plants over the growing season.

Bt resistance management in transgenic crops. The possibility of resistance to transgenic crops has prompted the development of a variety of conceptual strategies for managing resistance (Table 2). Most of these, for example, mixtures of various toxin genes within plants, the use of tissue-specific toxin production, and induced toxin synthesis in which toxin is only synthesized after an insect begins to feed, are years away from field deployment or commercial availability. In mixing genes within a crop plant (also known as pyramiding or staking genes), genes for two or more insecticidal proteins, of the same or different types, are engineered into the same plant. In tissue specific expression, the plants are engineered so that the toxin gene is introduced into the plant in such a way that it is only produced in tissues on which the insect feeds, for example, depending on the target insect, only in the roots, or only in the leaves. In the induced toxin synthesis strategy, the gene only produces the toxin protein after insect feeding is initiated. The molecular tools for developing such plants are already available. In the meantime, resistance management relies primarily on using a high dose and refuge strategy. In this strategy, some percentage of the crop, usually 4 to 25%, must consist of non-Bt plants. And the non-Bt plants must be planted together, usually as strips along the edge of the crop, or as blocks within the crop.

The value of the non-Bt plants is to maintain a high percentage of susceptible insects, that is, a high frequency of susceptible genes, in the target population. When moths lay eggs on Bt-plants, a high percentage of the first instars that feed on these plants will die, as this is the stage most sensitive to the toxin. However, most larvae that emerge and feed on non-Bt plants will survive, and as adults, theoretically these will mate with adults which survived growth on Bt-plants. The latter survivors presumably survived because they were heterozygous or homozygous for resistance. They should constitute a low percentage of the mating population, and by mating with insects not selected for resistance, the percentage of resistance genes is diluted and remains low in the target population.

Table 2. Key strategies for Managing Resistance to Bt-crops*

Protein pyramiding	Multiple Cry genes Cry plus other insecticidal genes
Protein synthesis	Consitutive Tissue-specific Chloroplast-specific Inducible
Field tactics	Refuges Spatial, Temporal Cry gene crop rotation

*From McGaughey and Whalon (1992)

The high dose/refuge strategy is being used to manage resistance in Bt-cotton and Bt-corn in the U.S. Growers have a contractual obligation to implement refuge strategy. Bt-cotton has been planted for three years, but it is not yet possible to assess the success of this strategy. During the first three years, there has been no confirmed evidence of resistance. But aside from the refuges planted in the crops, many surrounding non Bt-crops and noncrop plants provide refuges for susceptible insects, which then contribute to the dilution of resistance genes in the target population gene pool. The true test of this strategy will come when large contiguous areas, comprising square miles of Bt-crops producing Cry genes, are planted successively for several years.

While these experiments in nature are ongoing, more sophisticated plant engineering strategies are being used to engineer resistance management strategies directly into the plants. In addition to using combinations of Cry genes in the same crop plant, mixtures of insecticidal proteins with different modes of action are under development. Already several types of proteins to meet these needs have been identified, including non-Cry proteins from Bt, insecticidal non-Bt toxins, lectins, and enzymes selectively toxic to specific insects.

Resistance to Bt insecticides. Though resistance to Bt products under field conditions has been rare, laboratory studies show that insects are capable of developing high levels of resistance to one or more Cry proteins. Under laboratory selection, for example, populations of the indianmeal moth (*Plodia interpunctella*) developed levels of resistance ranging from 75- to 250-fold to Cry1Aa, Cry1Ab, Cry1Ac, Cry2A, and Cry1C (see Tabashnik, 1994 and Gould, 1998 for reviews). In addition, under heavy selection pressure in the laboratory, populations of mosquitoes (*Cx. quinquefasciatus*), beetles (the Colorado potato beetle and the cottonwood leafbeetle, *Chrysomela scripta*), and the tobacco budworm (*Heliothis virescens*), all developed levels of resistance ranging from several hundred to several thousand-fold to the Cry toxins against which they were selected. Rotation of Cry proteins in bacterial insecticides is a potentially useful tactic for managing resistance to individual Cry proteins. However, because most Cry proteins are related, the potential for cross-resistance remains a major problem. In fact, high levels of cross-resistance among Cry proteins has been demonstrated already in the laboratory.

Other Concerns about Bt-Crops. Concerns have also been raised about the safety of Bt proteins, and therefore Bt-crops, to non-target insects, especially the predators and parasites used as biological control agents. The purpose of Bt, of course, is to kill the target pest, but even Bt insecticides also cause mortality in certain non-target insects. For example, Bt products used to control caterpillar pests such as gypsy moth and spruce budworm larvae in forests will also kill certain species of non-target lepidopterous larvae in these habitats.

The mortality caused in the non-target populations should be kept in perspective and viewed in the context of the relative risk of using Bt in comparison to using available synthetic chemical insecticides. The latter typically have a much broader spectrum of toxicity, and will kill pest and non-target insects belonging to a wide range of insect orders. Because all Bt proteins have a very restricted spectrum of activity under field conditions, the use of Bt proteins is much more environmentally compatible than the use of chemical insecticides. Bt proteins may persist in the environment, when used in either insecticides or Bt-crops, but their toxic effects on non-target predators and parasites is low and temporary, and is reduced further after the crop is harvested.

It should also be obvious that as a control agent targeted to kill insect pests, Bt-crops will also reduce the predator and parasite populations, particularly the latter, that depend on the target insect for their reproduction. Again, the mortality caused by Bt in these non-target populations must be kept in perspective. Most crop production, especially that of field, vegetable and fruit crops, occurs in monocultures that are not natural ecological habitats. The crop uniformity characteristic of these monocultures permits pest insects as well as their predators and parasites to build up into populations that are much larger than those that would occur in more diverse natural habitats. In this context, the use of Bt-crops has a neutral effect in that it reduces predators and parasite populations that would not occur if it were not for the unnatural presence of a large crop habitat and concomitantly large host pest populations that the predators and parasites use as a resource. Moreover, even in the unnatural ecological habitat of a crop monoculture, the use of Bt, owing to its greater specificity, will have less impact overall on the predator and parasite populations than will the use of broad spectrum chemical insecticides.

Conclusion. Bt-crops are an effective and environmentally safe alternative to chemical insecticides. It is easy at present to be critical of first generation Bt-crops, as they represent simple constructs that could fail. However, with any new technology, there are likely to be problems. More importantly, tools and concepts have already emerged for making better second and third generation transgenic insect-resistant crops, and this will continue. Transgenic crops have the potential of not only being better from an agronomic perspective, but as they greatly reduce the need for synthetic chemical insecticides, they are much better for the environment, especially non-target organisms, including the predators and parasites used in biological control. Current protestations from environmental groups will slow down the adoption of this new technology, but transgenic plants will play a dominant role in food and fiber production in the 21st century.

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INTELLECTUAL PROPERTY RIGHTS CHALLENGES AND RESEARCH COLLABORATIONS IN AGRICULTURAL BIOTECHNOLOGY

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In the past decades, the dynamic interaction between biotechnology revolution and intellectual property protection has begun to transform the environment for agricultural research and the nature of collaboration among scientists in private and public sectors. While these developments offer great potential for progress in agricultural research, they also serve up some fairly thorny problems for research collaborations. Ownership and legal control over biological resources (from DNA sequences to entire plants) and the tools and processes of biotechnology is being rapidly "privatized" by public and private innovators in the United States and elsewhere. The nature of these new private property rights, and how they are enforced, will determine the amount of resources invested in innovation, how effectively they are used and how benefits will be share.

Intellectual property rights and biotechnology

Until very recently, intellectual property rights had little relevance for agricultural research on crop breeding. While nations have historically guarded access to plants or animals that gave them national advantages over their rivals (Juma 1989), these historical monopolies have been national rather than private. Domestically, there was no legal restriction on the use of genetic resources for breeding to produce new plant cultivars until early this century. Even several instruments introduced in this century, such as the United States Plant Patent Act of 1930 and the Plant Variety Protection Act of 1970 (revised in 1994), had almost no effect on plant breeding. Protected germplasm purchased in the market could be freely saved for a farmer's own use. Even if stronger protection had been available, enforcement would have been hampered by the difficulty of identifying claims of parentage of new distinct cultivars bred from a protected parent. Until the recent biotechnology revolution, the only effective protection against the use of privately developed germplasm for breeding successive generations of crops was the production of hybrids that do not breed progeny sufficiently high-yielding to encourage replanting.

The past few decades have witnessed a dramatic strengthening in legal protection of breeding materials and processes and their enforcement. In the 1980s, the United States federal patent law administration was reorganized in a way that effectively gave more weight to the claims of innovators. The Supreme Court expanded the class of patentable subject matter to new life forms (*Diamond vs. Chakrabarty* 447US303, 1980), and the 1985 *ex parte* Hibberd ruling confirmed the patentability of seeds, plants, and tissue. Plant Variety Protection Act was extended to "essentially derived varieties," and seed-saving for replanting was subjected to tighter limits. Advances in molecular technologies based on Cohen-Boyer recombinant DNA technology have made claims more verifiable. A flood of innovations in biotechnology products and processes has occurred in subsequent decades, based on this technology and stronger legal environment.

Today, firms seek the broadest possible patents on genes, seeds, clonally propagated plants, and highly sought-after technology "tools" (such as vectors, markers and promoters) and processes.

As is typical in areas of rapidly evolving technology, the scope and strength of patent protection in agricultural biotechnology are not yet firmly established. One example is the pair of patents granted to Agracetus in 1992 covering all cotton created in the United States through any technique of genetic engineering. The "freedom to operate" of other cotton breeders in any area of biotechnology has remained under a cloud for years. On the other hand, no one can know for sure whether the flood of patent applications for nucleic acid sequences (500,000 in one year (Enriquez, 1998)) associated with the genomics revolution of the past several years will in the long run be deemed patentable. Researchers using the methods and products of genetic engineering might be well advised to seek to identify any prior proprietary claims that could affect their work. Short of outright acquisition, access to research inputs must be obtained by on of several means (Wright 1998).

- *Patent license*: Research licenses are often cheaper and easier to get than commercial licenses, but may be blocked by the licensor, leaving the licensee in a weak bargaining position.
- *Material transfer agreement* (MTA): An MTA is a contract for transfer and use of breeding inputs for research or for commercial use. If access to the materials is not otherwise available, this protection may be effective in preserving the provider's rights to the germplasm.
- *Joint venture*
- *Technology use agreement*
- *Trade secret license*

Privatization of public research

In the past decade, research in public institutions also began to be privatized by the Bayh-Dole Amendment (1980) which confirmed the rights of researchers to take out patents on federally funded research. Universities and public institutions have been the major sources of basic biotechnology innovations. There is a continuing injection of additional public support, coming in not just from sources with an agricultural focus but more importantly in the form of basic research funded predominantly by the National Institutes of Health. In a real sense, the private or privatized research builds on the public investment. Increasingly, the output of public researches directly useful for plant breeding has been privatized, in the sense that others can use it only with the consent of the relevant property rights owner.

Intellectual property rights proliferation

Patents and other means of intellectual property protection create the strongest incentive to research when there are no prior intellectual property claims on the research results. The complementary effect of prior non-patented (mostly from public) research often enhances the value of first-round claims. As patents on research tools and products proliferate, the restrictive force of the monopoly conferred by prior patents comes to bear on the next generation of research. Part of this is a natural re-scaling as patent rewards are prevented from reaping the full benefits of a free ride on prior public and private research (Koo, 1998), much as United States hybrid corn companies no longer have elite publicly-developed inbred lines available for use as parents of their commercial cultivars.

In addition to the cost of the rent transfer to prior patent holders, the costs of actually consummating licensing deals may be significant. These include the costs of discovering the existence, nature and ownership of prior claims, including those not yet published. As patenting activity progresses in biotechnology, the number of separate rights needed to produce a new innovation proliferates. If ownership of these rights is diffuse and uncertain, the multilateral bargaining problem can become difficult, if not impossible, to resolve. This is the "Tragedy of the Anticommons" noted by Heller and Eisenberg (1998).

Recent experience has confirmed that there are serious contracting problems, including great uncertainty associated with pending rulings by the Patent Office and the courts, the cost of litigation, hold-up problems, different opinions about value shares, and so on. For example, Lerner (1995: 470) reports that for every 100 United States biotechnology patents, there are six patent suits, an extremely high figure relative to other areas of technology.[1] The willingness of all parties to expend such sums signifies genuine disagreement about the validity, value, and/or allocation of patent rights indicative of the pervasive uncertainty characteristic of the innovation environment. But these expenditures are also becoming an effective barrier to entry, and an incentive for further consolidation in the private sector. They are beyond the financial capacity of most non-profit research institutions.

Within the corporate sector, the high costs of transactions in intellectual property are being "solved" by rapid consolidation of biotech suppliers, and consolidation of these with plant breeding and seed distribution, and with plant protection chemicals. Firms are moving towards mergers that could integrate the whole gamut on the input and the output side, which could induce an oligopolistic "one-stop shop" for farmers' inputs and outputs. This phenomenon is also being driven by attempts to capture the maximum value inherent in novel output traits, to maintain the market price of crop protection and other traits embodied in the seed, and generally to protect the value of crop protection and other services in the face of rapid technological change. (Wright, 1999a).

Research collaboration and agricultural developments

With proliferation of intellectual property rights and privatization of public research, the collaboration between public and private research entities becomes more important and can dramatically influence future development of agricultural research. No single entity can hold the entire portfolio of technologies required to develop a new research output, and access to research tools and inputs held by others is a burning issue at the heart of research on biotechnology. A serious impediment to public research arises when the key technologies and/or materials needed for their development are not obtainable from patent holder on reasonable terms. Quite a few cases exist in which research outputs by public institutions were blocked by holders of proprietary technologies (Wright 1999b).

[1] Lerner (1995: 470) also estimates that patent litigation in the United States Patent Office and the federal courts initiated in the year 1991 will lead to total legal expenditures of $1 billion 1991 United States dollars, compared to U.S. $3.7 billion spending by firms on basic research in that year. Note that the figure excludes litigation in state courts.

Several strategies are needed to facilitate public sector research for this new environment (Wright 1999b). First of all, public research entities should re-deploy their resources to take account of the vast changes that are happening in the private sector as a result of the interaction of intellectual property rights and biotechnology. They must take care to keep their institutional structure relevant, and ensure that their extension services and research services are properly aligned with what is going on in the private sector.

A commonly used approach to gain access to proprietary technologies is to exchange technology inputs under research licenses which allow use of proprietary technology in research. However the licensor typically seeks to retain control of commercially interesting products, and is in a stronger bargaining position the more the research investment committed by the license. Cross-licensing, a popular option in the private sector, also raises real problems in the public sector. Cross-licenses avoid excessive conflicts about the details of valuation, and can help discourage other entrants. But the constraints on university licensing (e.g., the difficulty of assigning share of the value to researchers) make their transaction costs even higher than those of the private sector.

Another tactic is to adopt a strategy of market segmentation. In other words, public entities can make a deal where they get some technology from the private sector for uses quite distinct from those of interest to the private sector. For example, in international crop breeding centers the clientele for much of their technology is very poor and does not constitute a significant potential market for the private sector. If the farmers are subsistence producers of products with no foreseeable commercial demand, their output will not threaten the commercial farmers who are the corporations' customers. But for such deals to be feasible, corporations must be reassured that the technology they give away for free will not turn up in the hands of a competitor in some lucrative market. Some corporations (such as Monsanto) have been willing to do at least some of this market segmentation, even if part of the motivation is that it provides a cheap means of getting a lot of public benefit via public relations.

And finally, private support of public efforts can come directly from oligopolists or commodity producers. In some cases, private sector entities, often oligopolists, are willing to fund public biotech research or information. The case that brought this to mind was the case of Merck actually supporting public human genomic research rather than investing in an alternate, private initiative, and other examples are now coming to light (Hall, 1998). While the motivation is not completely clear, it is very interesting that public companies are willing to do these kinds of deals.

Policy implications

The revolution in biotechnology has opened up new avenues for agricultural biotechnology. But the proliferation of proprietary claims on that technology heightens concerns about access by public and non-profit plant breeders. They are at a disadvantage, in terms of resources and expertise, in the kind of bargaining over proprietary rights that occurs between for-profit corporations. They must re-deploy their resources to take account of the very vast changes that are happening in the private sector as a result of the interplay of intellectual property rights and biotechnology. They also must take care to keep their institutional structure relevant, and ensure that their extension services and research services are properly aligned with what is going on in the private sector.

It is important to realize that many of the problems of transactions in biotechnology are shared by the large human health research complex. Public and other non-profit research institutions should try to inject their interests in the broader discussion of these issues, both in research leaders like the United States and the European Union, and in less-developed economies where laws regarding intellectual property rights are being revised. Contractual innovations in other areas of biotechnology transfer should be followed closely. Efforts should be made to turn the particular disadvantages of public agricultural research centers in conventional contracting into opportunities for success in alternative forms of technology transfer.

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REGULATIONS FOR NON-NUTRITIVE ELEMENTS IN FERTILIZERS

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Background

In approximately 1995, the Fertilizer Research and Education Program provided a grant for a risk assessment on non-nutritive elements otherwise known as heavy metals in fertilizers. This three year study using state of the art, scientifically based risk assessment strategies developed risk scenarios to determine safe risk based concentration (RBC's) levels for the occurrence of heavy metals in fertilizers. The scientists who developed the risk assessment used what are considered the most conservative levels, for the most sensitive population groups in the development of the RBC's.

A draft report was peer reviewed by a panel of scientists and their comments were then addressed within the final draft of the report. The final report using the state of the art risk assessment process, developed RBC numbers for the primary metals of concern in fertilizers and micronutrients, lead, arsenic, and cadmium.

In September of 1998, the Department of Food & Agriculture initiated a task force made up of a wide range of interested parties to examine the issue of non-nutritive elements in fertilizers. The task force made up of representatives of production agriculture, food processing, environmental groups, county agricultural advisers, county health engineers, legislative representatives, and members of the fertilizer industry. Also participating was a variety of government agencies including, the Department of Toxic Substances, Office of Environmental Health Hazard Assessment, and the Department of Health Services. The representatives committed to review the issue and based on science, to make recommendations on standards for non-nutritive elements in fertilizers, and labeling for these elements in fertilizers.

The task force studied the issue for some 7 months, reviewing the CA Risk Assessment, listening to the recommendations of scientists, reviewing a second independent peer review of the CA Risk Assessment, and exploring other alternative proposed regulations. The task force voted in favor of adoption of the CA Risk Assessment as the interim standard for allowable RBC's of non-nutritive elements in fertilizers. The taskforce's final recommendations were as follows:

Standards

* The committee voted that the CA Risk Assessment Study (CRAS) presents the appropriate standard that should be used for heavy metals in fertilizers.

* The CRAS will be an interim standard. A sunset will be set in the rulemaking process to provide for evaluation of additional science and continued appropriateness of the CA standard.

Monitoring/Enforcement Program

* A monitoring program for phosphate and micronutrients will be administered by CDFA to enforce the CRAS. CDFA will also monitor for additional metals within its current lab capabilities. In addition, CDFA was given the authority to monitor, at their discretion, products (i.e., Gypsum) that may pose a risk in the future.

* It was agreed that products currently considered low risk are exempt from the monitoring program. This would include all nitrogen-based fertilizers.

* CDFA will test for the occurrence of dioxins in fertilizers. As this is an expensive procedure, CDFA will test on a limited or strategic basis. The department will monitor and include research-taking place in WA State, so research or testing is not unnecessarily duplicated.

* CDFA will enforce current penalties for misbranding/product adulterations or for metal level violations that are appropriate for those violations. CDFA will examine and recommend any additional penalties it feels should be adopted to maintain enforcement.

Research

* Field research will be conducted to verify and refine assumptions presented in the CRAS. This should be a priority research program for CDFA.

* Research will be conducted to evaluate the current data gaps within the CRAS relating to environmental risk. Research will be conducted to validate assumptions regarding the lack of environmental risk from heavy metals. This will be done through both a modeling process and field research.

* CDFA should engage additional state agencies to comment on the CRAS. OEHHA was very complementary of the report, and voted in support of using the CRAS for a standard, but would like to be able to study it more completely.

Labeling

* The committee agreed that some level of labeling on products that may contain heavy metals is appropriate. Products that do not pose a risk of metal exposure are exempt from any additional labeling (i.e., nitrogen-based products).

* Phosphate-based fertilizer manufacturers will provide retailers/blenders with a label guarantee that the product meets CRAS. Retailers may request, or suppliers can provide additional information if desired. It will be at the discretion (not required) of the retailer/blender whether they provide the label at the consumer level.

* Micronutrient manufacturers will provide retailers/blenders with a label guarantee that the product meets CRAS. Retailers may request, or suppliers can provide additional information if desired. Manufacturers of waste derived micronutrients will provide retailers/blenders with a disclosure that the product was derived from a hazardous waste. This was a compromise from a more restrictive disclosure that would have required a description of the industrial process from which the waste originated. It will be at the discretion of the retailer/blender whether they provide the label at the consumer level.

* Fertilizers derived from RCRA, non-RCRA hazardous wastes, or mining wastes must provide proof that the waste meets appropriate federal or state standards for land disposal of those wastes.

Since the taskforce has completed its work and recommended the CA Risk Assessment be used as an interim standard, additional risk assessments have been completed. The Weinberg Group, a scientific environmental research group has completed a comprehensive risk assessment on non-nutritive elements in fertilizers on behalf of The Fertilizer Institute. This independent risk assessment supports the work completed and expressed through the CA Risk Assessment. In addition, US-EPA has completed it's risk assessment of non-nutritive elements in fertilizers and has come to the conclusion that fertilizers do not pose an environmental or human health risk, and that as a result of their risk assessment, they will not recommend any additional regulations on fertilizers.

DAIRY WATER QUALITY COMPLIANCE PROGRAM

Jack Hodges

INTRODUCTION

In February 1998 President Clinton released the Clean Water Action Plan (CWAP), which provided a blue print for restoring and protecting water quality across the Nation. As part of this effort, the CWAP called for the development of a United States Department of Agriculture and Environmental Protection Agency Unified National Strategy to minimize the water quality and health impacts of Animal Feeding Operations (AFOs). An AFO is an animal or poultry growing operation for meat, milk or egg production, or stabling, in pens or houses wherein the animals or poultry are fed at the place of confinement and crop forage production is not sustained in the place of confinement. Wastewater and manure generated by the AFO in many instances is utilized on adjacent or other lands as a nutrient resource for growing a crop.

COMPREHENSIVE NUTRIENT MANAGEMENT PLAN (CNMP)

One of the key elements of the Unified National Strategy for AFOs (March 9,1999) and draft Guidance Manual and Example NPDES Permit for Concentrated Animal Feeding Operations (CAFO) (August 6,1999) is the development and implementation of a CNMP for all AFOs and CAFOs (A CAFO is an AFO that is, pursuant to federal regulations, regulated by an NPDES Permit).

In general, CNMPs should address, as necessary and appropriate, manure and wastewater handling and storage, land application of manure and other nutrient sources, site or land management, record keeping and feed management. CNMPs should also address other utilization options for manure where the potential for environmentally sound land application of manure is limited at the point where it is generated. CNMPs are site-specific, and the specific requirements of each CNMP will vary depending on conditions at each facility.

COMPONENTS OF SITE-SPECIFIC CNMPS

As discussed in the USDA-EPA Unified National Strategy, site-specific CNMPs may include some or all of the six components described below based on the operational needs of the facility.

1. Manure and Wastewater Handling and Storage

   Manure needs to be handled and stored properly to prevent water pollution from AFOs. Manure and wastewater handling and storage practices should also consider odor and other environmental and public health concerns. Handling and storage considerations should include:

   Divert Clean Water - Siting and management practices should divert clean water from contact with feedlots and holding pens; animal manure; or manure storage systems. Clean water can include rain falling on the roofs of facilities, runoff from adjacent land, or other sources.

   Prevent Leakage - Construction and maintenance of buildings, collection systems, conveyance systems and permanent and temporary storage facilities should prevent leakage of organic matter, nutrients, and pathogens to ground or surface water.

   Adequate Storage - Liquid manure storage systems should safely store the quantity and contents of animal manure and wastewater produced, contaminated runoff from the facility, and rainfall. Location of manure storage systems should consider proximity to water bodies, floodplains, and other environmentally sensitive areas.

   Manure Treatments - Manure should be handled and treated to: reduce the loss of nutrients to the atmosphere during storage; make the material a more stable fertilizer when land-applied; or reduce pathogens, vector attraction and odors, as appropriate.

Management of Dead Animals - Dead animals should be disposed of in a way that does not adversely affect ground and surface water or create public health concerns. Composting, rendering, and other practices are common methods used to dispose of dead animals.

2. Land Application of Manure and Wastewater
Land application is the most common, and usually most desirable method of utilizing manure and wastewater because of the value of the nutrients and organic matter. Land application should be planned to ensure that the proper amount of nutrients are applied in a manner that does not adversely impact the environment or endanger public health. Considerations for appropriate land application should include:

Nutrient Balance - The primary purpose of nutrient management is to achieve the level of nutrients (e.g., nitrogen and phosphorus) required to grow the planned crop by balancing the nutrients that are already in the soil and from other sources with those that will be applied in manure. At a minimum, nutrient management should prevent the application of nutrients at rates that will exceed the capacity of the soil and the planned crops to assimilate nutrients and prevent pollution. Soils, manure and wastewater should be tested to determine nutrient content.

Timing and Methods of Application - Care must be taken when land-applying manure and wastewater to prevent it from entering the streams, other water bodies, or environmentally areas. The timing and methods of application should minimize the loss of nutrients to ground and surface water and the loss of nitrogen to the atmosphere. Manure and wastewater application equipment should be calibrated to ensure that the quantity of material being applied is what is planned.

3. Site or Land Management
Tillage, crop residue management, grazing management, and other conservation practices should be utilized to minimize movement to ground and surface water of soil, organic material, nutrients, and pathogens, from lands where manure and wastewater are applied. Forest riparian buffer strips, field borders, contour buffer strips, and other conservation practices should be installed to intercept, store, and utilize nutrients or other pollutants that may migrate from the fields on which manure and wastewater are applied.

4. Record Keeping
AFO operators should keep records that indicate the quantity of manure produced and how the manure was utilized, including where, when and the amount of the nutrients applied. Soil and manure testing should be incorporated into the record keeping system. Records should be kept when manure leaves the property.

5. Other Utilization Options
Where the potential for environmentally sound land application is limited, alternative uses of manure, such as the sale of manure to other farmers, centralized treatment, composting and sale of compost to others users, and using manure for power generation may also be appropriate. All manure utilization options should be designed and implemented to reduce the risk to the environment and public health and must comply with federal, state, tribal, and local law.

6. Feed Management
Animal diets and feed may be modified to reduce the amounts of nutrients in manure. Use of feed management activities, such as phase feeding, amino acid supplemented low protein diets, use of low phosphorous grain, and enzymes or other additives, can reduce the nutrient content of manure.

TECHNICAL ASSISTANCE AND GUIDANCE AVAILABLE FOR DEVELOPING CNMP

AFO owners and operators may seek technical assistance for developing CNMPs from federal agencies such as the NRCS, state and tribal agricultural and conservation agency staff, Cooperative Extension Service agents and specialists, Resource Conservation Districts, and Land Grant Universities. Assistance in developing the plans may also be available from integrators, industry associations, and private consultants that are certified as capable of developing CNMPs. A number of computer based tools are being developed to facilitate the CNMP development process.

CERTIFIED SPECIALISTS IN DEVELOPING AND IMPLEMENTING CNMPS

The owner/operator of an AFO is ultimately responsible for the development and proper implementation of a CNMP. A "certified specialist" may develop CNMPs. The purpose of the certified specialist is to help ensure that the necessary expertise is used, and to help ensure that a CNMP addresses all CNMP components and is appropriately tailored to the site-specific needs and conditions of the AFO. USEPA draft guidance indicates that NPDES Permits for CAFOs should require that CNMPs be developed by certified specialists.

Successful development and implementation of CNMPs depends, in part, on the availability of qualified specialists from the private and public sectors to assist in the development and implementation of CNMPs. As indicated in the USDA/EPA Unified National Strategy for AFOs, USDA and EPA will work with states to facilitate and encourage participation of the private sector through certification, training, and other activities. USDA and EPA will review available certification programs to ensure technical adequacy and support the development of state certification programs. Certified specialists will also be needed to assist in CNMP implementation, and to provide ongoing assistance through periodic reviews and revisions to CNMPs, as appropriate.

CALIFORNIA DAIRY QUALITY ASSISTANCE PROGRAM (CDQAP)

In 1998 the state's dairy producers recognized the increasing focus on their operations by state and federal environmental regulatory agencies. This shift in regulatory priorities culminated with extensive media coverage, numerous large fines, and even producer jail time. In March the CDQA's steering committee directed that environmental stewardship become the program's top priority, and that food safety/animal welfare efforts would continue but at a lower priority. The task before the committee was to develop and fund an environmental education/certification program that would meet with regulatory agency approval.

The committee entered into dialog with every agency having regulatory authority on California dairies. These discussions made it clear that 1) every dairy was expected to develop a plan to protect surface and ground waters and 2) every dairy would be evaluated to see that its plan was in place and functional. Negotiations concluded with the October 9, 1998, signing of the "Environmental Stewardship Partnership Agreement" by 14 state, federal, university and industry organizations. On September 9, 1999, the Partnership Agreement was expanded to include the U.S.Environmental Protection Agency.

The purpose of the Partnership Agreement is to support the Environmental Stewardship component of the CDQAP as a voluntary/cooperative government and industry education/certification program. The program's objective is to assist California dairy producers in meeting all federal, state, regional and local requirements relating to manure and nutrient management. The program's ultimate goal is to help ensure a healthful environment for the people and wildlife of California. The program's core components include continuing workshops for producers, the creation of Environment Stewardship Farm Management Plans tailored to each dairy, and on-site evaluation by a third party. Producers completing this program will become "certified". The term "certified" or "certification" used in the agreement carries no regulatory significance other than to inform local, regional, state and federal agencies of the producer's efforts in meeting compliance. Nothing in the agreement shall be construed as surrendering existing statutory or regulatory authority of any regulatory agency.

In order for a producer to become certified in the Environmental Stewardship Program, each of the three requirements below must be completed.

1. Environmental Stewardship Short Course - Each producer (or authorized employee representing the dairy) must complete a workshop in environmental stewardship developed or approved by University of California Cooperative Extension (UCCE). Workshops will be held at various locations throughout the state and conducted by UCCE trained staff. Certificates of completion will be provided and records of attendance kept by UCCE.
2. Environmental Stewardship Farm Management Plan and associated documents - Each producer (or authorized employee representing the dairy) will complete an Environmental Stewardship Farm Management Plan and other associated documents tailored to his or her dairy. The producer is responsible for developing the farm management plan and the plan shall remain at the facility. A regulatory agency's authority to gather information, an operator's right to withhold information and the public's right to access the information shall be governed by existing laws and regulations.

   These plans will include the basic elements for protection of surface and ground waters as well as other plans that may be applicable such as:

   A. A CNMP
   B. A Stormwater Pollution Prevention Plan
   C. An Emergency Plan that describes how appropriate resources will be mobilized in the event of a discharge or impending discharge.
   D. Other such elements as may be required by the regional water quality control board, for example, Waste Discharge Requirements.
3. Initial On-Site Evaluation - The producer (or authorized employee representing the dairy) will participate in an on-site evaluation by a third party. This evaluation will only occur at the request of the producer. A checklist cooperatively developed by the participants in the Partnership Agreement will be used as the evaluation tool. Evaluations will rely heavily on examination of the Environmental Stewardship Farm Management Plan and related documents developed by the producer. The evaluation will include a visual assessment of the waste containment and runoff control facilities. The on-site evaluation will be non-regulatory in nature. Following successful completion of an evaluation, the third party will notify UCCE which will complete the certification process.

   In the event that an on-site evaluation reveals circumstances that need to be corrected, the evaluator will leave an itemized list of corrections and will schedule a subsequent re-evaluation. Upon successful completion of the re-evaluation, the third party will notify UCCE, which will complete the certification process.

   If a producer owns more than one facility, an employee representing the facilities will only have to attend the Environmental Stewardship Short course once. A separate Environmental Stewardship Farm Management Plan and associated documents will have to be completed for each facility where livestock are kept.

   Periodic re-certifications following the third party on-site evaluation protocol described above will be necessary for a producer to maintain his or her Environmental Stewardship Certification as current. The frequency of these re-certifications will be determined as part of policy and procedures developed following a pilot project.

Under the CDQAP the producer is responsible for developing and implementing an Environmental Stewardship Farm Management Plan which, where applicable, would include a CNMP. The producer or authorized employee could become a certified specialist or the services of a certified specialist could be utilized. The important issue is that whoever develops the CNMP has the necessary range of expertise relative to the operation of a dairy in California to assure that the implementation of the CNMP will address the needs of the facility and applicable water quality requirements.

REGULATION OF BIOSOLIDS AS A FERTILIZING MATERIAL IN CALIFORNIA

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The California Department of Food and Agriculture (CDFA) established a facilitated working group in March of 1999 to examine the regulation of biosolids as a fertilizing material. The working group was asked to provide recommendations to CDFA on developing additional regulations for biosolids as deemed appropriate. Members of the working group included participants from state agencies, sanitation districts, agricultural organizations, a county agricultural commissioner and a county environmental health officer.

The working group reviewed current authorities of various state agencies and how the different regulations interrelated. Representatives of the State Water Resources Control Board, Integrated Waste Management Board, Department of Toxic Substances Control and CDFA provided information on the role of their respective organizations in the regulation of biosolids. Dr. Rufus Chaney, U. S. Department of Agriculture, Environmental Chemistry Laboratory, attended one meeting and gave an account of research which assisted in development of biosolids regulation by the US Environmental Protection Agency. Dr. Chaney also addressed questions relating to metals uptake by plants.

The group concluded their activities in June of 1999 with recommendations to CDFA for the development of additional labeling and testing requirements. It was also recommended that an appropriate funding mechanism be developed to support additional oversight by CDFA.

It is anticipated that the department will begin working on new regulatory language by the second quarter of next year. Any new regulations developed by CDFA will be published as a proposed rule with a public comment period.

Currently the department provides for plant licensing and labeling of bulk shipments of biosolids when used as a fertilizing material. Current labeling requirements provide for a statement of nutrient content.

The recommendations made to CDFA by the working group would require additional statements be made on the label as a guarantee that the material does not exceed the pollutant limits for metals established in 40 CFR Part 503.13.

In addition, nutrient claims on the label accompanying each bulk load of biosolids will state minimum guaranteed percentage of nitrogen, guaranteed percentage of available phosphoric acid and guaranteed percentage of soluble potash on a standardized dry weight basis.

The proposal recommended that samples be analyzed for nutrient content and metal content to ensure compliance with label guarantees. Recommended analysis would also include the testing of Class A Biosolids for pathogen levels to ensure compliance with 40 CFR Part 503.32.

The UCCE Rangeland Watershed Program's Role in the Garcia River TMDL Development and Implementation Process

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Recent events have made sediment and temperature important water quality parameters on California rangelands. On many coastal streams, the coho salmon is listed on the Federal Endangered Species List with spring-run chinook and steel-head likely to follow. On inland streams, numerous native trout species are petitioned for listing on a regular basis. Impairment of cold water fisheries habitat due to fine sediments in spawning beds, the filling of deep pools, and elevated stream temperatures over historic levels are cited as some of the reasons for the decline in these species. Negative impacts from ranching activities can arise from poorly designed and maintained roads, as well as from excessive grazing pressure on stream channels and riparian vegetation.

In March 1998, the U.S. Environmental Protection Agency began developing Total Maximum Daily Load (TMDL) numeric sediment and stream temperature standards for 18 Clean Water Act Section 303d listed California North Coast rivers and their tributaries. This is in response to a law suit claiming that EPA and the North Coast Regional Board had not complied with the CWA by failing to develop TMDL's for these impaired rivers. The first of these 18 rivers to have a sediment TMDL developed for it was the Garcia in southern Mendocino County. The implementation phase of the process will formally commence in late 1999.

In short, an agricultural landowner on the Garcia has 3 options available for TMDL compliance: 1. Show that no sediment is leaving their property, 2. Implement the broad-brush management measures from the general Basin Plan for the North Coast, or 3. Develop a site specific erosion control plan for their property including inventory of sediment source sites, prioritization of source sites, identification of management measures to mitigate source sites, and monitoring to document implementation of management measures. Development of the Garcia River TMDL for stream temperature is scheduled to commence in 2001. It is not currently known what form temperature TMDLs will take in California.

In response to these events the California Farm Bureau Federation, American Farm Bureau Federation, Mendocino County Farm Bureau, Garcia Watershed Agricultural Landowners Group, and California Cattleman's Association formally requested the UCCE Rangeland Watershed Program's assistance to help landowners comply with this process in as technically meaningful and efficient a manner as possible. After a needs assessment involving meetings and tours with both landowners and regional board staff we determined that we could develop and train landowners on the tools required to comply with the TMDL implementation. These included: 1. Ranch Water Quality Short Courses to teach landowners how to develop site specific water quality plans for their property as well as about basic land use and water quality interactions, and 2. A Sediment Site Inventory and Monitoring Methodology. In addition to developing these extension products we are conducting a field based sediment source survey across north coast rangelands to provide quantitative information on the actual sources, and likely causes, of sediment from these lands, which has thus far not been done. In preparing for stream temperature TMDLs we are developing a Stream Temperature Inventory and Monitoring Methodology and are conducting monitoring and research on several north coast streams.

In this presentation we will discuss the process we have gone through to develop this extension program and it's supporting applied research projects. We will introduce the the extension products and preliminary applied research results. We will also discuss how we feel we have been able to maintain our role as educators and scientists attempting to provide data driven solutions in a politically driven situation.

PLANTING DATE, PLANT POPULATION, AND VARIETY EFFECTS ON YIELD, QUALITY, AND DISEASE OF WINTER-GROWN GARBANZO BEANS IN THE CENTRAL SAN JOAQUIN VALLEY OF CALIFORNIA

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Commercial production of garbanzo beans as an alternative to winter cereal crops began in the Central San Joaquin Valley in the early 1990's. Growers requested information on the effects of planting date, plant population, and variety on stand establishment, yield, seed size, and disease incidence/severity. Small plot trials were conducted in 1992 and 1994-1998 at the West Side Research and Extension Center in Five Points, CA. Beans were planted between November and March at seeding rates ranging from 50 to 100 pounds per acre. Planting configurations of single rows on 30" and 40" beds and double rows on 40" beds were evaluated in combination with seeding rates. Four varieties were evaluated within planting dates in 1998. Higher plant populations resulted in higher yields, unless disease was a factor. Early planting dates showed an advantage over late planting dates with respect to yield, but they often experienced greater disease pressure. Variety was the only variable to have a significant effect on seed size. For this area, the variety HB-19 appears to be superior to other varieties evaluated. It was higher yielding and had a higher percentage of larger-sized beans. Resistance to Ascochyta blight resulted in excellent performance under extreme pressure from disease.

THE INFLUENCE OF NITROGEN AND IRRIGATION MANAGEMENT ON YIELD AND QUALITY OF WINTER GROWN GARBANZO BEANS IN THE CENTRAL SAN JOAQUIN VALLEY OF CALIFORNIA

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Field trials on garbanzo beans (*Cicer arietinum*) conducted at the UC West Side Research and Extension Center during 1994 and 1995 showed a positive yield response to added nitrogen (N) fertilizer and increased irrigation. Additional trials were conducted in 1997 and 1998 to validate the small plot results on commercial scale plantings. Average yield response from 65 lb. added fertilizer N was 180 lb. field harvested beans and 270 lb/a for graded clean beans compared to an unfertilized control. The N response was consistent over both production seasons ($p = 0.01$). The N treatment by year interaction was not significant. Seasonal ETc ranged from 32 to 50 cm for 1997 and 1998 respectively. Large-scale field results from these trials matched predicted values from the ETc yield relationship (yield = $-14.4 + 3.67(ETc) - 0.0807(ETc)^2$) developed from the earlier study.

Organic vs. Conventional Farming:
A literature review of comparison studies

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Sustainable Agriculture is a type of food production system (agroecosystem) that:

1. Provides for basic human food and fiber needs over time within long-term ecological constraints and socioeconomic pressures.
2. Maintains soil fertility and enhances soil quality over time from locally available resources.
3. Controls pests by soil management and if necessary, environmentally benign pesticides.
4. Maintains economic viability.
5. Enhances the quality of life for farmers and society as a whole.
6. Is managed organically?

Since J.R. Rodale coined the term "Organic Farming" in the 1970's, there has been considerable interest in how organic production systems, which do not rely on chemical fertilizes, herbicides, and pesticides, perform in comparison to conventional production systems. To answer this question several different efforts across the world have implemented replicated trials to compare the differences in agronomic yield, economic profitability, soil fertility and quality parameters, soil-plant-microbial interactions, pathology, and many other parameters between the two systems. While the USDA supports some of these projects, as of 1996 less than one tenth of one percent of its $1.8 billion dollar research and education budget is geared towards organic farming research. Of 30,000 projects financed by the USDA in 1996, only 34 were geared towards organic farming; fortunately this percentage is increasing with time as the USDA slowly recognizes organic farming as part of mainstream agriculture. We did a literature review of all the studies that compare organic and conventional farming and summarized their findings. The first and foremost of these projects, according to the Organic Farming Research Foundation, is the Sustainable Agriculture Farming Systems Project (SAFS) at the University of California- Davis.

Soil samples taken after 8 years of organic management at SAFS show that organic farming practices result in enhanced soil quality; (higher levels of soil organic carbon, potentially mineralizable nitrogen, and microbial biomass). Organically managed soils also show more neutral levels of pH, higher levels of soluble phosphorus, and exchangeable potassium. This can be directly attributed to the difference in inputs between systems. Organically managed systems are more efficient at storing excess N inputs (show more favorable nutrient budgets) indicating that organic farming has more potential to mitigate nitrate pollution of groundwater than conventional farming. Organically managed fields show higher levels of soil organic matter, the basis for long-term fertility. Crops grown in an organically managed soil have been observed to display more resistance to disease than crops grown in a conventionally managed soil. After 10 years no statistical difference in yield was found between systems. Whole farm economic analysis shows that organically managed systems, once certified, are more profitable than a comparable 4 year conventional systems. Results from nearly every other comparison study we found concur with those of SAFS. The findings from all of the comparison studies we found suggest that organically managed systems have the potential to be more sustainable than conventional systems and to result in higher levels of productivity over the long term.

Title of Paper: Diurnal Fluctuations of Nitrate Uptake and In Vivo Nitrate Reductase Activity in Pima and Acala Cotton

Authors: M. Aslam, R. L. Travis, and D.W. Rains

Summary of paper: This study was conducted to determine whether diurnal fluctuations of nitrate reductase activity (NRA) in cotton leaves are regulated by NO_3^- flux or its concentration within the issue. Nitrate uptake rates in both Pima (S-7) and Acala (Maxxa) species increased upon illumination and reached a plateau in about 5 h. In the dark uptake rates decreased 25 to 30% in about 3 h. In vivo NRA levels in the leaves increased upon illumination, reached a plateau and then, unlike NO_3^- uptake rates, decreased after 4 to 6 h of light. Nitrate concentration in the leaves also increased up to 7 h and then decreased. In contrast, NO_3^- uptake by the seedlings remained constant during the period when NO_3^- concentration and NRA levels in the leaves declined. These results indicate that while the increase in NRA levels upon illumination may be regulated by NO_3^- flux, the decrease in NRA under prolonged illumination is independent of NO_3^- flux.

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EVAPOTRANSPIRATION OF HALOPHYTES AND A SALT TOLERANT FORAGE PROPOSED FOR INCLUSION IN ON-FARM, SEQUENTIAL, DRAINAGE WATER RE-USE SYSTEMS FOR THE WESTSIDE SAN JOAQUIN VALLEY."

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High water table and soil salinity are chronic problems on the Westside San Joaquin Valley (SJV). However the use of subsurface drainage to lower water tables and allow adequate leaching has been limited by environmental restrictions on the discharge and storage of drain water. Regulations arose from waterfowl poisonings in 1983 near the Kesterson Reservoir which stored subsurface drain water, high in selenium, that bio-accumulated in the food chain.

For growers who drain, a means of reducing drainage volumes is desirable. Reutilization of the drain water to irrigate salt tolerant crops, forages, and halophytes, has been proposed so that plant water use (ET) can reduce drainage volumes and concentrate salts prior to discharge of drainage into a solar evaporator. A small acreage solar evaporator, with little standing water, is a more environmentally acceptable method for drain water disposal than is the use of large evaporation ponds that often attract waterfowl. Although several options exist for re-using drainage water for irrigation, our efforts focus on ***"On-farm, Sequential Re-use"*** which we view as being the most sustainable. Drain water is reused several times, each time to irrigate progressively more salt tolerant crops and forages; often using halophytes as the final "crop" in the sequence. All drainage and salt is managed on-farm. A small portion of the farm, usually unproductive ground and/or an area with high water table, is designated as the ***"Re-use Area".***

Using sand-containing drainage lysimeters we measured field evapotranspiration (ET) for three halophytes, *Salicornia bigelovii*, *Distichlis spicata ("saltgrass")*, and *Atriplex nummularia* under irrigation with 30 dS/m, 48 ppm boron, drain water; and for a salt-tolerant forage, bermudagrass (*Cyndon dactylon*), irrigated with 15 dS/m, 25 ppm boron, drain water. The salt tolerant forages are of interest because they have better economic potential, and may be preferable for re-use systems with drainage that is less saline.

In 1998, the ET of saltgrass irrigated with high EC drain water from Mendota averaged about 60 percent of the ET of tall fescue irrigated with canal water (0.5 to 0.9 dS/m) for most of the season. From Aug. 22-29, nonsaline fescue ET was 11.4 to 12.9 mm/day and saltgrass irrigated with saline drainage had ET rates of 7.1 to 8.6 mm/day.

In 1999, daily ET rates for the period of 23 to 30 July were 6.7 (Atriplex), 6.8 (saltgrass) and 9.3 mm day^{-1} (fescue). Salicornia averaged 12.3 mm day^{-1}, but this ET appears high for a halophyte, and requires re-examination of the data. The fescue ET rate of 9.3 mm day^{-1} was lower than that of 1998 (11-12 mm day^{-1}, for a similar period). In 1999, the EC of the fescue irrigation water increased during the season to as high as 7.0 dS/m before tank waters were changed. It is likely that the rise in ET reduced the fescue ET. Data indicate that all three halophytes tested have relatively high ET rates (~ 7 mm day^{-1}), which should provided significant drainage reduction in the Sequential Re-Use cropping systems. Good growth has been obtained for the halophytes, in spite of differences in salt composition, and boron, between drainage water and seawater salinity.

CONSERVATION TILLAGE: WHY CALIFORNIA? WHY NOW?
(Preliminary results from exploratory studies)

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Over the last several decades, the term *conservation tillage* has come to signify a wide range of crop production practices that minimize or eliminate primary tillage operations such as chiseling, ripping and plowing and maintain residue or cover over the soil surface as much as possible. A variety of conservation tillage systems including no-till, ridge till and strip till are now common in many areas of the world. These production systems have been developed from various motivations including reducing erosion, cutting production costs and conserving soil moisture. Recently, there is also growing awareness of the potentially negative impact tillage has on soil organic matter storage. While moderate tillage may provide more favorable soil conditions for crop growth and development and weed control over the short term, intensive tillage of agricultural soils may lead to soil carbon losses. Deep tillage, as is done as a routine soil preparation operation, is also costly and requires high energy and increased subsequent effort to prepare seed beds. Despite more than a 300% increase in the use of conservation tillage in the Midwest during the last decade, less than 0.3% of the acreage planted to row crops in California is currently farmed using conservation tillage practices. Lack of suitable equipment for conservation tillage production of California's high value row crops and uncertainties related to how surface irrigation can be efficiently accomplished under high surface residue conditions explain in part, why conservation tillage approaches have not been widely adopted in California.

Several recently-initiated projects in California are exploring the utility and feasibility of these approaches. In studies conducted from 1997 – 1998 in Five Points, CA with processing tomatoes, the ability to transplant and harvest in high residue, cover-crop-derived surface mulches was established. High density rye/vetch and triticale/vetch mulches in the evaluations suppressed early-season, but not late-season weeds relative to an herbicide fallow control system. In 1999, a comparison of five winter cover crop mixtures including rye/vetch, triticale/vetch, subclovers, faba bean/pea/ vetch and faba bean/pea/vetch/oat with a standard winter fallow for processing tomato production was made in terms of fruit yields and quality, weed suppression and production costs. Yields ranged from 34.6, 32.0, 18.4, 29.7, 39.4 and 36.2 for the triticale/vetch, rye/vetch, subclover, vetch/pea/faba bean/oat, vetch/pea/faba bean and standard fallow systems, respectively. Fruit soluble solids and color were not affected by mulch surface cover relative to the fallow control system. In-season cultivation in the surface mulches reduced % weed cover late in the season compared to a no-till mulch system.

While there is growing interest in conservation tillage production approaches throughout many agricultural sectors in California, many of the interrelated components of these systems have not yet been thoroughly investigated under specific production regimes and environmental conditions. Soil and air temperature reductions that occur with mulches, potential allelopathic influences of certain cover crop residues on crop plants, as well as other possible pest and economic issues of these systems, are all critical factors that need to be evaluated.

TOXIC EFFECTS OF ORGANIC MULCHES ON CONTAINER NURSERY TREES

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The use of organic mulches in maintaining landscape plants has become a standard practice throughout the country. However, concerns about the toxic effects of mulches derived from certain species such as eucalyptus and walnut continue to exist. In fact, several studies have shown that extracts of fresh eucalyptus leaves may inhibit seed germination and seedling vigor of certain annual plant species. However, any phytotoxic effects appear to be short lived, and mulches applied to the soil around woody landscape plants have proven to have mainly beneficial effects. There have also been concerns about the effects of mulch on soil pH. It is commonly believed that mulch made from species such as pine are acidic, and will therefore lower soil pH, while those made from other species, like walnut, are alkaline, so raise soil pH.

In the current study, a 3 to 4 inch layer of fresh chips from river red gum(*Eucalyptus camaldulensis*), English walnut (*Juglans regia*) and aleppo pine (*Pinus halepensis*), were immediately applied as mulch around nursery trees growing in 15-gallon containers. The nursery tree species included camphor (*Cinnamomum camphora*), Chinese pistache (*Pistacia chinensis*) and ginkgo (*Ginkgo biloba*). The nursery trees were growing in a soilless media, consisting primarily of green waste compost and wood chips. There were 5 replications per mulch treatment for each of the nursery species tested. Water was applied immediately after the fresh mulch was placed into the containers, and thereafter on a regular daily schedule. Any allelopathic compounds contained in the mulch would leach directly from the freshly chipped materials into the root systems confined in containers, possibly resulting in visual phytotoxicity symptoms, or reduced growth of the test trees. Tree height and diameter were measured at the start of the trial on May 23, and at the close of the trial on November 8. In order to determine the effects of the various mulches on soil pH, soil samples from 0 to 2 inches deep were taken from each tree container and submitted to the DANR Analytical Laboratory at UC Davis for pH analysis. Additionally, branches from eucalyptus, pine, walnut and Valley oak (*Quercus lobata*) were chipped and composted separately, with no added organic or inorganic materials. After 15 months, finished compost from each species was collected from each container and sent to the DANR Laboratory at UC Davis for pH and electrical conductivity (EC) analysis.

None of the mulches tested had an effect on the heights or trunk diameters of the three landscape tree species. None of the mulches caused phytotoxicity symptoms in the nursery plants. Composts derived from eucalyptus and oak were weakly acidic (6.4 and 6.7, respectively), compost derived from English walnut was weakly alkaline (7.6), and pine compost was strongly acidic (4.9). The relatively high total salt concentration of English walnut (EC 6.9) did not cause visible phytotoxicity symptoms in any of the treated trees. The pH of the soil beneath the various mulches was not significantly different from the pH of the unmulched soil (6.9).

TRANSPORT OF RUMEN INOCULUM FOR DETERMINATION OF FORAGE IN VITRO DIGESTIBILITY AT REMOTE LOCATIONS

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Chemical determinations of forage fiber such as ADF (acid detergent fiber) and NDF (neutral detergent fiber) provide estimations of the amount of fiber in forages, however they are limited in their ability to predict the energy value of forages which may be relatively high in total fiber but that have significant quantities of more highly digestible fiber, such as boot stage winter cereals. Because of this, in vitro fiber analysis is becoming increasingly important as an evaluation criteria in corn silage, cereal and other forage variety and harvest timing studies, as well as providing valuable information to nutritionists when formulating rations of high-producing dairy herds. However, these determinations have traditionally been limited to on-campus or sophisticated private research facilities because traditional methods of in vitro analysis have been labor intensive and/or required immediate proximity to a ruminally cannulated animal.

A bulk in vitro procedure (e.g. Ankom Company, Fairport, NY) has gained some acceptance as an alternative method of in vitro fiber determination. With this method, about 100 samples may be digested simultaneously in four large slowly rotating jars in a constant temperature incubation chamber. NDF analysis can similarly be accomplished in batches of 24 using an Ankom fiber digester. These pieces of equipment simplify the in vitro NDF digestibility procedure to the extent that it can be accomplished in commercial laboratories or, in this case, in an off-campus county extension office with limited time and facility resources.

Having immediate access to ruminal inoculant remains problematic, however. In this study, ruminal fluid was maintained at a constant temperature of 102°F for periods of up to 6 hrs before starting the in-vitro procedure to compare the effect of simulated transport of the inoculant with results obtained with no delay. To see if the number of trips to obtain ruminal fluid could be minimized, a separate experiment compared the effect of storage for two days at bovine body, ambient, refrigerator and freezing temperatures. These treatments were all replicated three times and compared with in-sacco in vitro digestibility where the forage samples were put immediately into the rumen for the same period as the non-delayed in vitro digestion. Winter cereal, corn silage, sudangrass and alfalfa samples with higher and lower digestibilities were sealed into Ankom polyester fiber digestion bags for in vitro determinations except the in sacco treatment, for which samples were placed in nylon bags.

The 48 hr in vitro digestion of NDF was not influenced by storing rumen fluid for up to 6.5 hr at 39oC, indicating that the ruminal inoculant may be transported prior to initiation of the procedure. None of the 48 hr storage temperatures gave results comparable to the control. Because the various forages responded differently to inoculum stored for 48 hours, it is unlikely that it would be possible to use a forage with a known digestibility as internal control to 'correct' the low measured values to obtain a 'normal' value. Data from this study suggests that the bulk in vitro method utilized estimates 48 h in vitro NDF digestion values that are higher than a similar in sacco procedure.

TESTING SEED FOR *TILLETIA INDICA* IN CALIFORNIA

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The size-selective sieving technique developed by G.L. Peterson (USDA ARS) (Peterson *et al.* 1998) is a very useful procedure for routine testing of wheat (and other) seed to detect the presence of teliospores of *Tilletia indica,* the cause of Karnal bunt of wheat. The test is rapid, sensitive, requires only inexpensive equipment and materials, and is simple to teach to technical help. A 50 g sample of wheat is washed using a conventional centrifuge-wash method, but with the additional step of passing the rinse water through sieves of different mesh sizes. This removes extraneous material that is larger and smaller than the size range of the propagules of interest. Teliospores of *T. Indica* range from 22 µm to 47 µm, thus the sieve mesh sizes used are 53 µm and 20 µm. Size-selective sieving sharply reduces the amount of material in a centrifuge wash needing to be examined with the microscope. Well over 3000 samples of wheat and other grains have been tested for *T. Indica* in California using the size-selective sieve technique. Samples in which teliospores are detected are also checked for the presence of bunted kernels by examining the seed using a slightly modified treated seed inspection station, commonly used for seed purity exams.

A Soil Quality Index for Vegetable Production in the Central Valley

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Managers need decision tools for sustainable management. Indices of soil quality may fill this need. We tested 2 methods for choosing a minimum data set (MDS) and 2 methods of index formation. Ten years of chemical, biological, and physical data from vegetable rotations of the Sustainable Agriculture Farming Systems (SAFS) project, near Davis, CA, were used. The MDS components were chosen using principal components analysis (PCA) or expert opinion. Indices were created using an additive index or a decision support system. The efficacy of each minimum data set was tested by multiple regression of MDS variables against management variables such as yield, % weed cover, and water use. For the MDS chosen by PCA for tomato, r^2 values were 0.64 against yield, 0.97 against weeds, and 0.99 against water use. The corn MDS regressed against yield, weeds, and water use had r^2 values of 0.81, 0.90, and 0.90, respectively. Results are reported for organic, low-input and conventional treatments.

Changes in Soil Quality and Fertility Due to Oak Tree Removal in California Oak Woodlands

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Abstract

It was previously believed that removing Oak trees in a managed grasslands in the Sierra Nevada foothills would benefit ranchers in the form of increased forage production. Forage production does indeed increase but after 15 years the production starts to decline as the soil fertility is depleted .

This study was initiated in a blue oak *(Quercus douglasii)* woodland in the Sierra Nevada foothills to examine the effects of oak removal on soil quality and fertility at time intervals of 5, 15, 21 and 34 years following tree removal. This study documents the ability of the blue oaks to create islands of enhanced soil quality and fertility beneath their canopy as a result of organic matter additions and nutrient cycling. Total C, microbial biomass C, total N, mineral N and available P concentrations showed a significant decrease within five years of tree removal. In contrast, microbial biomass N, potentially mineralizable N, pH and CEC values showed a significant decrease within 15 years following tree removal. About 20 percent of the total C and N pools was lost from the 0-15 cm depth increment within five years after tree removal. These changes were largest in the 0-5 cm soil depth, but did occur at a slower rate in the 5-15 cm depth. Because all of the soil quality parameters measured are directly related to soil organic matter quantity and/or nutrient cycling processes, removal of oak trees quickly results in a deterioration of soil quality and fertility by cutting off the major input of organic matter to the soil and by breaking the major pathway for the recycling of nutrients to the soil surface. Thus, oak tree removal in grazed blue oak woodland ecosystems in the Sierra Nevada Foothills leads to a rapid decline in soil quality and fertility parameters.

Impacts of Water Deficits on Key Acala Lint Quality Parameters

University of California Cooperative Extension, Fresno County
Dan Munk and Jon Wroble

Abstract

Contrasting water management regimes were imposed on Acala Maxxa over a five-year period. High water stress and low stress treatments resulted in a wide range of yield impacts with the premature water terminations having the greatest impact on yield. Gin turnout information and fiber quality measurements including fiber micronaire, length and strength are compared to crop yield. An average leaf water potential measurement was developed during the critical flower set period and compared to crop yield. A high correlation was found between average LWP and lint yields for the 1995 to 1997 data evaluations. Gin turnouts were improved as crop water stress increased and yields declined while no change in micronaire was observed. The most sensitive fiber parameters to water stress measured were fiber length and fiber strength. Water management methods that resulted in highest lint yield also tend to produce the longest and strongest fibers both within and between years. Although fiber strength was elevated with high yield irrigation treatments, no explanation is offered for the lack of micronaire response.

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