25TH ANNIVERSARY

CALIFORNIA PLANT AND SOIL CONFERENCE

1997 PROCEEDINGS

AGRICULTURAL STRATEGIES FOR THE FUTURE

CALIFORNIA CHAPTER OF AMERICAN SOCIETY OF AGRONOMY
AND
CALIFORNIA FERTILIZER ASSOCIATION

JANUARY 15 & 16, 1997

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BIOGRAPHY OF DR. H.B. COOPER, JR.

H.B. Cooper, Jr. has been involved in some aspect of farming all his life. Having grown up in New Mexico in a family that worked in agriculture, Coop went on to receive his Bachelor of Science degree in plant science from the New Mexico State University in 1951. After serving three years in the United States Air Force, he received his Master of Science degree in plant science from the Colorado State University in 1956. He then finished his Ph.D. work in genetics at the University of Wisconsin in 1960.

Coop first became interested in cotton breeding in 1947 while working with Dr. G. N. Stroman as an undergraduate student at New Mexico. There he learned how to evaluate fiber quality by hand and also worked with several of the very early fiber testing instruments. Dr. Cooper's cotton breeding career began in 1960 at the New Mexico State University where he was an Assistant Professor of Agronomy and cotton breeder. It was there that he, in collaboration with other colleagues, developed his cotton breeding and testing procedures that have led to his numerous variety releases. He was then hired by the USDA in 1964 to continue the *Verticillium* wilt breeding program at the U.S. Cotton Research Station in Shafter, California. There he served as research agronomist and cotton breeder and then Station Director from 1972 to 1978 following John Turner. It was there that he employed his breeding and testing scheme to further evaluate Turner's germplasm that led to the release of Acala SJ-2 in 1973. This variety was the prominent variety in the San Joaquin Valley for about 20 years. It is still a popular variety in many parts of the world. Cooper's work on *Verticillium* wilt tolerance led to the release of Acalas SJ-3, SJ-4, and SJ-5 in 1974, 1975 and 1977 respectively. In addition to improving *Verticillium* wilt tolerance with these varieties, Cooper also improved the fiber and spinning qualities over Acala SJ-2. When the USDA terminated the applied breeding program at the Shafter Station in 1978, Dr. Cooper left the USDA to continue his work with the California Planting Cotton Seed Distributors. It was there that he used his breeding and testing scheme to develop the varieties Acala SJC-1, Acala Prema, Acala Royale, and Acala Maxxa which were subsequently released by C.P.C.S.D. in 1982, 1989, 1990, and 1990, respectively. Acala Maxxa was a very significant breakthrough in cotton breeding. This was the first variety that combined substantial earliness for the San Joaquin Valley with high lint yield on both wilt and non-wilt infested soils plus high quality fiber and spinning characteristics. Acala Maxxa is now planted on 70% to 80% of the San Joaquin Valley cotton acreage. After leaving the California Cotton Seed Distributors in 1988, Dr. Cooper started yet another breeding program at Phytogen which is now operated by the J.G. Boswell Company. This program was a new challenge because he began with only previously released varieties, public strains, race stocks, and breeder exchanges. Since 1988, Dr. Cooper has been responsible for the release of Oro Blanco Pima, Kings Acala Plus, El Dorado Acala, and Phytogen 33 Acala. This program is now becoming one of the most competitive breeding firms in the San Joaquin Valley.

The success of Dr. Cooper's cotton breeding procedures is evident from the list of successful varieties that have continued to improve the San Joaquin Valley's reputation for high quality cotton fiber and superior productivity. Dr. H. B. Cooper is responsible for the development of every major cotton variety in the San Joaquin Valley since 1973 except for one, GC510. This variety was, however, a direct selection out of an advanced breeding strain developed by Cooper while at the U.S. Cotton Research Station. The cotton industry throughout the world has been influenced by Dr. H.B. Cooper and his work for the last 36 years and will continued to be influenced by this knowledgeable and respected man well into the 21st century.

BIOGRAPHY OF "JOLLY" OLIVER A. BATCHELLER

Oliver A. "Jolly" Batcheller is affectionately known as the founding father of the Horticulture Program at California State Polytechnic University, Pomona. Born in 1915 in Mattapoiset, Mass., it was his older brother, Robin, who first called him a "Jolly Little Rascal" when he was a child and the name "Jolly" has stuck ever since. He still much prefers this name to Oliver!

In 1919 Jolly's father moved the family to Corvallis, Oregon where he accepted a teaching position in the School of Mines at Oregon State University. The Batcheller Hall Building on the Oregon State campus is named in honor of his father. Jolly enrolled in the Department of Horticulture at Oregon State University in 1932 with the influence of his neighbor in Corvallis, a Master Gardener. He graduated in 1936, immediately entered the military and was stationed at Camp Roberts close to another school that has the same name as ours! Jolly fought in Europe with the 69th Division through the crossing of the Rhine River and ended up in Paris on VE Day.

In 1946, while pursuing additional graduate work at Oregon State University, he interviewed with Dr. Julian McPhee, President of Cal Poly, who wanted "teachers who know and can do all of the practices in their field and are respected by their industry". Jolly was hired as one of the original six instructors at Cal Poly. He became very active in the California Association of Nurserymen, The International Plant Propagators Society, American Society for Horticultural Science, and the American Society of Agronomy. He built a budding program in 1946 from 25 students up to over 200 students with several well respected faculty members today.

Jolly was always there for his students. He instituted the "hands-on" approach to education we treasure to this day. Most of his students will remember student enterprise projects where students grew and marketed crops and shared on the profit. Jolly has always been involved with Cal Poly's float entry in the Tournament of Roses Parade, being the first advisor. It was Jolly's son that rode the first Cal Poly float in 1952. Jolly was instrumental in creating the C.A.N. Certified Nurserymen Program still in existence today.

Jolly has too numerous professional awards to list in this small space. He is also very active in community organizations including the Kiwanis International. Best known perhaps in our society for the unique gavel which is passed on to each new president. He has built 12 of these for Kiwanis Chapters in foreign countries, professional organizations and our own Kellogg Voorhis Chapter of Gamma Sigma Delta.

Upon his retirement from Cal Poly, Pomona in 1978, funds were contributed from all of his friends and industry to construct an 8,000 sq. ft. conservatory in his name at his beloved Ornamental Horticulture unit. To this date it is still the only structure on campus named after a faculty emeritus of the University. At the dedication, one of Jolly's good friends said that "this conservatory is very appropriate for it is big and hard to ignore, full of interesting things and a lot of hot air". At 81 Jolly still maintains his sense of humor and is honored by this recognition from the California Chapter of the American Society of Agronomy.

BIOGRAPHY OF JOSEPH RONSTADT SMITH

While there is a great deal of discussion about new and alternative crops, very few have been commercialized in recent years. Safflower is one of those few, and since the second world war it has become an important rotation crop in California farming systems. Joseph R. Smith has been instrumental in developing the safflower industry, both in California and worldwide. Without his lifelong effort, it is doubtful that safflower would be an alternative for California farmers today.

After receiving bachelors and masters degrees from the University of Colorado, he moved to California in 1950 and joined Pacific Vegetable Oil, where he worked for eighteen years. He subsequently became president of Agricom, International and then Oilseeds International, Ltd., continuing with all these firms to specialize in the safflower oil business. He retired in 1994.

To make safflower as a viable crop, Smith helped create and implement a number of business and marketing innovations, including profit sharing with farmers, and long-term contracts at stable prices with distributors. Mindful of the value and need for research and extension, he helped develop strong relationships with University of California faculty and farm advisors. Throughout a long career, he has been tireless in securing production acreage, developing markets and crushing capacity, maintaining product quality and price, and many other aspects of the safflower business, without which there would be no industry today.

He has been president of the National Sunflower Association and the National Institute of Oilseed Products. He has received a Distinguished Engineering Alumnus Award and the Centennial Medal from the University of Colorado's Engineering School. Since retirement he has published a new book on safflower, the most current and thorough reference on this valuable oilseed crop.

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1996
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AGRICULTURE 2000: THE FUTURE WHAT'S NEXT

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INTRODUCTION

Without water, life would not exist. Unfortunately, while 70% of the earth's surface is covered with water, over 99% of this water is in the form of seawater or ice, and only 10% of the earth's surface has access to fresh water. It is these supplies of fresh water which are becoming increasingly polluted with raw sewage, industrial effluents, pesticides, and fertilizers totaling 20 billion tons a year. Potable water is diminished as rivers are diverted for irrigation and underground aquifers are used faster than nature can replenish them. The World Bank, estimates that 25,000 people die every day from acute water shortage and polluted water.

Of the earth's surface having access to fresh water, there are over one billion acres of land with saline aquifers, while 40% of the potentially arable lands are affected by salt. Man has been a poor steward of the land. Because of improper management of water, each year over 14 million acres of productive lands are turned into waste by salt buildup. As the world population increases, each inhabitant has decreasing availability of arable land and fresh water.

It is vital for agriculturists to receive and use new technological findings to face the challenge of ever diminishing amounts of fresh water and tillable land. There are many new exciting programs available in greening the desert using new programs that encourage conservation rather than the exploitation of the land and water.

WATER MANAGEMENT AND CONSERVATION

Drip Irrigation. New concepts in irrigation are dramatically increasing the water use efficiency over those methods of irrigation used in the past, such as in flood and furrow irrigation. Drip (trickle) irrigation systems are basically plastic lines with small holes that lie along each row of plants. The lines can either lie on the ground or be buried below the surface of the soil. Water is delivered to the plants at frequent intervals from small holes or emitters along the tube.

Drip irrigation is the best means of water conservation along with control over increasing water, fertilizer, labor, and machinery costs. A major advantage is that up to 50% less water is used to grow a crop as compared to flood, furrow, or sprinkler irrigation. This is especially true in soils having a high sand content. Generally speaking, drip irrigation will have an application efficiency of 90-95% compared with sprinkler at 70% and furrow at 60-80%, depending on soil type, level of field, and how the water is applied to the furrows.

In irrigation trials in North Africa, the author found that drip irrigation produced twice the tomato yield as the same amount of water used in sprinkler irrigation. In Southern California, a comparison between the effect of furrow irrigation and drip irrigation on tomato yields indicated that drip irrigation could provide a 26.8% increase in total yield and a 13.7% increase in fruit size.

Other research carried out in California has demonstrated an increase in strawberry production of 12.5% in those plots which were drip irrigated as compared to those that were furrow irrigated.

Drip Irrigation with Mulch. Mulching is the practice of covering the soil around plants with an organic or synthetic (plastic) material to make conditions more favorable for plant growth and development, for water savings and higher crop productivity.

In China alone, over seven million acres of plastic mulch are used on all types of horticultural crops, as well as cotton, sugarcane, corn and peanuts. This cropping system has done more to increase food and fiber production in China than any other agricultural development since the introduction of nitrogen fertilizer and hybridization.

When plastic mulch is used, it is advisable to install drip irrigation under the mulch. Using drip irrigation in combination with mulch will normally increase yields significantly, as such a system of irrigation facilitates the application of water and fertilizer directly to the plant roots growing beneath the mulch. Trials in New Jersey, showed that much higher yields of eggplant can be achieved if drip irrigation is used in combination with plastic mulch (Table 1).

Table 1. Effect of plastic mulch and drip irrigation on eggplant yield in New Jersey

Treatment	lbs/acre
Unmulched, no irrigation	58,179
Unmulched, irrigation	75,306
Plastic mulch, no irrigation	78,672
Plastic mulch, irrigation	99,362

Source: Unpub. data, J. W. Patterson and N. Smith. New Jersey. Agric. Exp. Station, Rutgers Univ. New Brunswick

Controlled Environment Agriculture (CEA). Such systems of protected agriculture provide the ultimate in the control of plant growth both at the aerial and root levels. Production may take place in a greenhouse or in a totally enclosed structure that permits control of air and root temperature, humidity, atmospheric gas composition, light, water, growth medium and plant nutrition.

Usually accompanying CEA is hydroponics, a technology for growing plants in nutrient solutions with or without the use of an artificial medium (e.g., sand, gravel, vermiculite, rockwool, perlite, peat moss, coir, saw dust) to provide mechanical support.

The principal advantages of hydroponic CEA include high density maximum crop yield, crop production where no suitable soil exists, more efficient use of water and fertilizers, and minimum use of land area.

The technology of CEA is changing rapidly with systems today producing yields never before realized. In Arizona, tomato yields are approaching 60 kg/sq. meter/year. The future for such systems of agriculture appear more positive today than any time over the last 50 years, especially for desert regions of the world.

Remote Sensing. Space age technology is today being used on the farm, where it is now possible to determine when and how much water is needed by using new hand held and permanently mounted infrared thermometers along with new irrigation scheduling techniques and more sophisticated computers.

The irrigation technique referred to as Crop Water Stress Index (CWSI) was developed in the early 1980's by Agricultural Research Service personnel at the US Water Conservation Laboratory in Phoenix, Arizona. Since that time, the University of Arizona has refined the technique for use in several commercial row crops and orchard operations. It is successfully used on cotton, pecan, wheat, and watermelon crops. Successes have ranged from cotton lint yields being consistently one-bale higher than country averages, to reduced irrigation of pecan orchards by as much as 30 percent over three years. Research tests are presently underway on other crops such as turfgrass, apples, table grapes and corn. Not a cure-all for all crops, the technique tested unsuccessful on lettuce and lemon crops.

Farmers in Arizona and nationwide are beginning to adapt the CWSI and similar infrared thermometry - based techniques at the commercial level for automatic irrigation systems for golf courses and drip irrigation. In the future, airplane mounted, infrared thermal scanners may be capable of scheduling irrigations on hundreds of acres in seconds.

Precision Agriculture. Precision agriculture, often termed precision farming, means carefully tailored soil, crop, or animal management to fit the different conditions found within each field. Today, four high technologies are supporting precision agriculture - ground machine electronic sensors (often referred to as yield monitors or harvest machines), Geographic Information Systems (GIS), Geographic Positioning Systems (GPS), and Decision Systems Software for analysis and planning. These technologies combine the use of computers, and satellites to provide spray drift control, irrigation management, controlled site fertilization, controlled use of herbicide and pesticides, precise cultivation, and improved seed placement.

Weather Information Networks. Weather can have a profound effect on the profitability of agricultural and horticultural operations. A wide array of production decisions, including cultivar selections, planting dates, irrigation timing, pest management and harvest timing are affected by weather. Wise use of weather information cannot only avert wholesale disasters in an agricultural operation, it can improve productivity and/or reduce production costs, and water use, all of which results in better profitability.

Agricultural producers can now benefit from a new source of weather information that is specifically tailored for agricultural needs. In the State of Arizona, it is the Arizona Meteorological Network (AZMET). Other states have similar networks. The AZMET system combines the power of modern computers with state-of-the-art, environmental monitoring equipment to provide weather information in near-real time.

Central to the AZMET system is a network of automated weather stations located across southern, central, and western Arizona. Each station collects data on air and soil temperature, relative humidity, solar radiation, precipitation, and wind. Computers at the University of Arizona campus regularly poll the station network, then transform the data into summaries. Among the information available from AZMET are daily and hourly summaries of all monitored parameters, heat units for use in predicting crop and pest development and crop evapotranspiration estimates for use in irrigation scheduling. AZMET information is available free of charge to farmers in the State of Arizona. Direct access by computer requires only a personal computer, modem and communication software.

INTEGRATED AQUACULTURE/AGRICULTURE SYSTEMS

The rising cost of irrigation water is a concern to agriculturists throughout arid regions of the world. Researchers at the University of Arizona noted that Arizona's water storage and delivery systems were physically similar to traditional fish ponds and raceways.

Research is presently underway to integrate fish culture with conventional agricultural production in order to extend the use of irrigation water and that energy to pump the water, to grow another food crop - fish.

Sensitivity models of Arizona fish farming show that in conventional flow through systems a common break-even point is a cost of $10 to $20 per acre foot of water. Much of Arizona's farm water already exceeds this range. If, however, fish farm water is "free" in the sense that it is already on the property for the irrigation of field crops, the return on investment is exceptionally promising.

The use of existing water systems, such as canals, is preferable if irrigation operations do not conflict with the need of fish husbandry. It is obvious that a system of canals and/or reservoirs already in place reduces capital investment in establishing a fish farm. However, unlike crop irrigation, fish farming has minute-to-minute imperatives, including, particularly in narrow canals and ditches, a constant flow of good quality water. At the inadvertent closing of a valve, a valuable fish crop may perish. This can be mitigated by modifying irrigation practices or by constructing separate, adjacent fish holding facilities (off-stream) such as diverting pre-irrigation water through a fish farm and then back to the canal for delivery to the field crops. The University of Arizona is developing such an off-stream technology in parallel with in-stream, canal trials; both types of systems are demonstrating significant profitability.

The integration of fish culture with conventional agriculture not only improves the effective use of each unit of water, which is vital to desert land production of food and fiber, but also, as water costs increase, may mean the dramatic difference between overall farm profitability and loss.

RECLAIMED WATER

In arid and semi-arid regions where water is becoming a more limited natural resource, the concept of irrigation with reclaimed sewage water is increasingly attractive as shortages and/or costs of fresh water rise. While there has not been a great deal of competition for such water, it is anticipated to increase, especially for landscaping, golf courses and other forms of non-food agriculture.

The concept of using effluent or reclaimed water for irrigation of turfgrass and landscape is not new. For years the city of Tucson, Arizona, USA has successfully used reclaimed water for parks and golf courses.

The arguments favoring the use of such water for landscaping are the following: (1) Turfgrasses are generally "heavy feeders," requiring relatively large amounts of nitrogen and other nutrients. This characteristic would greatly decrease the chances of groundwater contamination by these elements in reclaimed water. (2) Reclaimed water is produced continuously, and any use of it, therefore, also needs to be continuous. A turfgrass "crop" is continuous (i.e., uninterrupted by cultivation, seeding, or harvest, all of which mean stopping irrigation for considerable periods). (3) Most landscaping expanses or irrigated turf are located adjacent to cities where the effluent water is produced; thus, transportation costs will be minimal. (4) Potential health problems related to the use of reclaimed water are lower when the water is applied to turf than when it is applied to food crops. (5) Soil-related problems that might develop due to the use of reclaimed water will have less social and economic impact if they develop where turf is cultivated than if they develop where food crops are grown.

XERISCAPE GARDENS

The term Xeriscape is derived from the Greek word Xeros, which means dry. Xeriscapes have plants that require water but less than a traditional area planted to turfgrass. It can be defined as a creative method to landscape for water and energy efficiency, comprised of seven sound horticultural principles. They are the following:

1. Good planning and design
2. Appropriate turf areas
3. Use of soil amendments to improve the water holding capacity
4. Efficient irrigation
5. Use of mulches to retard evaporation
6. Incorporation of low water use plants into the landscape. In the State of Arizona, over 400 species of plants are available for use in Xeriscapes.
7. Appropriate maintenance of plants and irrigation systems.

Appropriate landscaping may save in a home owners annual cooling costs. An energy conserving planting design has high branching, wide spreading trees that shade the roof and walls from the summer sun but allows sunshine on the south wall in winter. The late afternoon sun may be blocked by low branching evergreens.

Research by plant scientists suggests that vegetation in cities can substantially reduce commercial and residential building energy consumption and beautify the city.

ALTERNATIVE CROPS FOR DESERTS

Today there is a great deal of interest in alternative crops for deserts, whether they be landscape or food crops or plants that have potential products for new medicines, chemicals, fibers or oils.

Halophytes. If desert coastlines of the world could be made productive, millions of additional people might be fed. While more efficient irrigation and cultural systems will be used to meet the food needs of tomorrow, the fact remains that over 99% of the water on earth is in the form of sea water or ice. Most of the 20,000 miles of coastal deserts on earth remain uninhabited; but if given the amenities, they could be productive and pleasant places to live.

An alternative in the production of food in a desert seacoast would be to cultivate those plants that can grow on salty soils or be irrigated with brackish or pure seawater. Such plants are called halophytes. Research at the University of Arizona indicate certain crops, as *Atriplex*, to nearly equal alfalfa in yield and protein content. Excess salts which exist in the harvested plant may be removed by leaching. Initial animal feeding trials show promise for this plant to become an important forage crop for feeding of certain animals. Other crops, such as *Salicornia* sp. are being tested for the production of seed, high in cooking oil and protein content.

Extensive trials have also occurred taking seawater in which aquatic animals are raised, which is rich in nitrogen, and using it as irrigation water for halophytes. Excellent growth rates have been experienced by irrigating this nitrogen - rich seawater onto halophytes. These plants may one day play a future role in providing food commodities for man and animals.

Medicinal Plants. Many of today's prescription and over-the-counter drugs were originally obtained from plants. Most of these now - synthetic compounds came from plants native to tropical rain forests rather than deserts. Desert plants are subjected to stress, producing unusual chemicals that protect them from animals, microbes and even other plants. It could be that these plants could have anti-viral activities, specific against certain viruses such as those which cause AIDS (Acquired Immunodeficiency Syndrome). Trials are underway at the University of Arizona to test plant extracts for anti-viral activities along with the isolation and chemical characterization of the compounds that show this activity.

Other Crop Alternatives. Some alternative crops have already received a good deal of attention research-wise, such as jojoba, kenaf and guayule. Other crops of interest having specialty chemicals are chia, guar, tarweed, and gumweed. The crop, *Hesparaloe*, is a fiber crop, that has promise for high quality paper. Crops as *Lesquerella* and *Veronia* are becoming increasing popular as possible candidates for certain oil products.

With an increasing awareness in biodiversity, research on alternative crops will receive greater attention. Establishing new agricultural crop alternatives will provide new agricultural industries, replacing those cropping systems that demand greater water resources and production inputs.

BIOTECHNOLOGY

Man must make use of the technological advances at hand. The opportunities and alternatives for feeding tomorrow's population, using new programs to encourage conservation rather than exploitation of land and water, are here.

In the 1960's, the food situation was described as "desperate" particularly in Asia. Food specialists predicted famine but instead average crop yield per acre soared, thanks to the introduction of high-yielding varieties of rice and wheat and to expanded irrigation and chemical fertilizer use. The increased production now feeds 700 million people every day. It has been called the green revolution.

Although average yields continue to expand as more farmers adopt technology, the green revolution is clearly slowing. Yes, man has been able to quadruple yields in the last 100 years, but fortunately this is only the beginning, as the population continues to rise.

Today, through the new advances in biotechnology, we are able to provide phenomenal advances to the food industry, providing yet another revolution. Some say it will be more of a silent revolution. Its impact in the beginning may only be modest, but in the end, biotechnology will probably have a greater impact than the green revolution. It will be a cumulative process, not a dramatic one-year burst of productivity.

In the future, for example, genetic engineering offers the opportunity to transfer growth hormone genes between species of fish to stimulate growth four times the normal rate. We are able to transfer genes from animals to plants to safeguard plants against disease and pestilence. We may even have microorganisms designed to devour oil spills.

As we map the genome of animals and plants, we will one day be able to splice in gene characteristics at will. Soon we will be able to plant the desert coastlines of the world with salt tolerant crops, and we will be able to irrigate these crops with pure seawater. We will be able to plant the one billion acres of land that have saline aquifers and to again employ the 14 million acres of productive land that is turned into waste by salt build up each year. Through the processes of plant genetics and breeding, along with the new tools of biotechnology, new food production opportunities will be made possible in arid regions of the world, with minimal need for expensive and scarce chemicals now necessary for growing a good crop with some security. The efficiency of food production in agricultural lands, now not used to full capacity, will be greatly enhanced.

Incredible technology, research and progressive thinking will enable citizens of our countries to attain a standard of living conducive to world food security and world peace. We must make a commitment to the new research findings and the discoveries in molecular biology and genetics that will dramatically boost the world's food supply and enhance our quality of life, and we must implement them through programs of traditional research and extension, if we are to have a better world in which to live and a world at peace - in the 21st century.

THE FUTURE OF AGRICULTURE IN AN URBANIZING CALIFORNIA

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California is at the confluence of two conflicting facts: it is the nation's most productive agricultural state and also the fastest-growing. According to the U.S. Census, California will add the most residents of any state between now and the year 2020 and will also grow by the greatest percentage of any state, with nearly a 50% increase in population.

By the year 2040, the California Department of Finance predicts a California population of 63 million, nearly a doubling of the current population. During that same period of time, population in the Central Valley is expected to *triple*, from a current level of 4 million people to over 12 million. Fresno County, the nation's most productive agricultural county, is expected to nearly *quadruple* its population to 2.5 million residents by the year 2040. That would make Fresno County more populous than 20 of today's least-populous states.

While population gain means a greater demand for agricultural products, this population gain will be competing for the same resources upon which agriculture depends: water, air and land. Developed water for agriculture, already in short supply even in the wettest years, will become even more scarce as urbanized California places a greater demand upon this near-finite resource. Declining air quality, already estimated by the University of California to contribute to significant losses in agricultural production in the San Joaquin Valley, will negatively impact agricultural production in many areas of the state. And conversion of agricultural land to urban uses and housing, the "final crop", will reduce the supply of the most critical resource necessary for agricultural production.

Statewide, American Farmland Trust estimates that nearly 100,000 acres of agricultural land are converted to urban, suburban and rural development uses annually. Disproportionally, this development occurs on the most productive agricultural land, largely as a result of historical development patterns that placed our early communities in areas of high agricultural productivity. As these small farm communities grew over the years, they became the cities that we know today -- greater Southern California and the San Francisco Bay Area immediately come to mind, but this group also includes cities such as Ventura, Salinas, Stockton, Modesto and Fresno. As these urban areas expand, it is often onto the most productive agricultural land.

The Central Valley is probably the most illustrative example of the impacts of expanding population. A recent American Farmland Trust report, "Alternatives for Future Urban Growth in California's Central Valley: The Bottom Line for Agriculture and Taxpayers", examined the impact of projected population gain in 11 Central Valley counties (from Sutter County in the north to Kern County in the south) on agricultural production and the cost of providing public services such as roads, sewers and public safety. The study analyzed the impacts of the same population gain under two different scenarios. The first is a continuation of the current low-density, urban sprawl pattern of residential development in the Central Valley, averaging three housing units per acre over the entire urban area. The second is a more compact, efficient pattern of residential growth averaging six housing units per acre over the entire urban area. The study found that:

* Low-density urban sprawl would consume more than 1 million acres of farmland by the year 2040, over 60% of which is likely to be prime and statewide important farmland. In addition, agriculture would experience increased risks and costs, and lower productivity, within a one-third mile wide "zone of conflict" around urban areas, totalling 2.5 million acres. By contrast, more compact, efficient growth would reduce farmland conversion to 474,000 acres and shrink the "zone of conflict" to 1.6 million acres.

* By the year 2040, low-density urban sprawl would reduce direct agricultural commodity sales by $2.1 billion a year (1994 dollars) and related sales of suppliers, processors and other ag support businesses by $3.2 billion annually. Compact, efficient growth would reduce those losses by slightly more than half.

* The cost of providing the current level of public services to low-density urban sprawl would exceed the revenues from that growth in 39 Central Valley cities by about $1 billion annually in the year 2040, necessitating a reduction of services or an increase in taxes. By contrast, compact, efficient growth patterns would produce an annual budget surplus of $200 million, enabling services to be maintained or slightly improved.

Rudy Platzek, a retired planning consultant studying the impact of projected population gain in the Central Valley, estimates that nearly 2/3 of the irrigable farmland on the valley floor will be converted to urban uses by the year 2080. At that time, the Central Valley's projected population will total over 24 million people and the remaining farmland will not be enough to even feed the Valley's population, let alone the state or nation's.

What can be done to guarantee a future for agriculture in an urbanizing California? In the Central Valley, the momentum of urban sprawl requires a concerted effort to increase the efficiency of new development and protect the most important farmland. This can be accomplished through a consensus effort of the major stakeholders in growth and development issues to address the following goals:

* Housing developments that make much more efficient use of land with innovative, attractive architectural and neighborhood design.

* Commercial development and public facilities that minimize the amount of farmland and water they consume.

* New development that is contiguous to existing developed areas rather than fragmenting outlying agricultural areas.

* Maximum infill development of vacant and underutilized land within city limits.

* Reasonable, predictable rules for homebuilders and other developers with incentives for those who minimize public costs and agricultural impacts.

* Designation of the Central Valley's most important farmland as a "strategic agricultural reserve" where nonfarm development is prohibited or strongly discouraged by local policies.

* Within these reserves, a secure supply of affordable irrigation water for growers and expanded financial incentives for landowners to permanently commit land to agricultural production.

American Farmland Trust is working with interests throughout the Central Valley to accomplish these goals. Achieving these hallmarks of compact, efficient growth will not be easy in any community. However, the prospect of a sprawling, suburbanized Central Valley will be disastrous for continued agricultural productivity and is not an acceptable future scenario.

American Farmland Trust

California's Central Valley
Urban Sprawl 2040
Zone of Conflict

Base Map from California Department of Conservation Farmland Mapping and Monitoring Program Data
Population Projections from California Department of Finance
GIS by University of California/Institute of Urban & Regional Development
Produced by American Farmland Trust, 1995

Opportunities for Biotechnology Strategies in California Agriculture

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Abstract not submitted at time of printing.

SALINE DRAINWATER REUSE IN IRRIGATED AGRICULTURE: ECONOMICS AND MANAGEMENT

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INTRODUCTION:

Agricultural drainwater reuse conserves scarce freshwater supplies and mitigates environmental problems arising from drainage flows. A complete economic analysis requires evaluation at different spatial and temporal scales. At the field level, questions of interest include irrigation timing and the optimal mix of irrigation water from multiple sources. Since salts can accumulate over time, irrigation over a series of years also needs to be considered. At the farm and regional level, growers can practice sequential reuse whereby drainwater from salt-sensitive crops is applied for production on salt-tolerant crops. At the regional level over long time scales, deep percolation flows drive evolution of groundwater quantity and quality and this in turn affects agricultural production opportunities. This paper summarizes some economic studies addressing these and other issues.

IRRIGATION MANAGEMENT:

Knapp and Dinar (1988) develop an irrigation scheduling model with dynamic soil salinity and irrigation from alternate water sources differing in price and salt concentration. Daily evapotranspiration (ET) is a function of soil moisture and soil salinity. Soil moisture and soil salinity evolve over the season in response to ET and to quantity/quality of irrigation water. Deep percolation flows are the excess of irrigation water over moisture deficits, and yield is a function of seasonal evapotranspiration. Irrigation can occur at any time during the season and cost depends on the volume and salt concentration of applied water. The optimization problem is to choose irrigation timing, volumes and salt concentrations (reuse) to maximize net returns subject to the equations of motion and other constraints.

The model is applied to cotton with two irrigation sources: freshwater with EC = .67 dS/m and cost of $1.71/(ha-cm), and saline water with EC = 8 dS/m and pumping cost of $.09/(ha-cm). Model results show that optimal reuse in this case depends strongly on soil salinities at the beginning of the season. At low initial salinity levels all irrigation is from the saline source while at the highest initial salinity level considered (12 dS/m), approximately 1/3 of the total irrigation water applied is saline. Compared to no-reuse, total irrigation volumes are generally larger as would be expected; however, reuse does conserve on the use of freshwater. Yields are somewhat higher with reuse in response to the effectively cheaper water; however, ending salinities are somewhat higher. Reuse increases net returns by 6%.

SUSTAINABLE PRODUCTION AND REUSE:

Continued use of saline water for irrigation can lead to long-term buildup of soil salinity; this must be considered in any long-run analysis of reuse. Knapp (1992) analyzes field-level irrigation management over an infinite horizon with dynamic soil salinity. The model assumes two irrigation sources, nonuniform water applications, fixed crop rotations, and investment in irrigation systems. The empirical analysis is for a cotton-cotton-tomatoes rotation and five alternate irrigation systems.

Table 1 illustrates results for alternate fresh water prices (p_1^w) and EC of the low-quality source (ECI_2). Under the assumed conditions some reuse is generally optimal. Most or all irrigation is from the saline source for low concentrations (3-5 dS/m). For higher concentrations, the first cotton crop is irrigated solely out of the saline source, the second cotton crop is typically irrigated with a blend, and tomatoes are generally irrigated solely with freshwater. Over the long-run the system exhibits a limit cycle where soil salinity is highest after first-year cotton and then is driven down in the following year to accomodate tomatoes.

Conclusions: First, long-run reuse of saline drainage water may well be economically efficient, even without consideration of avoided disposal/environmental costs. This is subject to the qualification that only total salt effects on plant growth are considered here, not soil structure or specific ion effects. Second, some blending is likely to be optimal, at least as regards seasonal averages. Third, optimal reuse can be complex. It can vary over the course of the rotation, as well as with underlying biophysical and economic parameters.

AGROFORESTRY:

Farm and regional reuse analysis must account for multiple cropping activities of growers as well as alternate water management, irrigation technology, and disposal methods. Posnikoff and Knapp (1996) consider a closed drainage basin. Land can be used for crop production, agroforestry, or evaporation ponds. Crop deep percolation is used to irrigate trees; residual flows plus agroforestry deep percolation are disposed in evaporation ponds. Decision variables are crop areas, irrigation technology and applied water depths, and tree area and reuse depths. These are selected to maximize regional social net benefits subject to land, irrigation water and drainage constraints. The analysis is intermediate-run in that salt concentration of drainage water is fixed and salt removal from the ponds is not considered.

The historical results of table 2 replicate portions of the San Joaquin valley (SJV) drainage problem area in the 1980s before serious consideration was given to within-region drainage disposal. With unlimited drainage flows, no source control is practiced, no trees are grown, and no land is set aside for evaporation pond use. Crop acreage, water applications and irrigation systems, and net returns match historical values of the 1980s. The second case in table 2 assumes a closed region, but no management strategies other than evaporation ponds. With deep percolation of 0.87 a-f/acre, the evaporation pond area is 13% of the total area.

The third case also closes the region in terms of drainage outflows, and allows source control but not reuse. All four of the crops are now grown with a more uniform irrigation system.

Water applications also decrease as do deep percolation flows, hence decreasing evaporation pond area to approximately 9% of the total acreage. Regional net benefits are considerably reduced from the historical case, but exceed those of an evaporation pond only.

The final case considers source control, reuse, and evaporation ponds. While both cotton and wheat acreage decrease, with most of that land going to agroforestry, less source control is practiced and more water is applied on the crops resulting in greater deep percolation than without the possibility of reuse. This is a result of the less costly disposal of deep percolation flows on trees. As a result, the evaporation pond area is reduced to approximately 4% of the region and regional net benefits differ by only a few dollars from the open region net benefits. Shadow prices in table 2 show the value of providing external drainage facilities to the region, or alternately the efficiency-inducing emission charge/reuse subsidy. These range from $42.04/a-f to $25.53/a-f depending on the scenario.

GROUNDWATER QUANTITY AND QUALITY:

Long-run analysis of reuse must consider the resulting effects on groundwater quality and usage. We consider an agricultural production/groundwater aquifer system with a single crop, endogenous irrigation technology, and two water sources: surface water imports to the region and groundwater extractions. Crop yield and quantity and quality of deep percolation flows depend on irrigation technology and the quantity and quality of applied water. Water may also be extracted from the aquifer and disposed of in an evaporation pond. Hydraulic head and aquifer salt concentration evolve in response to groundwater extractions and quantity/quality of deep percolation flows. We consider cotton with five alternate irrigation systems, hydrologic parameters reflective of the southern SJV, and a 100-year time horizon. Results are illustrated in Figure 1.

Under common property usage, growers select technology and applied water volumes to maximize annual net returns for each period independently. Starting with a relatively full, nonsaline aquifer, the water table declines over 125 feet in the first seven years as the initially more expensive surface water is not used. Once surface water is brought in, groundwater use levels off at approximately 0.9 ft/year and, with deep percolation flows returning to the aquifer, hydraulic head gradually increases over time. Groundwater salinity increases over time as salts imported into the basin in surface flows gradually accumulate in the aquifer.

Common property usage is inefficient due to externalities: growers do not account for future impacts of their actions on hydraulic heads and salinity. Under optimality, the present value of social net benefits is maximized for the entire time frame; here actions in each period reflect future effects on the hydrologic system. In contrast to common property, optimal use implies both smaller deep percolation flows and reduced groundwater extractions, at least initially. This results in a much smaller drop in water table height initially and hence a higher water table over the remainder of the period, as well as reduced buildup of salinity in the aquifer. In both instances, applied water salinity is increasing as more of the groundwater is made up of returned deep percolation flows, but the increase is much more rapid under common property usage.

Excess deep percolation flows and groundwater extractions during the initial periods of the common property usage result in reduced future social net benefits in that greater lifts increase pumping costs, leading to more efficient and more expensive irrigation systems, and the diminished applied water quality results in reduced yields and hence reduced revenues. The present value of social net benefits under the common property solution equals $6506/acre whereas the optimal solution returns $6659/acre.

CONCLUSIONS:

Field-level analysis demonstrates that reuse of saline drainwater can be economically efficient, even without consideration of avoided disposal/environmental costs. Thus growers have some incentive to automatically reuse drainage flows, although the overall level of reuse will be less than optimal. However, the analysis also shows that optimal reuse quantities are sensitive to a variety of parameters including initial soil salinity, water prices and salt concentrations, that the nature of optimal reuse can be complex, and that profitability gains can be modest.

An analysis of drainwater management in closed drainage basins finds that agroforestry reuse in conjunction with source control and evaporation ponds is efficient, although this conclusion is sensitive to various parameters. More generally we find that agricultural net returns can be sustained at high levels over significant periods of time, and essentially indefinitely with cost-effective salt-removal mechanisms for the ponds.

Reuse and other water management practices influence the long-run evolution of groundwater quantity and quality. Under common property usage, growers are likely to have excessive levels of both deep percolation emissions and groundwater extractions. This lowers the water table below - and raises aquifer salt concentrations above - economically efficient levels.

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Table 1. Optimal irrigation systems and applied water depths with drainwater reuse.

P_1^w	ECI_2	Irrigation system	Field-average applied water depth [cm/yr] (salt concentration of the irrigation water [dS/m])*			
			Cotton-1	Cotton-2	Tomatoes	Rotation Average
3	3	Furrow, ½ mile	120 (3.0)	174 (3.0)	167 (2.9)	154 (3.0)
5	3	Furrow, ½ mile	120 (3.0)	176 (3.0)	165 (3.0)	154 (3.0)
3	5	Furrow, ½ mile	124 (5.0)	213 (5.0)	137 (1.8)	158 (4.1)
5	5	Furrow, ½ mile	129 (5.0)	255 (5.0)	214 (5.0)	199 (5.0)
3	7	Furrow, ½ mile	131 (7.0)	151 (2.7)	132 (1.7)	138 (3.7)
5	7	Furrow, ½ mile	133 (7.0)	236 (7.0)	118 (0.7)	162 (5.5)
3	9	Furrow, ½ mile	128 (9.0)	134 (1.1)	120 (0.7)	127 (3.6)
5	9	Furrow, ½ mile	137 (9.0)	189 (7.3)	127 (0.7)	151 (6.0)

*Optimal values in the limit cycle.

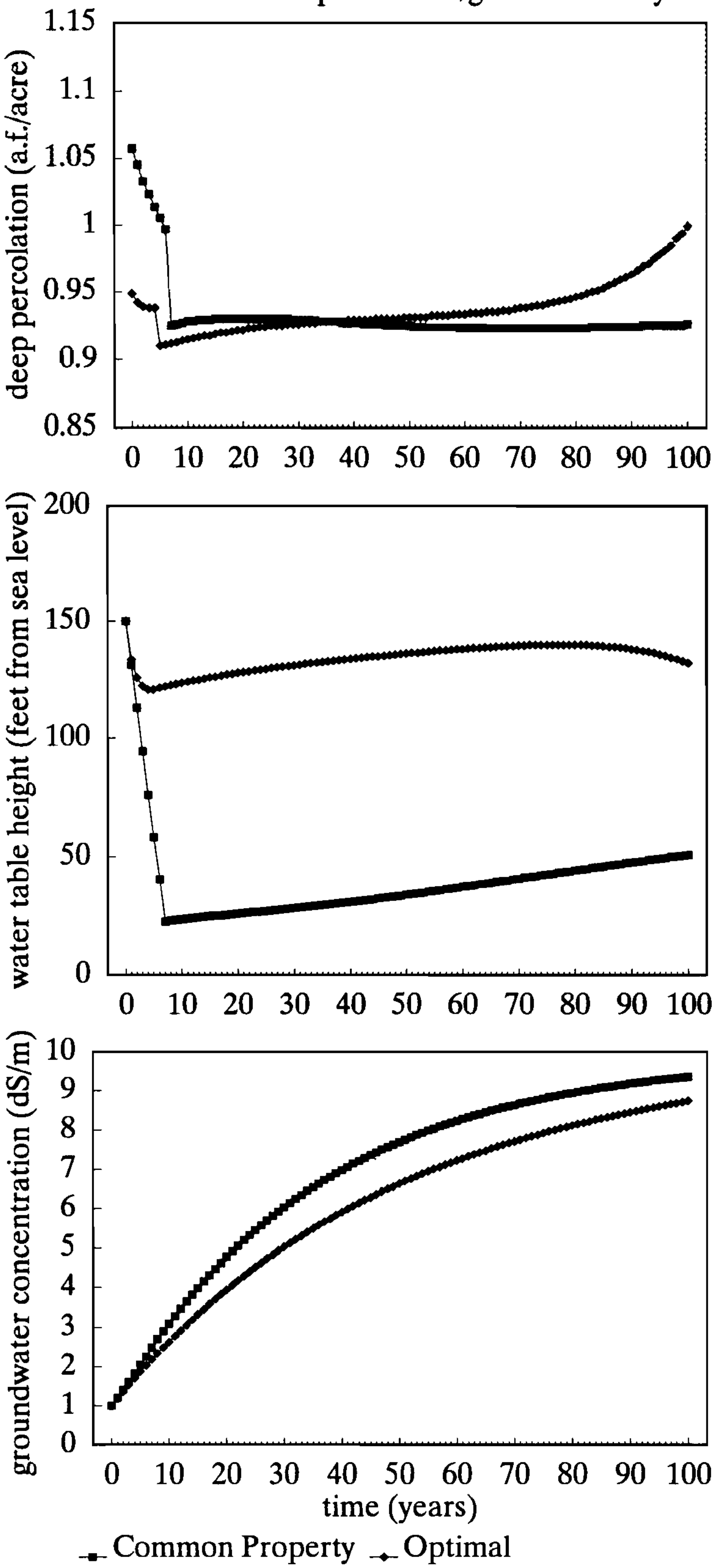
$ECI_1 = 0.67$ dS/m, $P_2^W = \$1/(\text{ha-cm})$, $e = 0$

Table 2. Efficient Water Management in a Closed Drainage Basin with Reuse

	Historic	Pond	SC +Pond	SC+Pond +Reuse
Crop Production:				
Cotton				
Land area (fraction of total)	0.49	0.43	0.44	0.42
Irrigation system	Furrow 2	Furrow 2	Furrow 4	Furrow 2
Tomatoes				
Land area (fraction of total)	0.10	0.09	0.10	0.10
Irrigation system	Furrow 2	Furrow 2	Furrow 4	Furrow 4
Wheat				
Land area (fraction of total)	0.20	0.18	0.18	0.16
Irrigation system	Furrow 2	Furrow 2	Furrow 4	Furrow 2/4
Lettuce				
Land area (fraction of total)	0.11	0.10	0.11	0.11
Irrigation system	Furrow 2	Furrow 2	Linear	Linear
Crop land area (fraction of total)	0.90	0.79	0.83	0.78
Applied water (a-f/yr)	2.30	2.01	1.78	1.80
Deep percolation (a-f/yr)	0.87	0.76	0.49	0.58
Agroforestry:				
Land area (fraction of total)	0.00	n/a	n/a	0.10
Reuse (a-f/yr)	0.00	n/a	n/a	0.58
Deep percolation (a-f/yr)	0.00	n/a	n/a	0.20
Evaporation pond:				
Land area (fraction of total)	0.00	0.13	0.09	0.04
Shadow price of drainage ($/(a-f))	0.00	42.04	37.65	25.53
Regional net benefits ($/(acre-year))	274.89	228.04	255.72	271.26

Source: Posnikoff and Knapp (1996). Results are for one acre of regional land area. Monetary amounts are 1992 dollars. Historic = free disposal of drainage outside of region; Pond = closed region, evaporation pond size sufficient to accomodate historic deep percolation flows; SC+Pond = closed region, source control (SC) and evaporation pond only; and SC+Pond+Reuse = closed region, source control, evaporation pond, and reuse.

Figure 1. Deep percolation, hydraulic head, and aquifer salt concentration in a production/groundwater system



WATER USE OF *EUCALYPTUS CAMALDULENSIS*, CLONE 4544, IN SALINE DRAINAGE REUSE SYSTEMS

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INTRODUCTION:

Leaching and drainage of agricultural lands are prerequisites for sustaining crop productivity in arid and semi-arid regions, but the drainage effluent, which contains dissolved salts, boron and other constituents, must be disposed of or managed to avoid long-term effects on the environment. In California's San Joaquin Valley, trace elements (e.g. Se, Mo, B) are also found in drainage water and their presence have added a new dimension to the management of agricultural drainage effluents (van Schilfgaarde, 1990). Since the closure of the master drain in 1986, use of saline drainage water for irrigation is one of only a few on-farm water management options available to growers in this area as a temporary means of reducing their effluent volumes (San Joaquin Valley Drainage Program, 1990).

The concept of drainage water reuse through agroforestry (i.e. eucalyptus) has been promoted as part of an environmentally-sound method for the reduction of saline drainage effluents (Cervinka, 1994). The drainage water reuse concept advocates sequential use of drainage water on progressively more salt-tolerant crops where application of concentrated effluents to eucalyptus trees is the next to the last crop, preceding halophytes, in the sequence. Eucalyptus trees have been found to reduce dryland salination in areas cleared of native vegetation in western Australia (Bari and Schofield, 1992). Revegetation with eucalyptus trees reduces ground water recharge and lowers saline-water tables thereby reducing salinization of the upper portion of the soil profile (Morris and Thomson, 1983). However the effectiveness of eucalyptus trees in reducing drainage volume is dependent upon their long-term ability to tolerate high levels of salinity and boron.

Over the past decade, eucalyptus plantations have been established throughout California's San Joaquin Valley. Often the poorest or most problematic fields such as those with high saline water tables or those that are poorly drained are selected for the eucalyptus trees. *Eucalyptus camaldulensis* has been an attractive species due to its relatively high tolerances to salinity (Donaldson et al., 1983; Marcar and Termaat, 1990) and waterlogging (Marcar, 1993; van der Moezel et al., 1988). The extent to which eucalyptus can reduce drainage volumes depends on maintaining high rates of evapotranspiration (ET). In non-stressed environments, the literature reports crop coefficients (K_c) for a full cover of eucalyptus trees between 1.2 to 1.5 (Stribbe, 1975; Sharma, 1984). However at one site in the San Joaquin Valley where *E. camaldulensis* was irrigated with saline drainage water (EC = 10 dS/m and 12 mg/L B), evapotranspiration was estimated using two energy balance methods and K_c value was 0.83 (i.e. ET of eucalyptus was 0.83 of the reference crop ET) (Dong et al., 1992). This lower K_c value was attributed to combined salt and B stress.

Salt tolerance information is readily available for conventional crops (Maas, 1993); and crop-water production functions for irrigation management with saline waters have been estimated for several crops (Letey and Dinar, 1986). Basic information on boron and salt-tolerance, water use, and ion distribution within the tree has not been adequately determined for irrigated eucalyptus. The specific objectives of this study were to determine crop-water production functions for the eucalyptus trees under different salinity and B treatments and characterize these over time; to determine ion-loading characteristics of a selected eucalyptus genotype; to determine the allometric relationships of the shoot parts to biomass; and to identify ion interactions that may contribute to foliar injury.

METHODS:

This experiment was conducted in 24 lysimeters (1.5 m x 3 m x 2 m deep) filled with a Lytle Creek sand having an average bulk density of 1.2 Mg/m^3. At saturation, the sand had an average volumetric water content of 0.34 m^3/m^3. Each tank was irrigated with solutions prepared in an individual reservoir (1.5 m diameter x 2.2 m deep) having a volume of approximately 4000 L. The salt solutions were pumped once daily from the reservoirs to the tanks and then returned to the reservoirs through a subsurface drainage system at the bottom of each sand tank. Total evapotranspiration from each tank was measured at maximum drainage every 24 h with an electronic water level detector installed in each reservoir. Water lost by evapotranspiration was replenished automatically each day to maintain constant osmotic potentials. Micrometeorological data including sand and air temperature, photosynthetically active radiation, relative humidity and wind velocity were recorded with a Class I agrometerological station installed at the experimental site. To estimate transpiration, the evaporation component of the total ET measured as a function of irrigation osmotic potential was measured in a plot without plants.

Two eucalyptus saplings (*Eucalyptus camaldulensis* Dehn., Clone 4544), 84.04 (± 0.27) cm high, were planted to each tank on 15 Jun 1995, and were irrigated with nutrient solution until trees were approximately 2 m in height (21 Sep) at which time treatments began. Simulated saline-drainage treatments consisted of nutrients with variable amounts of B and/or salts added to the solution in amounts characteristic of drainage water in the San Joaquin Valley. Sodium and sulfate were the dominant ions in the salinized treatments but the salinizing solution contained other common ions in typical soils as predicted by concentration-dependent solubility, absorption, desorption, and precipitation reactions (Simunek and Suarez, 1994). There were 6 salinity treatments (EC_w 2, 6, 10, 15, 22 and 28 dS/m) and 6 boron treatments (1, 4, 8, 15, 25 and 30 mg/L). The experiment was designed as a two-way factorial with partial replication. The extreme treatments were replicated as were several of the intermediate treatments. Surface regressions and two-way ANOVA analyses were performed on the data.

Trees were routinely measured for height, trunk, main branch, and primary-stem diameter as well as percent canopy cover. One tree was harvested on 1 May 1996, and used to determine the effects of treatment on the allometric relationships of the plant parts to biomass. The main trunk of the remaining tree was cut at the halfway point between the top and the lowest branch of the canopy. On 25 November 1996, the remaining tree was harvested. Allometric relationships were used to estimate plant foliar biomass based on trunk and branch diameters (Burton et al., 1991; Gower and Grier, 1989). Visible symptoms of phytotoxicity (chlorosis, dehydration, necrosis, leaf drop/death) were recorded and tissue samples were collected routinely and analyzed for mineral content (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, B, P, and S).

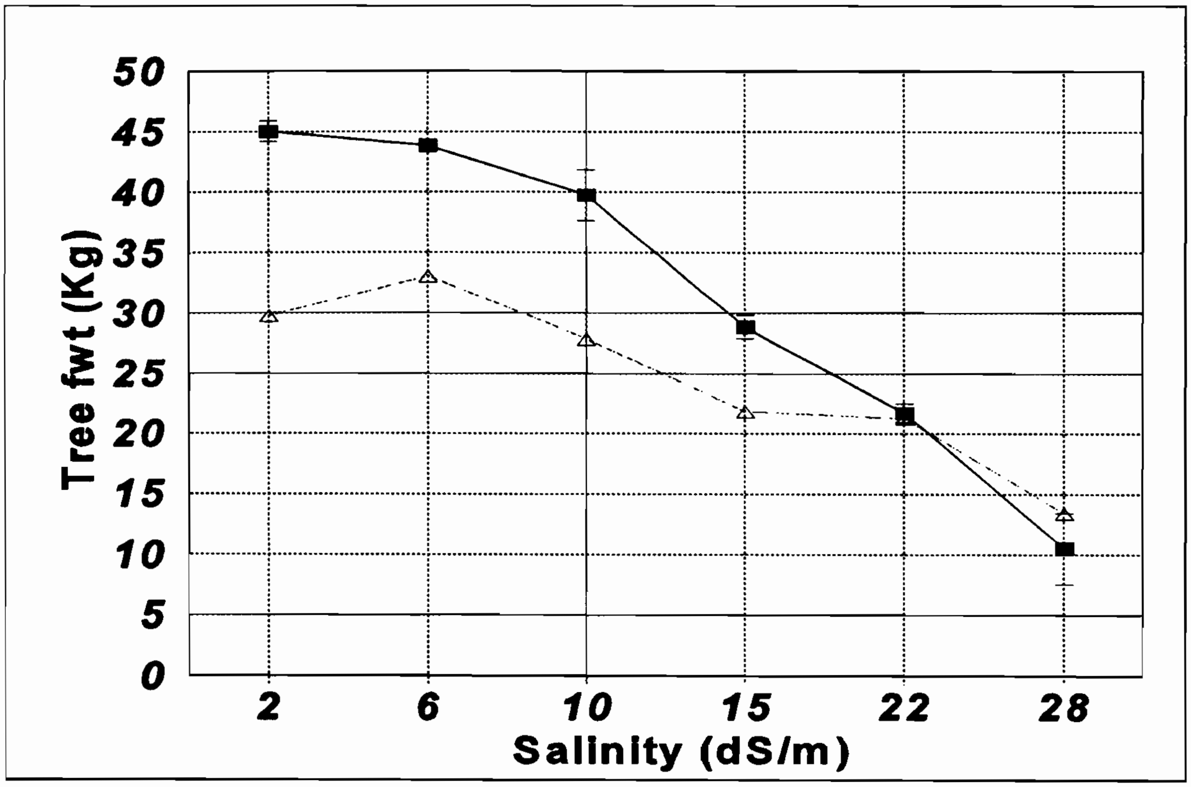
RESULTS AND DISCUSSION

Salinity reduced biomass yield, tree height, total leaf area, branch number, and leaf fresh weight of eucalyptus trees. Total biomass of harvested trees in May 1995, ranged from 12.05 kg to 2.28 kg. Salinity effects on biomass, total leaf area, branch numbers, and leaf fresh weight were highly significant and boron effects were significant on biomass reduction and reduced leaf fresh weight. Interactions were not consistently significant across all salinities. Total leaf areas ranged from 133,422 to 19,955 cm^2 and leaf weights varied from 4783 to 845 g/tree across treatments. A non-linear crop response model described by van Genuchten and Hoffman (1984) was used to fit the relative yield data. In earlier greenhouse studies, the salinity at which a significant decline in vegetative growth occurred for Clone 4544 (threshold) was about 7 dS/m and a 50 percent yield decline occurred at about 22 dS/m (unpublished). Preliminary analysis of final harvest data in the outdoor lysimeters indicated that the threshold salinity was approximately 8 dS/m and 50 percent vegetative yield decline occurred around 22 dS/m (Figure 1). For the purposes of these analyses, salinity treatments with B levels of less than 25 mg/L could be pooled because there were no significant differences due to B in total fresh weights. Coefficients of variation within salinity treatments with B < 25 mg/L were no more than 0.05. However, the effects of B levels of 25 and 30 mg/L were significantly different at salinities below 22 dS/m (Figure 1).

According to the guidelines by Ayers and Westcot (1985), *E. camaldulensis* falls within the moderately-tolerant to tolerant range. Classification of our data is indirect since salt-tolerance is usually reported as a function of EC_e. Our data are reported as EC of the soil solution. If a 2:1 approximation between EC soil water and EC_e (Ayers and Westcot, 1985) is assumed, our data also indicates that *E. camaldulensis* is moderately-tolerant to salt. Marcar and Termaat (1990) also evaluated the salt-tolerance of *E. camaldulensis* using sand cultures and reported that both 100 mol/m^3 NaCl and nutrient solution concentrated to an equivalent osmotic potential reduced shoot growth by 35% . In our study a similar salt level (i.e. EC_w = 10 dS/m) reduced shoot growth by only 12%. The differences in studies may be due to lower leaching fractions used in the study by Marcar and Termaat (1990).

There was a linear relationship between tree height and plant girth but the slope and parameterization of the relationship varied with time as the trees grew. In mid-December 1995, tree height ranged between slightly more than 2 m to almost 3.5 m. By mid-April 1996, tree height ranged from just under 3 m to almost 5 m, whereas; girth ranged from 6 to 14 cm.

Figure 1. Effects of salinity and boron on the vegetative growth of *E. camaldulensis*, Clone 4544. (■, B < 25 mg/L; Δ, B = 25 to 30 mg/L; bars above and below low B treatments indicate standard deviation from the mean.)



Although biomass was reduced by high boron under low salinity, the effects of B were not as dramatic as salinity increased. This observation was also noted with respect to damaged leaves due to boron toxicity. The most damaged leaves based on visual symptoms were those under less saline, high boron treatments. Leaf boron concentrations varied with boron treatments within a given salinity level; however, highest concentrations (>1000 mg/kg) were at the lowest salinity (Table 1). Analysis of leaf samples taken in December 1995, indicated that there is a strong interaction between salinity and boron in the irrigation water on leaf B accumulation. Increasing B in the irrigation water from 1 to 25 mg/L at 2 dS/m increased leaf B from 152 to 1043 mg/kg dry weight. This is nearly a 7-fold difference. However at 22 dS/m, leaf B concentrations increased only about 4-fold. Salinity apparently has a strong influence on reducing leaf B.

From the data collected so far it is impossible to determine how salinity is reducing B uptake. Salinity has substantially reduced transpiration so it is possible that the net flux of B from the root to the shoot is also reduced. Calcium additions to the substrate have been shown to decrease leaf B concentrations (Gupta and MacLeod, 1981) as well as alleviate B toxicity in *Prunus* species (El-Motaium, 1993). Evidently Ca increases B retention in root tips thereby reducing translocation to the stem and leaves and it is likely that B and Ca are quantitatively associated with each other in cell wall material (El-Motaium, 1993).

The older leaves of trees treated with high concentrations of B and low levels of salinity showed injury characteristic of B toxicity. Injury began to show as dark red color (anthocyanins) on the tips and margins and those portions of the leaves began to burn as injury became more acute. Injured leaves were separated into anthocyanotic, burned and uninjured tissue. In leaves that showed anthocyanins and no burn, the B in the anthocyanic leaf margins were about twice that of the uninjured tissue. In the burned leaves, the burned margins of the leaves contained nearly twice the amount of B as anthocyanic margins but their uninjured portions were about half the concentration as the uninjured leaves only showing anthocyanins. Although data are limited as this time, it appears that B in the middle uninjured portion of the leaves continues to move out towards the tips and margins as injury becomes more severe.

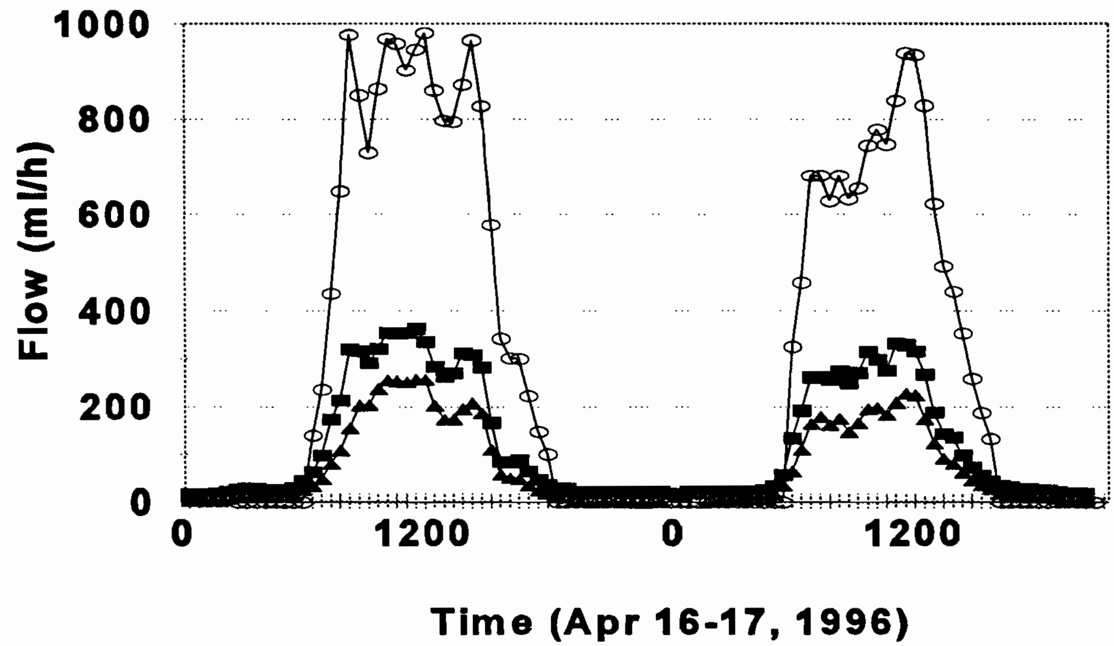
Table 1. The effects of salinity and boron on B accumulation in the leaf samples of *E. camaldulensis*, Clone 4544. Values in mg B/kg dry weight. (nd = no data)

Salinity	Boron					
dS/m	1	4	8	15	25	30
2	145	nd	312	nd	1043	nd
6	nd	199	nd	452	nd	839
10	138	nd	272	nd	709	nd
15	nd	145	nd	291	nd	906
22	110	nd	251	nd	433	nd
28	nd	142	nd	210	nd	376

Water Use Measurements. Data on cumulative water use indicated that salinity had a profound affect on evapotranspiration. Evapotranspiration in December 1995, from tanks with trees irrigated with 28 dS/m water was nearly half that from trees irrigated with non-salinized nutrient solution. Since cumulative evapotranspiration is directly linearly related to biomass (Howell, 1990), a 50% reduction in cumulative ET translates into a 50% reduction in the growth rate of the tree. High B has a lesser effect on cumulative water use.

Efforts were made to calculate sap flow using heat balance methods (Baker and van Bavel, 1987). Insulated thermocouple gages were attached around the trunk, approximately 75 cm from the base of the tree and sap flow was measured by a heat balance method with values averaged every 30 minutes. Gages were attached to the nonsaline treatment without boron and to the high salinity treatments with and without boron. Sap flow was measured for a period of two weeks. Data for the dates of April 16 to 17, indicated that flow rates calculated on an hourly basis were higher in the nonsaline treatment than that in the high salinity treatments and that there was a measurable difference between the high salinity treatments due to boron (Figure 2). The tree with high salinity, high boron had lower daily water use rates than the salinized tree without boron.

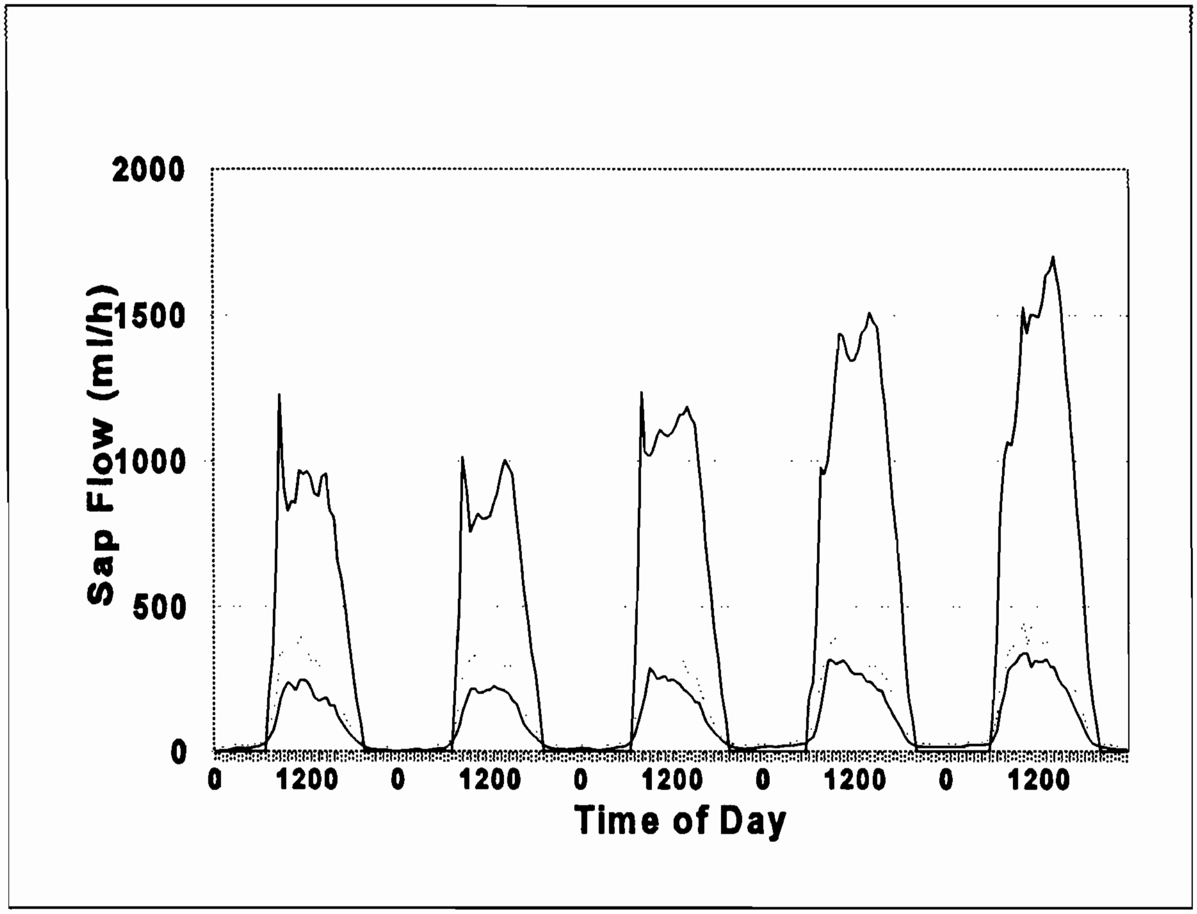
Figure 2. Sap flow measurements of eucalyptus trees grown low salinity, low boron (•, 2 dS/m, 1 mg B/L), high salinity, low boron (■, 28 dS/m, 4 mg B/L), and high salinity, high boron (▲,).



Over a longer time period, from April 20 through April 24, daily variations were noted due to environment, but the relative water use rates, from dawn to dusk were significantly different among treatments (Figure 3). When accumulative water use measurements based on water replenishment were compared to calculations based on sap flow, it was found that sap flow under-estimated water use by a factor of 2 to 3 under nonsaline conditions and by a factor of about 25 percent under saline conditions.

Future efforts will be directed to correlate leaf surface areas to evapotranspiration and weather data in these studies. Allomeric relationships will also be determined. These preliminary data indicate that salinity reduces both plant growth and consumptive water use in eucalyptus and that this species classification as a moderately tolerant agroforestry crop is correct. In perspective, *E. camaldulensis* is not as salt tolerant as barley, cotton, sugarbeet, Bermudagrass, wheatgrass, or date trees. The benefit of eucalyptus to agroforestry situations involving the reuse of drainage waters, may be in that the crop can be grown over several years without replanting and that trees can extract water from lower depths. The economic value of growing eucalyptus should be evaluated against species with higher salt tolerance and greater market potential.

Figure 3. Water use of eucayptus over a five-day period, from April 20 to 24, 1996.



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Potential Suitability of Specialty Crops for Saline Drainage Water Reuse Systems

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California is a leading, year-round producer of leafy vegetables. Although information on tolerance of leafy vegetables to chloride-based salinity is available to a limited extent, yield response to sulfate-based salinity is generally lacking. Certain vegetables species belonging to families whose members exhibit salt tolerance could fill an economic niche in drainage water reuse systems where moderate tolerance to salinity is required. Pak Choi, mustard greens, kale, orach, spinach, and New Zealand spinach were grown in outdoor sand tanks at the US Salinity lab and were irrigated with 6 different salinity levels. Salinity treatments were imposed at three different planting dates (31 Jan. - 4 March). In general, C50 values, the predicted soil salinity where a 50% reduction in yield occurs, decreased with later planting dates. The chenopods, spinach and orach were less affected by increasing salinity compared to the other four. C50 values for these chenopods ranged from 15.6 to greater than 25 dS/m, respectively.

LESQUERELLA AN ALTERNATIVE INDUSTRIAL OILSEED CROP

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INTRODUCTION:

Farmers in many areas of the U.S. are faced with changes in markets for traditional crops, increased farm production costs, and decreased yields due to continuous cropping. Cotton is the primary crop grown on irrigated lands in most of the southwestern U.S. Grain sorghum or small grains are sometimes rotated with cotton. Unless these crops can be sold locally, freight costs prohibit marketing out of the area and they are plowed under as green manures. Recent disease problems have also hampered some of these markets. Farmers in other parts of the country face similar situations. Alternative crops are needed to provide diversification for the marketplace and for crop rotations.

An industrial oilseed crop being developed for potential commercialization is *Lesquerella fendleri* (Gray) S. Wats., Brassicaceae. This species is native to the southwestern U.S. and has a hydroxy seed-oil similar to oil from castor. Most known species of *Lesquerella* are native to the U.S. and all contain one of three different types of hydroxy fatty acids (HFA) in their seed-oil. Hydroxy fatty acids have applications for lubricants, paints and coatings, plastics, nylons, oleochemicals, emulsifiers, and cosmetics. Important coproducts from lesquerella seed include gums from the seed-coat, seed meal for animal feed, and glucosinolates.

The unique seed-oil of lesquerella was first identified in the 1960's at the USDA, ARS, National Center for Agricultural Utilization Research (NCAUR), Peoria, Illinois, where the three types of hydroxy fatty acids were named and characterized. Agronomic studies and breeding of lesquerella began in 1985 at the USDA, ARS, U. S. Water Conservation Laboratory (USWCL), Phoenix, Arizona. Others from state universities, private industries, and other federal agencies have since been involved and significantly contributed to crop development. The purpose of this paper is to provide an overview in the developments of *L. fendleri* for potential commercialization and discuss other species of *Lesquerella* that may also have potential for domestication.

BIOLOGY AND CULTIVATION:

Commercialization interests are presently focused on *L. fendleri* because of its growth and productive yield characteristics. It is a perennial plant although grown in cultivation as an annual crop. Native populations are found throughout Arizona, Colorado, New Mexico, Texas, Utah, and northern Mexico. Seeds are contained in capsules or pods, referred to as siliques. Each capsule normally contains between 6 and 25 seeds. Seed weight varies between 0.5 and 1.2 g/1000.

Lesquerella grows best in production on well drained soils. Planting is accomplished by direct seeded with a broadcast planter such as a Brillion used to sow alfalfa. Sowing the seed by aircraft has also worked successfully. The most critical element for a good plant stand is keeping a moist soil surface to allow germination. Emergence occurs 8 to 14 days after planting. Seedlings remain very small until early February in Arizona when temperatures start to increase. Rapid vegetative development takes place and full soil cover is attained within two months. Recommended seeding rates are between 6 and 8 kg/ha. Seed preconditioning treatments of gibberellic acid and potassium nitrate were effective in reducing seed dormancy, and improving rate of germination.

Lesquerella has been successfully cultivated on both raised and flat fields. There are tradeoffs between the two field setups. Salts may be better managed on raised beds depending on the farms irrigation capabilities. Germination is restricted with high salt concentrations. However, flat fields facilitate harvesting and conserves soil moisture. Planting is best in Arizona the first two weeks of October. Texas and New Mexico are better seeded by the end of August until mid-September.

Flowering begins in February and seeds develop and mature between March and late May. In the field, bees or other pollinators are necessary for seed-set. To obtain optimum seed yields for large plantings, bees have been supplied during the flowering stage.

Nitrogen fertilizer applied at rates of 60 to 120 kg/ha resulted in increased dry matter and seed yields. A good strategy for irrigation scheduling of lesquerella in Arizona is to irrigate about once every 15 to 20 days starting in late February through mid-April, then once every 10 days between late April through May. The seasonal water requirements range between 20 and 30 inches per season.

Irrigation is stopped in mid-May and the plant is allowed to dry until seed moisture has reached about 12% before harvesting. Plants are harvested from mid to late June to avoid rainstorms. Chemical termination has been used successfully to allow plants to dry faster in the field, and earlier combining. Conventional combines with suitable sieves are used for seed harvesting. Seed losses can be as little as 5% with properly equipped and operating combines. Seed yields of 1800 kg/ha have been obtained in breeding test plots. Large scale field trials have yielded about 900 kg/ha.

Weed control studies have been conducted in Texas and Arizona. Based on lesquerella tolerance and weed control, the following herbicide treatments are recommended for use in production: Treflan (preemergence) at 1.5 to 2.5 pints per acre, Goal (postemergence) at 2.5 pints per acre, Fusilade (postemergence) at 8 to 16 ozs per acre, and Cyclone / Starfire (preharvest desiccant or harvest aid). The treatments are registered in Texas and Arizona to meet a special local need pursuant to Section 24(c) of the Federal Insecticide, Fungicide, and Rodenticide Act for nonfood use.

GERMPLASM EVALUATION AND BREEDING

There are no major barriers to domestication of this plant. The goals of our breeding program are relatively simple and aimed at increasing various yield related components that remain stable over different environments. We have collected germplasm from across the U.S. of *L. fendleri* and other species and evaluated it. Originally, germplasm available to our breeding program was from relatively few accessions, and did not represent the geographical range of the species. These new collections benefit breeding by producing new variability from which to select.

Other species of *Lesquerella* also have potential to be domesticated in the future as sources of one of the other HFA, or as another source of lesquerolic acid for other geographic locations where *L. fendleri* is not adapted. Since 1993 we collected accessions of 52 different species of *Lesquerella* and accessions of 19 species of *Physaria*, a genus closely related to *Lesquerella*. Many of these have not been previously included in the National Plant Germplasm System. Some are on Endangered Species lists. Most accessions have only small amounts of seed from the original collection. Over the 1994-1997 growing seasons, we increased seed amounts and evaluated them by planting in caged field plots supplied with honey bees to prevent cross-pollination between accessions.

The most important criteria for domestication of any of these species, is seed productivity and ability to be grown as an annual crop. Many species have higher oil contents or lesquerolic acid contents than *L. fendleri*. However, if these two criteria are not met, it is unlikely they could be considered as potential crop candidates. This eliminates many *Physaria* species. Valuable traits may be transferred from them and used in breeding. Other species being considered for development are *L. auriculata* and *L. globosa*. Further evaluation will be necessary.

Increases in oil and fatty acid contents have been achieved through recurrent selection populations. The first improved germplasm lines were submitted for official release in Fall of 1996. These were developed from three generations beginning in 1992-1993 growing season with bulk seed of *L. fendleri*. WCL-LO1 has a seed-oil of about 26% compared to standard bulk populations averaging 22 to 24%. WCL-LH1 has a lesquerolic acid content (C20:1-OH) of about 55% compared to standard bulk populations of 51 to 54%. WCL-LY1 has lesquerolic acid yield of 16% (oil content multiplied by lesquerolic acid content) compared to standard bulk population of 11 to 13%. Small quantities of seed will be available for distribution.

Within these populations we are concentrating on selecting for other desirable characteristics such as autofertility and upright growth habit. Autofertility is important since it would eliminate the expense of supplying bees in the field to improve seed-set. Variability for this trait is present within the available germplasm. Upright growth habits would improve combine harvesting efficiency.

Yellow seed coat lines are also being developed with the prospect of use in the cosmetic industry. Oil from seed with normal orange-brown seed-coats has a pigmentation that must be removed for their applications. The yellow seed-coats may have less or no pigmentation and could eliminate the extra processing step. A yellow seed coat line should be ready for official release by the end of the 1996-1997 growing season.

CONCLUSIONS:

Many environmental and economic benefits can result from the commercialization of lesquerella including: (1) decreased dependence on imports, (2) developing new industrial products from renewable raw materials, (3) expanding market opportunities for farmers, (4) providing economic opportunities for rural communities, and (5) providing plant diversification. Lesquerella has progressed in development in a relatively short time. This crop could be on farmers fields within the next five years.

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IS THERE A PLACE FOR HALOPHYTES IN IRRIGATED AGRICULTURE?

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INTRODUCTION:

The potential of using halophytes as irrigated crop plants has received increasing attention during the past two decades (O'Leary, 1994; O'Leary and Glenn, 1994; Choukr-Allah et al., 1996). Much of that interest has centered around direct use of seawater for irrigation, especially in developing countries, but there may be a role for halophytes in conventional irrigated agriculture. Selection for, and improvement of, agronomic characteristics will undoubtedly be required before any halophyte becomes a commercially successful crop, but some of them already possess several characteristics that make them attractive candidates for use as irrigated crop plants. Those characteristics and the encouraging results of the limited research so far in domesticating halophytes are discussed below. However, there are potential problems associated with use of halophytes as crop plants, and those problems are discussed as well.

EXTENT OF THE RESOURCE BASE:

The name "halophyte" does not designate a member of any specific taxon. The word literally means "salt plant" and is used to refer to any plant that is capable of growing and reproducing in areas subject to high salinity during all or a substantial part of the time. The definition of "high salinity" is somewhat subjective, but most people consider a salinity equivalent to about 0.5% NaCl in the soil water as a rough approximation of the lower end of the high salinity range. Based on that definition, there are over 1500 species in at least 117 families that can be called halophytes. With 312 species, the Chenopodiaceae family accounts for about 20% of the total number of halophytes. Members of this family include *Salicornia* and *Atriplex* as well as beets and spinach. Halophytes occupy the complete range of terrestrial environments from coastal marshes to arid deserts (Flowers et al., 1986). So far only a relatively small number of halophytes have been investigated for their potential as irrigated crop plants.

PRODUCTIVITY:

The dry matter productivity of several halophytes, even when irrigated with highly saline water, is similar to that of conventional forage crops irrigated with fresh water. Most of the high producers are members of the Chenopodiaceae, but a few grasses have relatively high productivity as well. Halophytes typically have high salt or ash content, so dry weight yields often overestimate the true organic matter productivity. Nevertheless, even when corrected for ash content, some of the yields still are high enough to be considered within the range of "good" agricultural yields for forage.

NUTRITIONAL VALUE:

In general, a high content of crude protein, nitrogen-free extract, calcium and phosphorus, combined with a low fiber content, indicate high feeding value for ruminant monogastric animals, and halophytes such as *Atriplex* rate relatively well in this regard (O'Leary, 1988; Watson, 1990). In conventional forage crops such as alfalfa, crude protein ranges from 15 to 30% (Hartman et al., 1981). Some *Atriplex* species have been reported to have crude protein values ranging from 13 to 20%, at least in leaf material (O'Leary et al., 1985). This may be an overestimate of the true crude pretein level, however. Crude protein values typically are calculated values based on the assumption that all of the Kjeldahl-N is protein nitrogen, but halophytes often contain substantial amounts of other non-protein nitrogen such as proline and quarternary ammonium compounds. Another consideration is that most of those reported values are from plants in small experimental plots where the material was harvested by hand and consisted of largely, if not entirely, leaves. However, when plants are harvested using conventional farm practices and equipment, the sample of cut and baled forage consists of both leaves and stems, and stems can account for as much as 50% of the harvested biomass (Watson et al., 1987). When crude protein levels were determined for several *Atriplex* species grown on a commercial farm and mechanically harvested, the values ranged from 7 to 13%. The fiber content of *Atriplex* is comparable to alfalfa. In fact, a comparison of 8 different families of forages revealed that the Chenopodiaceae had the lowest fiber content (Larin, 1947).

As mentioned above, halophyte biomass typically has high salt content, which reduces the usefulness of the halophyte forage as animal feed. The high salt content limits the amount of the halophyte forage that an animal will voluntarily consume. Most animals will only eat enough to provide the daily maximum tolerable salt intake, after which they just stop eating. This problem can be overcome by blending the halophyte forage material with other feed components. Some halophyte foliage contains saponins, oxalic acid, or other secondary compounds that reduce palatability, or even act as growth inhibitors in ruminants. Many of these compounds can be counteracted, at least partially, by addition of materials such as cholesterol to the feed mix.

USE AS SEED CROPS:

The seeds of halophytes do not accumulate any more salt than seeds of glycophytes, even when the foliage may contain extremely high levels of salt. In *Salicornia*, for example, when the shoot tissue has salt content of about 50% of the dry weight, the seeds of those same plants contain only about 5% of the dry weight as salt. Thus, halophytic seed crops are particularly attractive. *Salicornia* has been investigated as a potential seed crop for irrigation with seawater on desert seacoasts, for example (Glenn et al., 1991). When irrigated with seawater in plots on the Mexican coast, the 6-year mean seed yield was 2,000 kg/ha (1,800 lbs/acre). The seeds not only have a high protein (30%) and oil content (28%), but the linoleic acid level in the oil is about 75%. That high content of unsaturated fatty acid makes the oil particularly attractive for use as a human food.

A few other halophytes have been investigated as potential seed crops also, such as saltgrass, *Distichlis palmeri*. Seeds of that plant resemble wheat in size and composition, and preliminary results of milling, baking, and taste tests indicated that products baked from *Distichlis* flour compared favorably with products made from wheat flour. A disadvantage of this species is that it is dioecious, which means that only about half of the plants in a field would be seed-bearing. On the other hand, it is perennial, which means that it might be possible to harvest several crops from a field, once established, without planting every year.

CONCLUSIONS:

The halophyte flora of the world contains a wide range of plant types, monocots and dicots, annuals and perennials, woody and herbaceous, and they are adapted to a wide range of habitats. Thus, this represents a relatively underexploited resource, from the standpoint of providing crop plants. So far, based on the relatively small percentage of those plants that have been investigated, it is clear that reasonably good biomass yields can be obtained from halophytes when irrigated with highly saline water. The potential use of that biomass as an animal feed is constrained by the high salt content of the foliage, however. The high salt content is not a problem in seeds of those halophytes, though, so seed crops may be the most likely types of crops to be successfully developed from halophytes. There are problems to be overcome in that regard also. Uneven seed ripening and shattering are characteristics of most halophytes, so selection and breeding probably will be required before a halophytic seed crop will be commercially successful.

In addition to the above considerations, the soil/water management aspects of irrigating halophytes will be a limitation to where such crops can be successfully grown. In its simplest terms, the dilemma facing a halophyte farmer is as follows. It would be desirable when using highly saline irrigation water to have a soil that is very permeable, to insure adequate leaching. However, those soils that are permeable enough to prevent salt accumulation when irrigated with highly saline water will have low water-holding capacity, so irrigation frequency will have to be high, especially in a hot, dry environment. Also, soils that do not retain much sodium and chloride won't retain much nitrates, phosphates and other desirable ions. Therfore, fertilzer applications may have to be frequent as well. These problems would be mitigated by having a soil with a higher water-holding capacity, but the problem of salt accumulation becomes more likely with such a soil. Thus, should the halophyte farmer strive for a soil high in sand and low in clay or vice versa? Where along this continuum is the satisfactory combination?

All of these problems can be overcome with sufficient effort. The potential for successful cultivation of halophytic crops, irrigated with highly saline water, and production of adequate commercial yields is high. When conditions such as resource availability indicate the need for such crops, in particular areas, they will be available. However, anticipation of those needs well in advance is important in order to have sufficient time to conduct the required selection and improvement of the halophytes best suited for that situation, as well as addressing the other required steps mentioned above.

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Impact of Alternative Crops on Salt Disposal Strategies

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Salt is the focus of this paper. Particularly, its management along the westside of the San Joaquin Valley between Mendota and Wheeler ridge where approximately one million acres are irrigated with water from the California Aqueduct and from ground water. Approximately two tons of salt are applied annually to each acre of irrigated land and it is disposed of in the underlying soil strata and groundwater. Surface disposal of salt occurs in about 2000 acres of evaporation ponds. These ponds serve about 20,000 acres of irrigated lands with tile drainage, or about 2% of the irrigated area. Consequently soil salinity continues to increase in the irrigated soils and underlying soil strata and groundwater, and shallow, saline water tables continue to pose a problem for the lower lying lands.

Recent reductions in water allocations by Federal legislation encourages the continual use of groundwater to supplement surface water supplies in this land-locked region. Although pumping groundwater will help control problems with shallow water tables, the more that is pumped, the faster it will be salinized. Eventually the groundwater will become too saline to irrigate the commonly grown crops in the region.

The following options could extend the lifetime of the groundwater:

- Importing more water.
- Revising irrigation and drainage water management practices.
- Reducing the irrigated acreage.

Developing new surface water supplies to reduce groundwater usage seems a logical option were it not for the unresolved salt disposal problem. For example, routing wastewater from large metropolitan cities into the San Joaquin Valley is under consideration. However, without a long term plan to export salt from the region, importing more water and the salt it contains increases the salt problem. With regard to the second option in the previous paragraph, the time the groundwater would remain usable for irrigation would be extended by increasing the fraction of applied water used by the crops. This would also decrease the volume of saline drainage water generated by irrigation.

It will take 40-150 years (Quinn, 1991) for salinity levels in the unconfined aquifer to reach levels which will become too saline for irrigation. Once this occurs groundwater pumping will likely be needed to control water table depths. Consequently, there is a need to develop acceptable methods to export salt from the region, or to dispose it on the soil surface. Without some means of resolving the salt disposal problem, the irrigated area will decrease in the long run. That there is time to work on solutions before the salinity of the groundwater becomes a serious problem is the most positive aspect of the problem.

Methods to decrease drainage volumes and the area needed for surface disposal of salts would be a major step forward. Large evaporation ponds pose environmental problems to mitigate and manage the negative environmental impacts of selenium, a toxic element commonly found in drainage water in the region. An acre of evaporation pond annually evaporates about five acre-ft of water and commonly serves about 10 acres of tile drained land in the region. Irrigation of moderately salt tolerant trees and salt tolerant crops and halophytes with drainage water, would reduce its volume and increase its salinity (Cervinka, 199). This strategy may make it possible for one acre of evaporation pond to serve from 100 to 200 acres of irrigated lands.

Two terms, bioconcentration and evapoconcentration will be used during the rest of this paper. Their definitions are:

> Bioconcentration, the salinization of the soil solution due to crop water use and evaporation of water from the soil surface.
>
> Evapoconcentration, the salinization of water in evaporation ponds due to water evaporation.

Strategies of Crop and Land Management for Bioconcentration and Evapoconcentration.

The cropping and land management plan outlined in Table 1 allocates six acres of land to evapoconcentration in a solar evaporator. This area would serve as the salt disposal site for 620 acres of tile-drained lands. The assumptions used to prepare Table 1 follow: 1. The salinity of the drainage water from prime lands, lands irrigated with 2.5 acre-ft/acre of good quality water, will remain about 8 dS/m for some undetermined time. 2. Annual drainage discharge from prime lands equals 0.5 acre-ft/acre. 3. Tile drains intercept all the drainage water. 4. Salinities of drainage water from lands used for bioconcentration and irrigated with drainage water are steady with time. 5. A reduction in the average evaporation rate from the solar evaporator from 6.6 ft/yr to 5 ft/yr properly accounts for rainfall.

Drainage control in terms of timing and amount drained is a crucial aspect of the plan. Without control, the largest drainage rates generally occur during late fall and winter, a time when crop water requirements are low and rain occurs. The impact of allowing uncontrolled drainage during this period on the land area required for bioconcentration could be very large. Little effective evaporation would occur from lands used for bioconcentration. During late fall and winter, the drainage flows need to be almost totally stopped and the soil used to store drainage water generated by irrigation and rainfall. Most of the drainage would need to occur from late spring through early fall. This would provide the needed leaching for salinity control, and it would lower the water table thereby creating the needed storage capacity in the soil for water generated by irrigation and rainfall during late fall and winter.

There is flexibility in the crops that could be grown on the lands used for bioconcentration. For option 1 (Table 1), 90 acres irrigated with 8 dS/m drainage water would be required for the first stage of bioconcentration. Cyclic irrigation with nonsaline and saline drainage water could be used to irrigated commonly grown agronomic crops which are at least moderately salt tolerant. The saline drainage water could also be used to irrigate perennial crops like moderately salt tolerant trees and salt tolerant forages. The second stage of bioconcentration would require about 20 acres dedicated to growing halophytic forages and other halophytes. This area would be irrigated with the drainage water (21 dS/m) generated by the first stage of bioconcentration.

A troubling aspect of option 1 is that annual drainage rates on the lands used for bioconcentration approach one acre-ft/acre during the growing season. This would require good water infiltration and redistribution through the soil. Not only is the inherent ability of the low-lying, fine textured soils in the region to conduct water often low, but the poor water quality of the drainage water could reduce the ability of the soil to conduct the water. Irrigation with saline-sodic drainage water will generate high levels of exchangeable sodium in the soil. Land management of the area devoted to bioconcentration will likely require the use of soil amendments (Oster, 1994), particularly if a cyclic irrigation strategy is used.

The second bioconcentration option (Table 1) has a much lower drainage rate; about 0.3 acre-ft/acre, during the growing season. This option would require growing crops that are capable of bioconcentrating an 8 dS/m irrigation water to 45 dS/m. Halophytes likely have such a capability. Salt tolerant forage crops may also be able to accomplish this. Work is currently underway at the U.S. Salinity Laboratory to determine whether common bermuda, seashore paspalum, and salt grass have this capability.

Combining source control with drainage control could reduce both the land area required for both bioconcentration and evapoconcentration. Reducing the annual drainage rate generated by the prime land from 0.5 to 0.25 acre-ft/acre would still provide the leaching required for an irrigation water with a salinity of 1 dS/m. If this drainage rate could be achieved, the acreage of prime land would increase from 500 to 550 acres, the area required for bioconcentration would decrease from 110 acres to 60 acres, and the acreage needed for evapoconcentration would decrease from 6 to 3 acres. Source control would involve any combination of crop, land, irrigation and drainage management options which increase the fraction of applied water that is used by the crop.

Reflections

The cropping and land management stategy in Table 1 does not take into account the following concerns and questions.

1. Salinity effects on crop water requirements. Crop water use decreases with increasing soil salinity (Letey and Dinar, 1986) when the average rootzone salinity, based on saturated-soil extracts, exceeds the threshold salinity of the crop.
2. Neither crop growth or water infiltration are uniform. Crop lands are often overirrigated to compensate.
3. Imperfections in farming and irrigation management could result in increased drainage.
4. Can salt tolerant crops and halophytes continually generate drainage waters that have salinities of 44-56 dS/m? The equivalent electrical conductivity of a saturated-soil extract taken from the soil located below the rootzone would range from about 25 - 32 dS/m.

5. Can drainage and source control achieve monthly drainage discharge rates which do not exceed the monthly evaporation rates from a free water surface?
6. Does irrigation of trees, forages, and halophytes with drainage water high in selenium pose an environmental hazard?
7. Can evapoconcentration rates be enhanced by spraying water into the air, or by enclosing the solar evaporator with a plastic shelter which may increase the efficiency of utilizing incoming solar radiation?
8. The salt in the evaporation basin could be a toxic waste because of the toxic elements it contains. Where will it disposed of after the basin is full?

Concluding Comments

If a one acre solar evaporator could serve 200 acres of irrigated land, it becomes reasonable to explore ways to enclose the solar evaporator within a plastic greenhouse and totally isolate it from its surroundings. There would be obvious advantages in terms minimizing environmental impacts on wildlife. Since it would be protected from rainfall, the evaporative capacity of the evaporator would be increased. Further increases may be possible if the plastic greenhouse would increase the utilization of solar radiation for evaporation of water. The final, unresolved problem would be the location for disposing the salts, which may be toxic wastes, that will collect in the solar evaporator.

With improved control of irrigation water coupled with drainage control, the associated land area needed for bioconcentration would be about the same as that need by existing evaporation ponds, about 10 % of the area served. The volume of drainage water requiring disposal would also be small, about 1.2 % of the volume of irrigation water. Perhaps the resulting volume would be sufficiently small to make ocean disposal financially feasible thereby eliminating the need for a solar evaporator.

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Cropping and land management plan: The 6 acre evaporation basin option.

Land Use Class	Crop Salt Tolerance Characteristics[1]	Area	Water Applied	Water Drained	Leaching Fraction	Drainage Water Salinity dS/m
			acre-feet			
Prime land						
all crops	S-T	510	1275	255	0.2	8
Bioconcentration: Option #1						
Stage 1. forages, trees, and cyclic strategies with grain and fiber crops	T	90	255	80	0.3	21
Stage 2, halophytes	T	20	80	30	0.4	45
Bioconcentration: Option #2						
Stage1. forages and halophyte	T	110	250	30	0.1	45
Evapoconcentration						
Solar evaporator		6	30			

Assumptions:

1. Prime land is irrigated with only canal water.
2. Salinity of drainage water from prime land is 8 dS/m, because of native salts in the soil.
3. Drainage discharge of 0.5 acre-ft/acre can be controlled in terms of both timing and amount.
4. Drainage water salinity has been corrected for precipitation of gypsum and calcite in the rootzone using an assumed composition typical to the westside of the San Joaquin Valley and steady state conditions.

[1] S --- Sensitive, T --- Tolerant

WHAT IS PESTICIDE RESISTANCE AND HOW DO WE DETECT IT?

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Pesticide resistance is a trait that an insect can inherit that allows it to survive a rate of pesticide that other individuals in the population can not survive. The survivor then passes the gene(s) for resistance on to the next generation. The more often the pesticide is sprayed, the faster the susceptible individuals are eliminated and the faster the proportion of resistant individuals increases in the population.

Insects and mites use several methods to resist pesticides. They may increase the number of enzymes in their bodies that can breakdown the pesticides, they may alter the enzymes in their bodies that the pesticides attack so that the pesticides don't recognize them, they may change their body so the pesticides don't penetrate very well, or they may change their behavior to avoid the pesticides.

If an insect develops resistance to one pesticide, it may develop resistance to a closely related insecticide even if it has not been exposed to it. We call this phenomenon cross-resistance. An example of cross-resistance is that when an insect population develops resistance to one pyrethroid it is usually resistant to all pyrethroids. Insects can also be resistant to two different pesticide groups because they use the same mechanism to detoxify both groups of pesticides. An example would be that most insects that developed resistance to DDT years ago develop resistance to pyrethroids very easily. Multiple resistance is when insects have several mechanisms to withstand the pesticides because they have been exposed to many different pesticides over many years time. Sadly, many of our key pests have developed multiple mechanisms of resistance to pesticides. This means that when new pesticides are introduced, the insects have one or more genes ready and waiting to resist the new pesticide.

What can we do about pesticides resistance? First, we can monitor for pesticide resistance in insects and mites using a bioassay. A bioassay means that we treat groups of living insects with a pesticide and then assess the amount of kill that results as we increase the concentration of the pesticide. There are many different bioassay methods used to detect resistance. Common methods include dipping or spraying foliage or fruit with the pesticide and then caging insects or mites on the treated plant material. Spider mite, aphid, and scale resistances are often monitored this way. Another method involves coating vials, bags, or plastic dishes with pesticides as is done for Lygus bugs and aphids. Still other researchers spray pheromone cards or yellow sticky cards with pesticides and catch the adults and evaluate their survival. These types of tests have been used for detecting codling moth and whitefly resistance.

Frequently, we find that the insects are using enzymes to resist the pesticides. If this is the case, we can create a biochemical test for resistance where we simply crush the insect on a paper or place it in a well in the presence of chemicals that react by producing a dark color if the resistance enzymes are present. These types of tests have been used for detecting pesticide resistance in mosquitos, aphids, and California red scale.

When we plot the response of the insect to increasing dosages of the pesticide, we use a log scale on the x-axis and a probit scale on the y-axis so that we can produce a graph with a straight line (Fig. 1). These lines allow us to compare different populations of insects. The LD_{50} is the most common measure of resistance and it is the dose of pesticide that kills 50% of the population. If a population has a low LD_{50}, then that population is easily killed and is susceptible. If a population has a higher LD_{50}, then it is hard to kill and has some level of resistance. The LD_{50} of one population should always be compared to the LD_{50} of a susceptible group of the same species of mite or insect. Sometimes it is difficult to find a susceptible population of the insect because the pesticide has been used for many years and most of the insects are resistant to it.

An alternative method for defining resistant populations of insects is to use a discriminating concentration. A discriminating concentration is the concentration of pesticide that kills nearly all the insects in a susceptible population and very few of the insects in a resistant population. To estimate the LD_{50} we need many insects because the population must be tested with five or more dosages of the pesticide. The discriminating concentration method is a faster way to detect resistance because you only need one concentration of pesticide and so fewer individuals to detect resistance. The discriminating concentration can help us detect the presence of resistance, but the LD50 method gives a more accurate assessment of how severe resistance is.

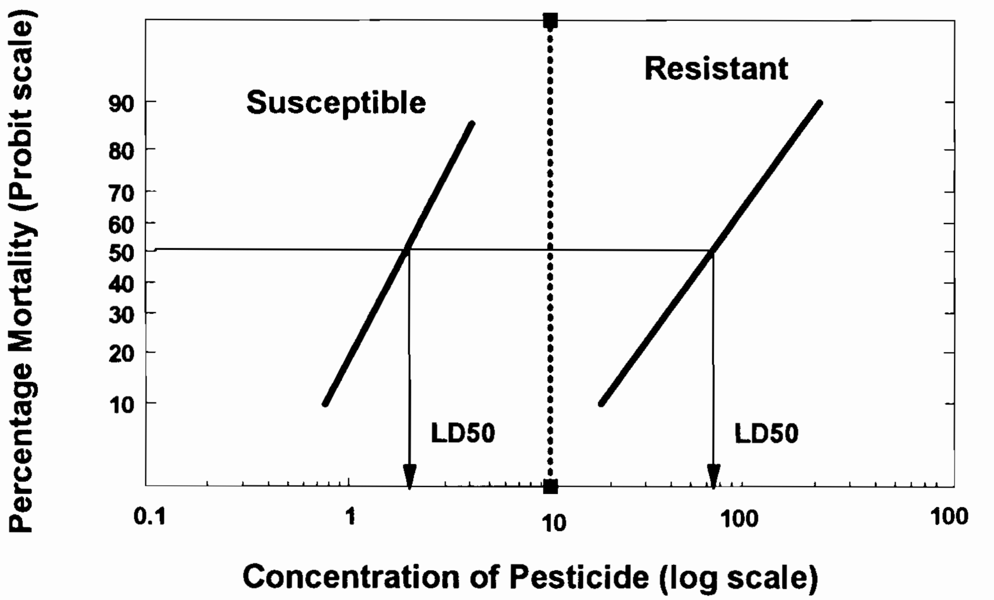
Once we detect resistance using a laboratory bioassay, we need to conduct field tests to find out what level of resistance in the laboratory corresponds with failure of the pesticide in the field. We can have some resistant insects but still achieve some control of the pest with the pesticide in the field. This is because there are usually both susceptible and resistant insects in the field, and because we don't perfectly cover the crop with pesticides.

The reason we need to monitor for resistance is to detect pesticide resistance in the early stages and manage it before it is widespread and common. If a grower knows that the insects are developing resistance to a particular pesticide, the grower can switch to a pesticide with a different mode of action and delay the development of resistance to any one pesticide. This is called alternation or rotation of pesticides. This will allow the pesticides to be used for a longer period of time because we keep switching the type of attack made on the insect population and make it hard for them to develop resistance. It is very important for the grower to understand which chemical classes each of the pesticides are in, in order to take advantage of their different modes of action. If resistance is widespread and/or all the registered pesticides have a similar mode of action, the grower needs to stop using the pesticides and depend more on biological control.

Pesticide resistance develops fastest under the following conditions; 1) resistance is inherited in a dominant fashion, 2) immigration of susceptible individuals that could dilute the resistance is low, and 3) the economic threshold is low and so the pesticide selection pressure is high. For example, in spider mites, resistance to miticides develops the fastest in crops such as roses and strawberries because the tolerance of the plant of damage is very low so the growers have to spray frequently. On the other hand, spider mite resistance to miticides has evolved relatively slowly because the resistance is not genetically dominant, so when susceptible mites move into the field the resistance is diluted. Insect pests frequently develop dominant resistances and move throughout large geographical regions resulting in widespread resistance.

In summary, simply stated, the more often a grower sprays, the faster resistance will develop. Therefore, growers must use nonchemical methods (biological and cultural) of pest control as much as possible and use pesticides as infrequently as possible in order to extend their useful life.

Figure 1. How pesticide resistance is represented graphically.



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INSECTICIDE RESISTANCE MANAGEMENT PROGRAMS : EXAMPLES FROM AROUND THE WORLD

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Maintaining agricultural production requires access to effective pest control materials. When insecticides are applied to pests, selection pressure is exerted resulting in a shift toward less susceptible individuals. Managing the insecticdes in a manner which extends the length of efficacy is the domain of resistance management.

Integrated pest management (IPM) seeks to minimize the necessity of costly, disruptive products through the use of careful sampling and evaluation of pests. When treatments are required to reduce a pest population, selection of the most appropriate insecticides is encouraged. Considerations include secondary effects on the environment, the crop, and non-target species as well as the need to preserve the existing arsenals of insecticides. The latter factor introduces the concept of resistance management.

Managing resistance in insect pests encompasses a broad range of activities. The term IRM fits into larger and wider context aimed at regional management through large, integrated regional projects. There are two major approaches to regional resistance management. First is limiting a product from being used on an annual basis and rotating the product through regions. An example of this approach is spider mite management in cotton of Zimbabwe. Here the cotton production is grown in three regions and growers voluntarily agree to rotate through three acaracides, each used only once every third year. This approach has successful maintained the efficacy of the products for more than 20 years.

Another more sophisticated approach are programs involving the alternation of materials (rotation through the season), restrictions of product or class of products except during critical periods, and close monitoring of the target pest.. The justification for such programs include:

- limiting the use of products only during critical crop periods, crop protection is afforded while selection pressure is removed, allowing for reversion to susceptible stages
- IRM works best when a region is brought under the program in order to assure that pest infesting multiple crops are not subjected to the protected products.

The best known example of this approach is the management of *Heliothus armigera* (bollworm) in Australian cotton. In 1983, pyrethoid resistance was noted in cotton and shock waves were felt throughout the industry. This key pest was managed almost entirely through the use of this insecticide class. To preserve these products, restrictions on pyrethoid and endosulfan were imposed. The season divided into time three periods. During the first period, endosulfan could be used, during the second pyrethoids and endosulfan could be used, and during the third, neither of the products could be used. This program was imposed across the entire region and **applied to all crops**, not just cotton. This program has had almost universal compliance and was successful in slowing but not stopping increased resistance in *H. armigera* from 1983 to 1993.

Similar programs are underway in Israel for *H. armigera* and *Bemisia argentifolia*, silverleaf whitefly. The key elements from program for silverleaf whitefly has been adopted by Arizona producers to manage this pest and resistance. Key to the success in Israel was the introduction of insect growth regulators (IGRs) which affected the insect in novel ways and limitations on existing insecticides. In 1996, Arizona took this concept and adjusted for their conditions. First, close field monitoring is required before any action can be taken. The IRM is divided into sections based on the population of silverleaf whiteflies. In summary the program required the following:

Stage	Insecticides	Thresholds for action
I	IGRs	0.5 - 1 large nymph/leaf disk AND 3-5 adults/leaf
II	Non-Pyrethoids	5 adults/leaf
III	Pyrethoid Mixtures	5 adults/leaf

Pyrethoids were held until late in the season and used only in combination with another insecticide class. There are restrictions on the number of products to be used in a season. The industry fully supported the approach and complied with its rules and the results from 1996 show great promise

Successful IRM programs have several key elements. These include:

- regional acceptance of the severity of the situation and
- regional compliance of the rules seeking to preserve key insecticides
- understanding of the mechanisms governing the resistance
- a program to monitor the level of resistance
- monitoring pest populations and treating only when the crop is threatened

Most resistance management programs are designed as stop gap measures to buy time while new approaches are being discovered. These approaches usually involve new insecticides with different modes of action. However, long term stability in a production region will require a basic IPM program to be followed in order to minimize the exposure of the pests to insecticides. This implies multiple control tactics, including a larger reliance on biological control and indigenous natural enemies. It requires as a complete understanding of the crop and the surrounding cropping systems as possible. This will require the development of long term strategies which seeks to integrate more biologically intensive approaches. These include

- balancing crop protection, economics, and yield
- regional approaches to managing biological resources such as natural enemies and their refugia
- increased awareness of the relationships of crop and pests with surrounding crops and through time

MONITORING RESISTANCE DEVELOPMENT IN SEED ALFALFA

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Pest management is perhaps the most difficult component of alfalfa seed production in California and other Western seed-producing states. There are few chemicals registered for use on seed crops which effectively control insect pests. Many chemicals have been lost either through changes in registration or due to insects developing resistance after a period of use. Lygus (*Lygus hesperus*) is the major insect pest limiting seed production. Other important insects include mites, stinkbugs, chalcid, and occasionally aphids.

Currently registered materials include Monitor, Capture, Carzol, Thiodan, Lannate, Lorsban, and Metasystox-R. Monitor is typically used as a "clean-up" material in late May to early June. Because this material is hard on pollinators, it cannot be used when honey bees are present in the field. Capture has also been used in some cases as a clean-up material, but it is safer for honey bees and is usually reserved for insect control during the pollination period. The number of Capture applications to a single field is limited, so growers may also use various combinations of the materials listed above depending on pest pressure.

With such a limited number of chemical alternatives for insect control in seed alfalfa, resistance management practices become critically important to extend the number of generations that pest populations can be controlled economically by a pesticide. One very practical resistance management practice is rotating the use of materials to other chemical families, for example rotating between a pyrethroid and an organophosphate. In order for growers to consider using alternate materials, they need to have some indication of efficacy. Bioassay techniques can be used to evaluate resistance levels and predict insecticide performance. Given this information, growers can make more informed choices with respect to materials for pest management.

A successful bioassay technique was developed by Bill Brindley at Utah State University to determine dose response regressions and LC_{50} values. The bioassay technique reported here is very simple. Small plastic ziplock bags are pretreated with solvent containing concentrations of insecticide bracketing expected residues for effective bioassays. Five to six treatment brackets, including the check, were included in all of the bioassays conducted. Each treatment was replicated 4 times. Treatment bags were stored in a freezer until taken to the field to conduct the bioassays. In the field, a small cork and alfalfa trifoliolate were placed in each bag. Adult lygus were collected by sweep net and 5 insects were placed in each bag. Bioassay bags were held at about 30°C (68-70°F) in a portable incubator. After 8 hours in the incubator, the lygus bugs in each bag were observed and mortality levels recorded. Regression analysis on each bioassay data set derived LC_{50}, slope, and r^2 values. The LC_{50} is the concentration of the material which kills 50% of the target population. A low value indicates susceptibility and a high value indicates resistance. The slope value provides an indication of the homogeneity of the sample population. Dose response screening of 100-120 adult lygus occurred with each bioassay. Bioassay test results need to be correlated with the performance of individual materials in the field.

Since the time Capture was first registered in 1991, growers were concerned about resistance development. Lygus populations could potentially be treated in cotton three times during a single season and in seed crops twice. Since the crops are grown in close proximity, it was possible that lygus populations could be exposed to up to five applications each year. In order to monitor the development of resistance, we began to conduct bioassays in area seed fields in 1990 and continue to the present. Information from growers regarding pesticide efficacy in the field was recorded along with bioassay information.

Although Metasystox-R (MSR) maintained its registration through the years, growers felt that it was no longer effective in controlling lygus in area seed fields due to the development of resistance. For this reason, MSR was selected as the "control" material for bioassays conducted in area seed fields. MSR bioassay results would not be expected to change from year to year since there was little or no selection pressure. MSR continued to be used extensively and successfully in the Northwestern seed producing states.

MSR and Capture bioassays have been replicated over several sites and years (Figure 1). LC_{50} values from 1990 indicate pre-treatment levels since neither MSR nor Capture were used prior to this sampling.

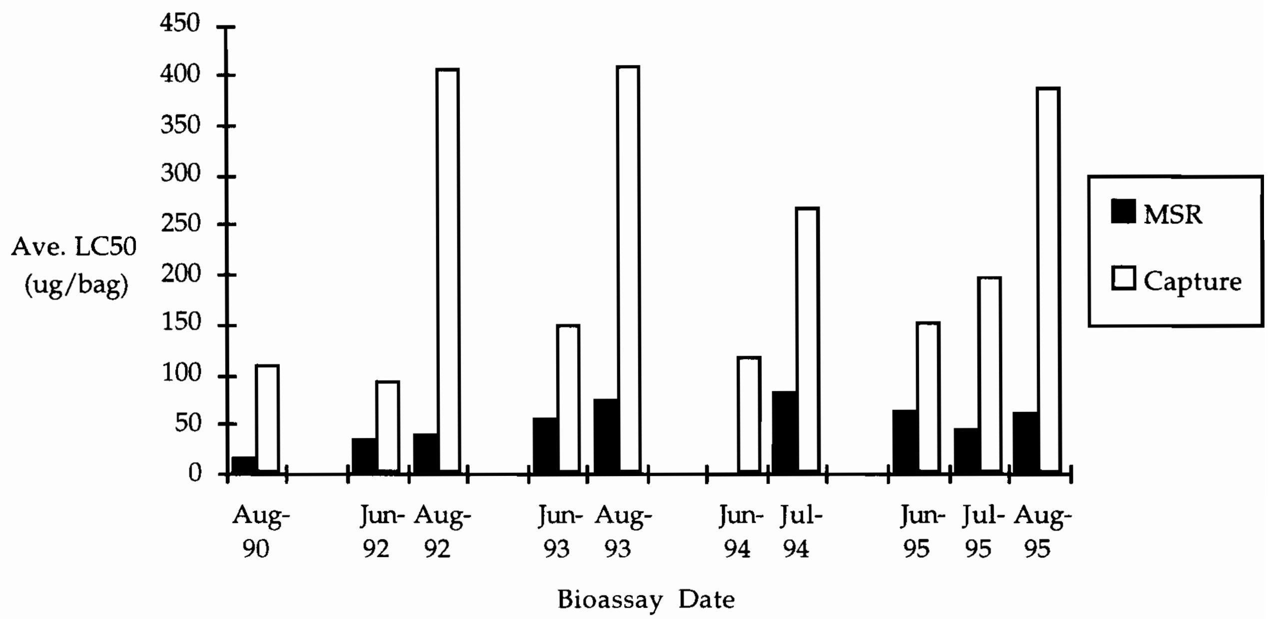

Figure 1. Average LC_{50} values for insecticide bioassays with *L. hesperus* adults. Fresno, CA.

1990: [MSR] 400, 100, 40, 10 ug/bag	[Capture] 400, 200, 100, 50 ug/bag
1992: [MSR] 100, 50, 20, 10 ug/bag	[Capture] 200, 100, 50, 25 ug/bag
1993: [MSR] 200, 100, 50, 25 ug/bag	[Capture] 600, 400, 200, 100, 50 ug/bag
1994: [MSR] 400, 200, 100, 50, 25 ug/bag	[Capture] 600, 400, 200, 100, 50 ug/bag
1995: [MSR] 300, 100, 60, 30, 10 ug/bag	[Capture] 600, 400, 200, 100, 50 ug/bag

As expected, LC_{50} values for MSR did not change significantly between 1990 and 1994 since the material was not extensively used in this area. Values ranged from 15.7 to 82.7 ug/bag which are comparable to values from the Northwestern states where the material still performs well. When results from bioassays conducted in area seed fields were first published, there was a renewed interest in the use of MSR. All indications were that it would control lygus. Several growers used this material during the bloom period in 1995 with good success. LC_{50} values remained below 100 ug/bag indicating good control would be expected. Field efficacy data from the sampling sites in 1995 substantiated the bioassay results. Growers continued to use this material in 1996, limiting the number of applications to once per season as a result of concerns regarding resistance development.

We did expect to see changes in Capture LC_{50} values since there is tremendous selection pressure for resistance. Within any given year, there was a significant increase in the LC_{50} value following repeated use. June bioassays took place prior to Capture application in most years. July and August bioassays followed at least one, and in many cases two, applications of Capture. LC_{50} values were three to four times higher at the end of the season compared to prebloom values. Growers' pesticide efficacy reports from the field were well-correlated with bioassay results. As early as 1993, growers began to report that the material was not as effective as it was the first two years of use. In fact, second applications of Capture during the 1994 production season were holding ten days or less in many cases, compared to 35 days of control in 1991. In 1995, a bioassay was conducted in a field that received three Capture applications. Results are not included in Figure 1, but the LC_{50} value from that one field was 955 ug/bag! (The Capture label changed recently to allow only one application to seed alfalfa each year.)

Our bioassay test results with Capture indicate that lygus populations are rapidly developing resistance to this material. This information is well-correlated with grower observations that the material is becoming less effective. The LC_{50} threshold where the insecticides would begin to fail in field applications is not known at this point. Growers should keep good records of pest population levels and pesticide use and performance data. They should also adopt rotation of insecticides whenever possible as a routine part of their pest management programs in both cotton and seed alfalfa. Changing insecticides and encouraging biological controls will retard the development of resistance. Changing between classes of insecticides is best, but even rather small differences in chemical structure within a class can make a substantial difference.

SUSCEPTIBILITY MANAGEMENT STRATEGY FOR LYGUS -- AN INDUSTRY APPROACH

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INTRODUCTION

Over 1,000,000 acres of cotton are grown in the San Joaquin Valley of California, and a healthy crop with high yields contributes significantly to the overall agricultural economy of the state. Lygus bugs, primarily *Lygus hesperus,* have periodically been a severe pest on cotton in the San Joaquin Valley (Goodell and Narbeth, 1996). Damage caused by lygus can significantly reduce cotton yields. Lygus feeding, especially when it occurs during the 'critical fruit formation' period, damages squares causing them to shrivel and drop from the plant. Additionally, lygus feeding on young bolls may damage or inhibit seed development and frequently results in stained lint around damaged seeds (Godfrey et al., 1996). Ultimately, boll retention is reduced, thus reducing yield.

Alternate hosts for lygus in the San Joaquin Valley include alfalfa, safflower, vegetables and vegetation from the surrounding foothills and uncultivated land. Lygus frequently migrate to cotton fields from adjacent fields as crops are harvested or native plants begin to dry down. When lygus move from crop fields to cotton stands, there is a high likelihood they have been previously exposed to at least one pesticide application.

Pyrethroids are the most common pesticide class used to control lygus in cotton and other crops in the San Joaquin Valley. Reports of diminishing efficacy of pyrethroid pesticides, possibly linked to loss of pest susceptibility to pyrethroids, caused FMC Corporation to evaluate the use of its products across the spectrum of crops grown in the San Joaquin Valley.

SUSCEPTIBILITY MANAGEMENT STRATEGY DEVELOPMENT

Ideally, pest management programs utilize a variety of tactics including cultural practices, crop protection products and biological control agents. Cultural practices and biological control agents can be effective when pest infestations are not severe. Once pest populations reach threshold levels however, growers usually rely on pesticides for quick knockdown and residual effects. With continued pesticide use, many researchers and agricultural practitioners have noted a decrease in pest susceptibility to various classes of insecticides and other pesticides (Dennehy et al., 1995).

Resistance to pesticides occurs when genes conferring susceptibility to a compound are replaced by a gene, or genes, which enable pests to survive a normally lethal dose of pesticide. Genes which enable individuals to survive exposure to doses of insecticides that would normally control the pest are naturally present in most populations. Resistant populations develop when pesticide control practices are such that resistant individuals are selected (survive) while susceptible individuals are eliminated from the population. Eventually the percentage of resistant individuals in the population reaches a level that exceeds the economic threshold and the pest can no longer be controlled by the pesticide.

Resistance to pesticides is a growing concern to the agricultural community as the number of new pesticides introduced to the marketplace each year is very low (Frisbie et al., 1987). Therefore, maintaining the viability of and pest susceptibility to available pesticides is important not only to registrants, but to the user community as well. Susceptibility management programs are designed to reduce or eliminate the selection of resistant individuals from pest populations.

Susceptibility management programs are built around several basic principles. First, it is critical that pesticides be applied at recommended rates, good plant coverage be obtained and pest populations be treated before infestations reach unmanageable levels. For example, use of lower than recommended rates can increase selection of resistant individuals quickly, and inadequate plant coverage is equivalent to the use of reduced pesticide rates. Certainly, with high numbers of pests in a field, the actual number of resistant individuals surviving can be quite large. The net result is the creation of a relatively large amount of resistant individuals from which the next generation can develop.

Another principle includes the use of chemical class rotation in a susceptibility management scheme. Compounds from different chemical classes have different modes of activity against a given pest (Frisbie et al., 1987). That is, different biological pathways are targeted by compounds from different chemical classes. Therefore, rotating the use of pesticides from different chemical classes will likely maintain a pest's susceptibility to compounds within a chemical class.

Finally, mixtures of pesticides from different classes may maintain pest susceptibility to those pesticides as well. It is important that chemicals in the mix are used at rates that provide equivalent control and persistence (Thompson, 1996). Frisbie et al. (1987) noted that it is more difficult for an insect to develop resistance to several insecticides simultaneously.

FMC's approach to maintain the viability of its premier pyrethroid insecticide for lygus control, Capture® Insecticide/Miticide, was to evaluate pesticide use and cotton development in the San Joaquin Valley throughout a typical growing season. Of special interest to us was the relationship between cotton and other crops being grown and the economically important pests which may be found on those crops and cotton. This approach was taken because cotton fields are often adjacent to other crops, and lygus as well as other pests may migrate from nearby fields to cotton plants (Dennehy and Russell, 1996). In the development of our strategy, we met with pest control advisors (PCAs), growers and university personnel. We worked with the University to ensure we maintained a scientifically sound approach to the development of our susceptibility management program for Capture.

We realized that pesticide applications on crops other than cotton could influence pest population dynamics and subsequent pesticide recommendations on cotton. Figure 1 demonstrates development of a typical cotton plant from time of planting to harvest and expected insect pests as they relate to a particular developmental stage of the cotton plant. Additionally Figure 1 shows other crops grown in the San Joaquin Valley and the insect pests expected to be found on those plants at various times of the year.

Although lygus bugs are significant pests throughout the season on safflower, alfalfa and other crops, they most frequently are a problem on seed alfalfa from approximately May through August. Much of this time period coincides with the 'critical fruit formation' period of cotton (approximately June - July) when the majority of bolls formed are those that determine the plant's yield potential. As mentioned previously, lygus feeding reduces boll retention, so control of this insect is important for optimum production. Pyrethroid use early in the season, especially if used at lower than recommended rates, potentially exposes lygus to multiple pyrethroid applications, allowing less susceptible individuals in the population to survive. The offspring of these survivors may inherit the resistant gene and pass it on to future generations, thus leading to the possibility of a largely resistant population.

To minimize the potential for the above scenario, FMC Corporation developed and promoted a susceptibility management program for use of Capture in the San Joaquin Valley (Figure 1). The program included a 'Pyrethroid Window' approach and incorporated the strong recommendation that growers wait to use Capture (or any pyrethroid) as long into the 'Pryethroid Window' as economically feasible. Additionally, we recommended that Capture (or any pyrethroid) be used once, and only once, during the 'Pyrethroid Window', approximately June 1 -August 1, which is the critical fruit formation period of cotton.

Recognizing that many seed alfalfa growers depend on Capture to control lygus early in the growing season, FMC worked with the California Seed Association to amend their Special Local Need registration for Capture on seed alfalfa. The revision reduced the number of Capture applications from two to one per season, thereby reducing the likelihood of lygus being exposed to multiple pyrethroid applications. To go along with this revision, FMC recommended that pyrethroid applications on seed alfalfa take place only during the "Pyrethroid Window" defined above.

We also recognized that lygus may need to be controlled for a longer period than Capture provides (typically 14- 21 days) and strongly encouraged users to rotate to other chemical classes when choosing follow-up applications. To assist users in knowing to which class a particular pesticide active ingredient belonged, we developed a table of the classes of commonly used cotton insecticides registered in California.(Table 1). By using this table, growers and PCAs could easily determine if pesticides they were choosing for sequential applications belonged to different chemical classes. Along with Table 1, we developed a decision matrix chart (Table 2) which outlined examples of possible control recommendations based chemical class rotation for pest problems at various developmental stages of cotton. When possible we chose chemicals that are highly selective (per UC IPM Pest Management Guidelines) for early season insect control to protect predators and other natural enemies that may be present in the field.

As a part of its educational outreach program for the 1996 growing season, FMC produced a brochure that had the Capture susceptibility management program on one side and the table of chemical classes of cotton insecticides on the other (Figure 1/Table 1). FMC sponsored numerous educational meetings with PCAs, applicators and regulators and distributed this brochure to participants. We have had favorable feedback on the usefulness of this brochure, especially the chemical class chart which has generic utility for insecticide rotation selections on other commodities.

As a companion study to the above program, bioassay tests were performed on lygus collected from various locations throughout the San Joaquin Valley during the 1996 growing season. Lygus were collected with sweep nets and bioassayed in glass vials as described by Knabke and Staetz (1991). Data have been collected and are currently being analyzed to determine the extent and level of populations susceptible to bifenthrin and their possible relationship to previous pyrethroid exposures.

CONCLUSION

It is premature to conclusively evaluate the success of FMC's susceptibility management program for Capture. Lygus populations in the San Joaquin Valley were unusually low during 1996, thus Capture and other pyrethroid pesticide use was lower than in previous years. When used as recommended, Capture performance was generally successful. As mentioned, feedback to our approach was positive, especially from regulatory officials and University personnel.

FMC has taken a leadership role in the industry for promoting the proper use of its products and development of stewardship programs. We will maintain our strong commitment to agriculture and take the steps necessary to ensure that growers have viable tools available to them so they can be competitive in a global marketplace.

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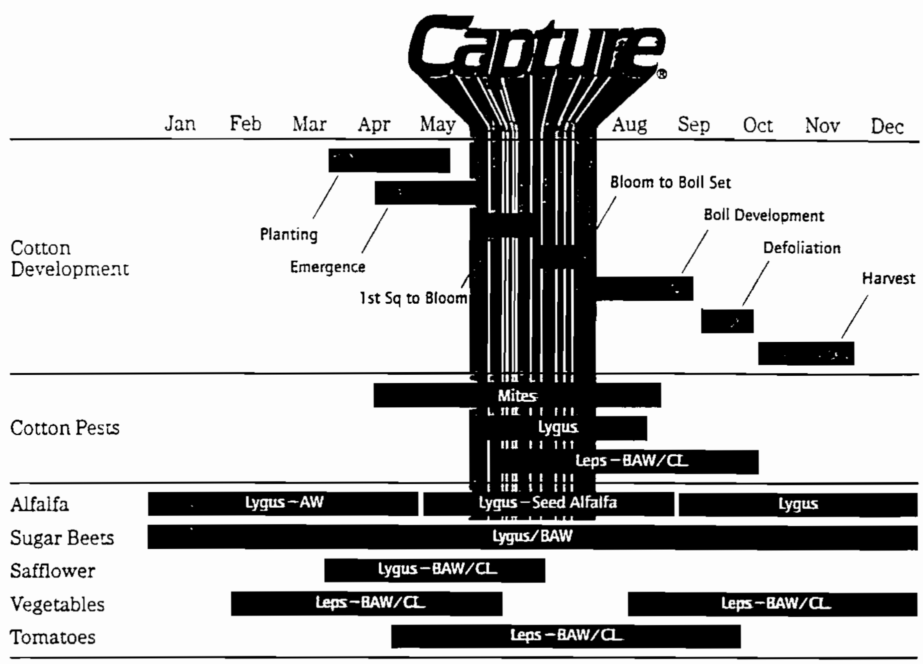

KEY: AW = Armyworm, BAW = Beet Armyworm; CL = Cabbage Looper

For Resistance Management purposes FMC strongly recommends: Apply Capture or any other pyrethroid only one time per season. Apply only when scouting reveals Lygus bugs are present. Apply during the critical fruit formation period, approximately June 1 – July 31 in the San Joaquin Valley of California. Rotate pesticide chemical classes; never use pesticides in the same chemical class, back to back. Use pesticides at recommended rates.

Figure 1. Susceptibility Management Program for Capture® Insecticide/Miticide for lygus control on cotton.

Table 1. Chemical classes of cotton insecticides registered in California.

Chemical Classes of Cotton Insecticides*

Class	Common Name	Trade Name	Mode of Action
Avermectin	abamectin	Zephyr	Blockage of the neurotransmitter GABA
Biologicals	*Bacillus thuringiensis* var. kurstaki; Heliothis Nuclear Polyhedrosis Virus	Biocot, Biobit, Condor, Design, Dipel, Javelin Elcar	Ceases pests feeding leading to death; Viral attack
Carbamates	carbofuran aldicarb carbaryl methomyl oxamyl thiodicarb	**Furadan** Temik Sevin Lannate Vydate Larvin	Nerve toxin, reversible cholinesterase inhibitor
Chloronicotinyl	imidacloprid	Admire, Provado	Interruption of acetyl choline metabolism
Cyclodienes	dicofol endosulfan	Kelthane Thiodan, Phaser	Axon poison which blocks normal electrical impulse transmission along nerve
Formamidines	amitraz	Ovasyn	Monoamine oxidase inhibitor
Organophosphates (OPs)	acephate azinphos-methyl chlorpyrifos dimethoate disulfoton fenamiphos malathion methamidophos metasystox-R methyl parathion naled phorate phosmet profenofos	Orthene Guthion Lorsban Dimethoate Di-Syston Nemacur Malathion Monitor MetaSystox-R Methyl Parathion Penncap-M Dibrom Thimet Imidan Curacron	Nerve toxin, cholinesterase inhibitor
Pyrethroids	bifenthrin cyfluthrin cypermethrin esfenvalerate fenpropathrin zetacypermethrin	**Capture** Baythroid **Ammo** Asana XL Danitol **Mustang**	Transmission blocking effect on the nerve axon

*May include products not currently registered in CA

Table 2. Example of susceptibility management decision matrix for San Joaquin Valley cotton based on class rotation and chemical selectivity.

1996 Susceptibility Management Decision Matrix For San Joaquin Valley Cotton

May 15 - May 30 Seedling to First Square	June 1 - July 30 First Square to Green Boll	August 1 - Sept 15 Boll Maturation
Aphids - Temik (AP/SD) - Provado - Thiodan - Biological	Aphids - Temik (SD) - OPs - Thiodan - Ovasyn	Aphids - OPs - Furadan
Lygus - OPs - Temik (AP/SD) - Provado	Lygus - Capture - OPs - Temik	Lygus - OPs
Worms - OPs - Bts	Worms - Pyrethroid + OP - OPs - Bts	Worms - OPs - Methomyl - Pyrethroids
Mites - Temik - Kelthane - Zephyr - Sulfur Dust	Mites - Comite - Zephyr - Capture + Miticide - Curacron	Mites - Comite - Zephyr

RESISTANCE MANAGEMENT

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INTRODUCTION:

Going back to the 1950s and 60s, we were looking for production at a cost that would be economical and effective, so this meant sulfur for mite and DDT for lygus and worms. Those of us who were in school in those years learned that pest control was no major problem. However, as time passed, we were very much aware of the problems we could possibly create for the grower and ourselves as consultants.

Little was thought that cultural practices would change insect control or possibly create a greater problem. The grower cut the stalks, disced the field, plowed, and he might have ripped the ground, depending on his equipment.

When we look back on those times, we ask the questions, "What about a host free period?" No. In those years cotton was picked into the Spring. "What about compaction?" No, we worked the ground wet mostly in the lighter soils, and tried to get on the soil as soon as possible in the heavier soils.

After we worked the ground through the Winter, we would pre-irrigate and then plant. We used the fuzzy seed and planted 30 to 40 pounds per acre. Wow, how about that, no seed treatment. It just went that way. Growers did not consider plants per acre or possible early mite damage. Sulfur was the tool.

Then about the first of June, we watered, and were on our way. We began to notice that Sulfur didn't seem to control all the mites anymore. What were we to do? In the early 50s, a product by the name of Kelthane came along and we were on our way to season-long mite control. In those years we also started using Panogen-treated seed for the soil borne diseases. Yes, we had it made. We thought we had solved our problems. Then a pest called Lygus came along in the cotton. Aphids started in the alfalfa, corn ear worms in cotton, corn , tomatoes, and other crops. What we were to do? DDT, the answer to all our problems, came along. The more we used it, the more we used it. What was happening? The lygus were coming through. The answer was to add toxaphene, and "shazam" we had tox 4 DDT2. Yes, many of us know now that possibly we made many mistakes in those years . When we look back, they were not all lost. Those were the growing years. Many questions and a new name came into pest control in our agriculture. Names with questions like, predators. What are they? What do they do? How effective are they? What about timing? How important? What about target pests? What levels can we stand?

When I think of those days, I remember names like Curt Farris, County Entomologist; Les Stromberg, County Cotton Specialist. Remember the whole U.C. Extension System and how important it was to those of us who were struggling for answers as growers and consultants? This hasn't changed. Today we look to the Pete Goodells, the Dan Monks, the Ron Varguses, the Bruce Roberts, the Bill Wiers for help. You so ably helped us in our cotton, and we thank you.

PROCESS IN RESISTANCE MANAGEMENT:

Now after the history lesson, what does it mean today. There are five questions I ask myself when I look at a cotton field:

1. Planting date?
2. Irrigation schedule?
3. Target pest?

4. Beneficial insects?
5. Plant condition?

Of course, I feel this is basic on all crops when it comes to pest control.

If a decision is made for pest control, this leads to another set of questions. What chemical tool do we use? Or, do we use any? Let's make the assumption we don't go the chemical way. Then the buzz words, "Integrated Pest Management" enters in. And this started some 35 years ago.

1. What is our target pest?
2. Predator Population?
3. Condition of Plant?
4. Temperature?
5. Surrounding Crops?

All of these questions enter into the decision of our pest control. Assuming the predators stay high in population, and the other conditions stay normal (a term used loosely), we get along just fine. However, let the situation change and the target pest increases. Then the chemical step must be taken. Now we must face another decision as to what chemical to use. We have more questions:

1. Lygus is the pest?
2. Time of year (early)?
3. What will it do to predators?
4. Will it set the crop up for additional applications and how soon?
5. What will it do to the plant (phytotoxicity)?

Yes, every decision in the cotton field leads to another set of questions. Questions that must be answered as scientifically as possible, yet with much concern for the next step in the crop.

I believe it is very important to alternate chemicals in pest control, particularly in mite control. We seem to take the attitude that it is working well, so let's not change. Well, that is not all wrong. However, pest management can be very complex, and you know that mites in particular, when they get going, there is no stopping them, as we experienced in 1995. When I pursue mite control, I am pleased that in itself it does not create other problems. I have found when I treat early for Lygus, worms, or aphids, I tend to create other problems, more treatment and most of the time at a higher cost.

CONCLUSION:

In conclusion, for resistance pest management, I feel the reason for treatment must be evaluated for a day or two and then the questions must be answered that have been mentioned before. Yes, we can get very technical, and we can rationalize many things. When the crop is harvested, you will know how technical you were or how rational you were. You will be accused of screwing up the crop if it does not meet the grower's expectations. If it is a great crop, you will have the satisfaction of being successful and looking forward to another year. Realize that every season is different, and it will present new and greater challenges.

RESISTANCE MANAGEMENT: A GROWER'S PERSPECTIVE

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A major concern of growers today is resistance of pests to chemicals. As a grower in the San Joaquin Valley, I will share my views and ideas on why resistance is occurring and will explore alternatives that could increase the longevity of chemicals.

As growers, we need to understand what is causing resistance and look at ways that we could change the trend of a chemicals shortened life span. What can we do as growers to increase the life span of chemicals available for us to use?

The following comments will be directed at insecticides/miticides used in row crop production:

1. Reliance of a chemical or class, time and time again. (I tend to use materials that will give me the best economical control). Without alternative materials growers rely on what has worked and stick to that compound until it loses its' effectiveness. We need more materials to combat our pest problems. Without them, resistance will continue to be a problem. We may need to rotate classes of chemicals (windows approach).

2. Rate: What rate should we really be using? Chemical companies need to come to a consensus on high or low rates. Are high or low rates or differing rates in a given area leading to resistance?

3. Economic Threshold: How high should we allow a population to build before we spray? Most Pest Control Advisors have a better understanding of chemical effectiveness in the field than the recommendation of pest thresholds being made by researchers. As an example: Fifty percent mite infestation before spraying and/or high aphid populations, etc. The materials we have cannot do a sufficient job if we wait to spray at high population levels. The result is more escapes which lead to potential resistance.

4. Duration Dynamics: Growers need more information concerning hardest to kill stages, (which nymph stage) which stage is easiest to kill. Residual ability to kill, etc. Are we applying material at the wrong stage of development which could be increasing resistance potential.

5. Pest Aspects: Life span, number of generations per year, alternative hosts. We must be better educated in pest and plant physiology - feeding habits, over wintering aspects, etc. Maybe we could kill pests prior to their reinfestations. Can we attack an overwintering host. Is it better to block crops together or mix them up?

6. Environmental Conditions: Under what conditions does a material lose its' effectiveness? Wind speed, rain, water being used in spray mix. In our need to apply a material are we stretching certain weather conditions which decrease a chemicals' effectiveness increasing pest escapes?

7. Coverage: This is the one area (being covered on this paper) which growers, can influence the most. We must continue to enhance application techniques. We can improve coverage! Ground speed, air speed, pressure, nozzles droplet size, pH, water, night time, application versus daytime. We can improve our application and we must do a better job getting the chemical to the target pest.

8. Regulations: Plant back restrictions, re-entry periods, drift, etc. Regulations must change to allow us to maintain profitability. Decisions must be science based using common sense. Eliminating materials only compounds resistance and it also increases the number of sprays needed to protect a crop from devastation. We need more materials, it will help us all!

9. Cost: As growers, we realize that regulations increase our costs, they also increase the cost of our chemicals. The cost of a materials effects rates being applied which may be contributing to reduced life span and increased pest escapes. Chemical companies need to deliver as low a cost of control as possible, so P.C.A.'s can apply recommended rates that a grower won't try to reduce to save money. By using a certain chemical is it increasing our profitability, is it really the right choice?

10. Neighboring Conditions: Farmers' must help each other. They need to communicate more effectively. Farmers need to be responsible for pests leaving their ranch just as they would a chemical drifting onto a neighbors field. We must work together looking at our crop rotations, understanding each others' views, needs, etc. If we are using different P.C.A.'s they need to communicate. Are we timing our sprays? Are we using comparable materials and rates? Are we protecting each other from subsequent infestations? Would a windows approach to chemical applications work in our area?

It is very short sighted when a grower cuts his hay without leaving strips, infesting a neighbors cotton field with lygus, or not spraying his safflower as a trap crop and allowing those pests to affect surrounding crops. These type of practices hurt us all and influence the survival of pests and their ability to gain resistance. We must work together if we want to reduce resistance opportunities.

DEFICIT IRRIGATION OF ORCHARD CROPS

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INTRODUCTION:

Fruit and nut tree growers in California and throughout the world face the possibility of reduced irrigation supplies due to increased competition for water from the municipal, industrial, and environmental sectors. In California, planners estimate that the state will have a shortage of 1.9 million acre-ft in the year 2000. Since the chance of new water resource development is remote and agriculture currently uses in excess of 80% of the state's developed water, it's likely that overcoming the state's shortfall will include redirection of existing agricultural water use to other sectors of society. Coupled with the likely imposition of groundwater pumping restrictions, growers are simply going to have to farm with less water.

There are two traditional source control approaches to minimizing irrigation losses; improved application efficiency and irrigation scheduling. The former involves better uniformity of water application by improved management of existing systems or switching from generally inefficient systems, such as surface, to high frequency, low volume application, such as drip. The later includes soil, plant, and atmospheric based methods such as the tensiometer and neutron probe, pressure chamber, and matching net irrigation amounts to the crop water requirements (water budget technique) using estimates of crop evapotranspiration (ETc), respectively. Traditionally, the goal of irrigation scheduling has been to fully meet the potential ETc of the orchard and to avoid stressing the trees. Indeed, relationships between yield and ETc (production functions) are usually described in the literature as linear. However, recent work indicates that some fruit and nut trees may tolerate transpiration-reducing water deficits during certain periods of the season without production losses.

Regulated deficit irrigation (RDI) is the practice of purposely creating water deficits during specific times of the growing season primarily to save water while minimizing or eliminating negative impacts on yield or crop revenue. Additionally, RDI has also been used to control vegetative growth and in some cases, has improved harvested fruit size. RDI represents a possible third type of water conservation through source control. Moreover, increased water costs and periodic droughts make the development of RDI information a high priority. During droughts and restricted water supplies, irrigating to prevent tree-water stress isn't possible in many cases; it's a question of **when** can the orchard be most safely stressed and to what degree (**how much** water should be applied). The work in peach and grapevines show that these crops can be deprived of water at certain times of the season without affecting yield or quality of marketable product. This paper reports on RDI research to date on almond, pistachio, and olive in California.

METHODS:

There are three potential RDI triggers: soil water status, tree water status or growth, and ETc. Since the tree is our target, the trigger should ideally include tree water status or growth. A device (biosensor) is needed that provides an accurate, reproducible, automated, and relatively inexpensive measurement. Unfortunately, such a device is not currently available. While soil-based monitoring instruments do offer most of the desired characteristics outlined above, they are expensive and beyond the research of especially small growers. Thus, the RDI regimes used in our studies were based on irrigating at percentages of potential ETc. We recognize the limitations of this technique. The impact of the initiation of deficit irrigation on tree water status depends on the size of the soil water reservoir and evaporative demand. Rooting depth, soil water holding capacity, and irrigation method (coverage) determine the size of the reservoir. We take this into account in designing the RDI regimes; the initiation of the deficit irrigation is earlier in orchards with large soil water reservoirs.

Specifics of the RDI regimes and tree performance monitoring are outlined as follows for each crop.

Almond

The almond RDI study evaluated three levels of irrigation (22, 28, and 34 inches per season) each applied under 3 timing regimes (Table 1). The "A" treatments imposed the stress primarily before harvest and emphasized reserving some water for some postharvest irrigation. The "B" treatments did just the opposite; emphasizing preharvest irrigation and save relatively little water for postharvest. The "C" treatments irrigated at the same percentage of ETc throughout the season. Regardless of the seasonal irrigation amount, care was taken in the "A" and "B" regimes to provide as much water as possible in the 4 week period just before and after harvest. This was to enhance hull split and successful flower bud development, respectively.

The study is being conducted with a commercial almond producer and covers 50 acres. Each treatment is imposed by engineering the irrigation system to apply different amounts of water while irrigating at the same frequency. This is accomplished by using different combinations of operating pressures and microsprinkler sizes (flow rates). The goal is for each irrigation regime to wet the same surface area.

At harvest, gross yield, and individual nut sizes, and bark damage due to mechanical shaking are determined.

Pistachio

Potential ETc of pistachio orchards is high; the peak crop coefficient (Kc) is 1.19 and seasonal water use is 44 inches per season. While pistachio is extremely drought tolerant--trees not irrigated for 4 years survived and produced a small crop--sustained water deprivation (irrigating at various percentages of potential ETc over the season) resulted in decreased productivity. This was primarily due to lower nut loads, shell splitting, and harvestability and high blank nut production. The magnitude of yield loss was directly related to the degree of sustained deficit irrigation.

The time-course development of pistachio nuts appears to offer an ideal period to implement RDI. This is the 6-8 week period from mid May (after full shell size has been attained) through early July (the onset of rapid kernel growth). This period (sometimes called growth stage 2) is our stress focus since it's after the initial shoot growth flush, there's minimal nut growth (primarily shell wall thickening), and potential water use is increasing . A typical irrigation schedule for the proposed conservative RDI regime is shown in Table 2.

To assess nut quality parameters in addition to those supplied by the commercial processor, subsamples (200 nuts) were collected from each replication and analyzed for:

1) nut quality
   - a) blank nuts -- no evidence of embryo growth
   - b) aborted nuts -- terminated embryo growth
   - c) unsplit nuts
   - d) split nuts

2) fresh and dry weights of nut components (hulls, shells, and kernels) of each quality type.

The effectiveness of mechanical shaking was assessed by hand-removing all the nuts that remained after harvest on 3 trees per replication. Harvest weights of these trees are taken individually using a mechanical shaker to collect the nuts for weighing. The relatively small number of trees was due to the time required for this procedure. Harvestability of the total tree nut load for the "denutted" trees was calculated as the total weight of nuts left in the tree ("in-tree" nuts) divided by the total of harvested and in-tree nuts. The harvestability of the denutted trees was assumed to apply to the entire replication allowing for the calculation of an average "in-tree" nut weight based on the average harvest weight for that replication. A composite in-tree nut subsample was collected from 200 trees in each replicate and analyzed for the nut quality parameters outlined above.

Olive

Previous work showed that irrigating mature cv. Manzanillo trees using a Kc of 0.75 resulted in maximum grower revenue for canning olives and that there was a strong, exponential relationship between applied water and grower revenue between 8 and 37 inches of applied water. The water cost compensation point (where the revenue generated by applying the water was just balanced by the cost of the water) between 24 and 37 inches of applied water was almost $3000/acre-ft. This indicates that fully meeting the irrigation requirements over the season rather than chronically deficit irrigating is essential for maximizing profits.

Our approach to olive RDI was to fully irrigate what we considered critical periods including reproductive bud differentiation, flower development, and rapid shoot and fruit growth. We found that shoot growth peaks in early June and slows significantly by the end of July. Our focus for the least sensitive growth period was during the lag phase of fruit growth after pit hardening occurs. In California, this is from mid June through July. We believe the key for successful RDI is to reduce irrigation without significantly reducing fruit size.

Our RDI study evaluated 3 RDI regimes in addition to a fully irrigated control (Table 3). The RDI regimes tested saved 13% of potential water use (T2), 21% (T3), and 40% (T5). This equates to 4.6, 7.4, and 14.0 inches of water saved, respectively.

We modified the microsprinkler irrigation system to include drip irrigation lines that apply either 25 or 50% of normal irrigation. By using 0.5 gph drip emitters, we attempt to wet the same surface area regardless of the percentage of normal irrigation being applied.

Weekly measurements of fruit fresh and dry weight were taken. At harvest, the following was assessed:

Gross yield
Fruit fresh weight, dry weight, and size
Fruit size distribution determined at a commercial processor
Fruit value (sizes determined by processor)

RESULTS AND DISCUSSION:

Almond

There are 2 major yield components in almond; individual kernel weight and tree nut load. Second (1994) and third year (1995) results show no influence of any of the "A" treatments on nut loads (Table 4). This is surprising since tree growth, as expressed by changes in primary scaffold cross-sectional area, has been reduced in the 22 inch regimes. This implies that these treatments have a higher fruiting density; that the tree has compensated for reduced canopy growth by setting more fruit per unit length of shoot. Increased fruiting in response to stress in relatively common in fruit and nut trees.

Nut loads with the "B" treatments show a trend toward lower values, although none are statistically lower than the control (Table 4). "C" treatment nut loads were similar to the control.

Kernel size has been the primary yield component affected by the RDI regimes. When averaged for the 3 experimental years, there has been an 18.2, 16.7, and 12.9% reduction in kernel weight for the 22A, 28A, and 34A regimes, respectively (Table 4). The "B" treatments also had smaller kernels but to a lesser extent. In most cases, the least impact of the RDI regimes occurred in the "C" regimes. There were no statistically significant differences between 34B and 34C vs. the control.

Our work to date indicates that RDI in almond has some promise. When averaged for 1994-95, total kernel yields in 22 "A", "B", and "C" were reduced by 16.8, 23.6, and 9.2%, respectively. These are comparatively mild responses to regimes that applied 45% less water than the control. With the "A" and "C" regimes, it's clear that kernel size has been solely responsible for the yield reductions; the RDI regimes have been successful in maintaining fruit loads.

Figure 1 shows kernel dry weight accumulation for 28A and the control. Even though there was significant tree water stress beginning in June, kernel weight wasn't affected until early July. Our data show that kernel girth, rather than kernel length, is reduced. We believe that the kernel is a strong sink for photosynthate and has the potential to achieve full size if severe tree water stress is prevented in July through harvest. We plan to test this theory in 1996 with RDI regimes that deficit irrigate primarily in June and early July. These new regimes save about 10 inches of water (25% of potential ETc).

An additional beneficial aspect of the almond RDI has been reduced hull rot, a disease that can cause shoot dieback. Even with the mild and short duration stress in 34B (irrigating at 50% ETc during the first 2 weeks of July), hull rot was significantly reduced. The specific mechanisms of this reduction are not known but if may involve earlier separation of the hull from the pedicle restricting the transport of toxins from the hull to the shoot.

Visual observation indicates no difference in bark damage due to mechanical shaking for the 10 irrigation regimes.

Pistachio

Since pistachio is an alternate bearing crop and this results in considerable variability in yearly production values even though we had 6 replications, we report in this paper mean data from the final 2 years of this project; 1994-95. RDI applied water was 19.8 % less (5.9 inches) than the control.

There were no statistically significant differences in yield or yield component values (Table 5). These data include both laboratory and commercially-obtained results. Marketable yield, in-shell yield, shell splitting, nut load, edible yield, and harvestability varied little between the control and RDI regimes. There have been no carryover effects of water deficits on the following season's tree performance.

We should point out that in the first year of this 3 year study, there was a significant increase in total shell splitting with the RDI (56.0 and 64.3% of the filled nuts for the control and RDI regimes, respectively). Shell staining in 1993 was lower with the RDI. These beneficial production aspects were not observed in the other years. Results from other experimental sites (data not shown) indicate that with severe deficit irrigation, the incidence of the fungal disease *Alternaria alternata* is reduced. This is presumably due to lower humidity levels in the tree canopies. Under these conditions, we have observed increased shell splitting and reduced shell staining. While the latter is a direct result of less fungal activity on the hulls of the nuts, the former may involve improved growth of specialized cells along the suture line of the shell due to lower disease pressure. At this point, we are not recommending severe deficit irrigation (irrigation at less than 50% ETc during stage 2) unless fungal disease is a major problem. Indeed, we believe that pistachio RDI should not be represented as a technique to enhance yield components but rather as an approach to water conservation.

Olive

Much to our surprise, there were no statistically significant first year impacts of the RDI on olive yield and quality. Some slight variation in fruit load was attributed to alternate bearing even though we had 6 replications per irrigation treatment.

To factor out the influence of fruit load, we selected replications that had equal fruit loads; both high (25,000 fruit/tree) and low (11,000 fruit/tree). The effects of the most severe RDI regime (T5) on fruit diameter development is shown in Figure 2 for high fruit loads. While the low fruit load trees had larger fruit, the patterns between full irrigation and the RDI were similar. Predawn LWP during the season is also shown in Figure 2. There was some reduction in fruit growth during the most severe period of RDI (mid June through mid August). However, the size appeared to recover when full irrigation returned.

Second year individual fruit growth results were similar (Table 6). For equal fruit load trees, harvest fruit size and weight were nearly identical across treatments.

Since size reduction was the greatest factor in reducing revenue due to season-long deficit irrigation in the previous study, olive RDI appeared promising. However, for trees with equal 1994 fruit loads, 1995 fruit loads were significantly lower in T5 and trended lower in T3. This resulted in lower mean gross tree yield (1994-95) for T5 (Table 7). It should be pointed out that in heavy crop years, growers chemically thin the fruit during bloom to reduce fruit load and enhance fruit size. This is due to the fact smaller fruit is valued much less by the processors. It may be possible to use severe RDI rather than chemical means to thin olive fruit. Clearly, this should be done only when excessive crop loads are anticipated.

Table 1. Almond RDI regimes evaluated.

Dates	Control Normal ETc (in)	34A RDI (%)	34A App. water (in)	34B RDI (%)	34B App. water (in)	34C RDI (%)	34C App. water (in)	28A RDI (%)	28A App. water (in)	28B RDI (%)	28B App. water (in)	28C RDI (%)	28C App. water (in)	22A RDI (%)	22A App. water (in)	22B RDI (%)	22B App. water (in)	22C RDI (%)	22C App. water (in)
Mar 1-15	0.5	100	0.5	100	0.5	85	0.5	100	0.5	100	0.5	70	0.4	100	0.5	100	0.5	55	0.3
Mar 16-31	1.1	100	1.1	100	1.1	85	1.0	100	1.1	100	1.1	70	0.8	100	1.1	100	1.1	55	0.6
Apr 1-15	1.4	100	1.4	100	1.4	85	1.2	100	1.4	100	1.4	70	1.0	100	1.4	100	1.4	55	0.8
Apr 16-30	1.8	100	1.8	100	1.8	85	1.5	100	1.8	100	1.8	70	1.2	50	0.9	50	0.9	55	1.0
May 1-15	2.3	100	2.3	100	2.3	85	2.0	50	1.1	100	2.3	70	1.6	50	1.1	50	1.1	55	1.3
May 16-31	3.0	100	3.0	100	3.0	85	2.6	50	1.5	100	3.0	70	2.1	50	1.5	50	1.5	55	1.7
Jun 1-15	3.2	50	1.6	100	3.2	85	2.7	50	1.6	50	1.6	70	2.2	50	1.6	50	1.6	55	1.7
Jun 16-30	3.4	50	1.7	100	3.4	85	2.9	50	1.7	50	1.7	70	2.3	50	1.7	50	1.7	55	1.8
Jul 1-15	3.8	50	1.9	50	1.9	85	3.2	50	1.9	50	1.9	70	2.6	0	0.0	50	1.9	55	2.1
Jul 16-31	3.9	100	3.9	100	3.9	85	3.3	50	2.0	50	2.0	70	2.7	50	2.0	50	2.0	55	2.2
Aug 1-15	3.4	100	3.4	100	3.4	85	2.9	100	3.4	100	3.4	70	2.4	50	1.7	100	3.4	55	1.9
Harvest																			
Aug 16-31	3.3	100	3.3	100	3.3	85	2.8	100	3.3	100	3.3	70	2.3	100	3.3	100	3.3	55	1.8
Sep 1-15	2.7	100	2.7	100	2.7	85	2.3	100	2.7	100	2.7	70	1.9	100	2.7	50	1.3	55	1.5
Sep 16-30	2.2	100	2.2	100	2.2	85	1.9	100	2.2	50	1.1	70	1.5	100	2.2	0	0.0	55	1.2
Oct 1-15	1.5	100	1.5	0	0.0	85	1.3	100	1.5	0	0.0	70	1.1	50	0.8	0	0.0	55	0.8
Oct 16-31	1.1	100	1.1	0	0.0	85	1.0	50	0.6	0	0.0	70	0.8	0	0.0	0	0.0	55	0.6
Nov 1-15	0.6	100	0.6	0	0.0	85	0.5	0	0.0	0	0.0	70	0.4	0	0.0	0	0.0	55	0.3
TOTAL	39.3		34.1		34.1		33.4		28.3		27.8		27.5		22.5		21.8		21.6

Note: This schedule is adjusted for effective rainfall.

Table 2. Pistachio RDI regime evaluated.

Growth stage	Approximate phenology	Period	Reference water use ETo (inches)	Crop coeff. Kc	Normal ETc in period (inches)	RDI level (%)	RDI ETc (inches)
Stage 1	Bloom	Apr 1-15	2.36	0.07	0.17	100	0.17
	Leafout	Apr 16-30	2.36	0.43	1.01	100	1.01
	Shell expansion	May 1-15	3.19	0.68	2.17	100	2.17
Stage 2	Shell hardening	May 16-31	3.40	0.93	3.16	50	1.58
	Shell hardening	Jun 1-15	3.84	1.09	4.19	50	2.09
	Shell hardening	Jun 16-30	3.84	1.17	4.49	50	2.25
Stage 3	Nut filling	Jul 1-15	4.13	1.19	4.92	100	4.92
	Nut filling	Jul 16-31	4.41	1.19	5.25	100	5.25
	Nut fill/Shell split	Aug 1-15	3.54	1.19	4.21	100	4.21
	Shell splitting	Aug 16-31	3.78	1.12	4.23	100	4.23
	Hull slip	Sep 1-15	2.66	0.99	2.63	100	2.63
	Harvest	Sep 16-30	2.66	0.87	2.31	25	2.31
Postharv.	Postharvest	Oct 1-15	1.71	0.67	1.15	25	1.15
	Postharvest	Oct 16-31	1.84	0.50	0.91	25	0.91
	Postharvest	Nov 1-15	0.80	0.35	0.28	25	0.28
		TOTALS			41.1		31.7

Note: This schedule is adjusted for effective rainfall.

Table 3. Olive RDI regimes evaluated.

Dates	Control ETc (inches)	T2 RDI (%)	T2 Applied H2O (inches)	T3 RDI (%)	T3 Applied H2O (inches)	T5 RDI (%)	T5 Applied H2O (inches)
Mar 1-15	1.2	100	1.2	100	1.2	100	1.2
Mar 16-31	1.2	100	1.2	100	1.2	100	1.2
Apr 1-15	1.8	100	1.8	100	1.8	100	1.8
Apr 16-30	1.8	100	1.8	100	1.8	100	1.8
May 1-15	2.3	100	2.3	100	2.3	100	2.3
May 16-31	2.5	100	2.5	100	2.5	50	1.3
Jun 1-15	2.9	100	2.9	50	1.5	50	1.5
Jun 16-30	2.9	50	1.5	50	1.5	25	0.7
Jul 1-15	3.1	50	1.6	50	1.6	25	0.8
Jul 16-31	3.3	50	1.7	50	1.7	25	0.8
Aug 1-15	2.7	100	2.7	50	1.4	25	0.7
Aug 16-31	2.8	100	2.8	100	2.8	50	1.4
Sep 1-15	2.0	100	2.0	100	2.0	50	1.0
Sep 16-30	2.0	100	2.0	100	2.0	100	2.0
Oct 1-15	1.2	100	1.2	100	1.2	100	1.2
Oct 16-31	1.3	100	1.3	100	1.3	100	1.3
Nov 1-15	0.5	100	0.5	100	0.5	100	0.5
TOTAL	35.4		30.9		28.1		21.4
H2O saved (in)			4.6		7.4		14.0
H2O saved (%)			13.0		20.9		39.5

Note: This schedule is adjusted for effective rainfall.

Table 4. Mean values to date of almond kernel yield, yield components and scaffold growth.

Irrigation regime	Full hull split kernel wt. (gms/kernel)*	Fruit load (#/tree)**	Total kernel yield (lb/ac)**	Scaffold x.s. area growth (cm^2)*
22A	1.08 a	11184 b	1835 ab	19.9 a
22B	1.14 a	9827 a	1685 a	18.3 a
22C	1.14.a	11457 b	2002 bc	17.1 a
28A	1.10 b	11599 c	1932 d	21.6 c
28B	1.19 c	10518 c	1880 d	24.0 c
28C	1.22 c	10856 c	2045 de	22.5 c
34A	1.15 d	11222 d	1964 f	25.9 d
34B	1.24 e	10693 d	2032 fg	24.0 d
34C	1.29 e	11104 d	2177 g	25.0 d
Control	1.32 e	11054 abcd	2205 ceg	26.9 bcd

* Mean of 1993-1995 (1st-3rd years).
** Mean of 1994-1995 (2nd and 3rd years).
Numbers of the A,B, and C treatments within each irrigation regime and the Control not followed by the same letter are statistically different using Duncan's Multiple Range Test at the 5% confidence level.

Table 5. Mean values of pistachio irrigation, yield, and yield components for 1994-95, the second and third years of the study.

Irrigation regime	Applied water (inches)	Gross harvested fresh wt. (lbs/tree)	Total tree nut load (#/tree)	Total split nuts (% by #)	Split removal (% by #)	Dry harvested split nut wt. (gms/nut)	Yield dry in-shell (lbs/ac)
RDI	24.6	66.2	13070	51.8	92.3	1.24	1588
Control	29.9	64.4	13790	48.3	93.0	1.22	1578
Total		NSD	NSD	NSD	NSD	NSD	NSD

NSD indicates no significant differences using Duncan's Multiple Range Test at the 5% confidence level.

Table 6. Olive fruiting characteriestics for equal fruit load trees in 1995, the second study year.

Irrigation regime	Equal fruit load trees per regime (#)	Fruit load (#/tree)	Individual fruit size (mm)	Individual fruit weight (gms/fruit)
Control	9	5780	18.7	4.70
T2	12	5590	18.7	4.73
T3	18	5760	18.7	4.77
T5	11	5450	18.5	4.71
TOTAL			NSD	NSD

NSD indicates no significant differences using Duncan's Multiple Range Test at the 5% confidence level.

Table 7. Olive yield and yield component averaged for 1994-95; the first and second study years.

Irrigation regime	Gross yield (lbs/ac)	Individual fruit wt. (gm/fruit)	Fruit load (#/tree)	Crop value ($/ton)	Gross revenue ($/ac)
Control	10880 b	3.92 a	13530 b	536 a	2946 ab
T2	10690 b	4.13 ab	13011 ab	574 a	3052 ab
T3	10610 b	4.37 b	12592 ab	590 a	3144 b
T5	8850 a	4.36 b	10634 a	574 a	2528 a

Data within each column not followed by the same letter are significantly different using Duncan's Multiple Range Test at the 5% confidence level.

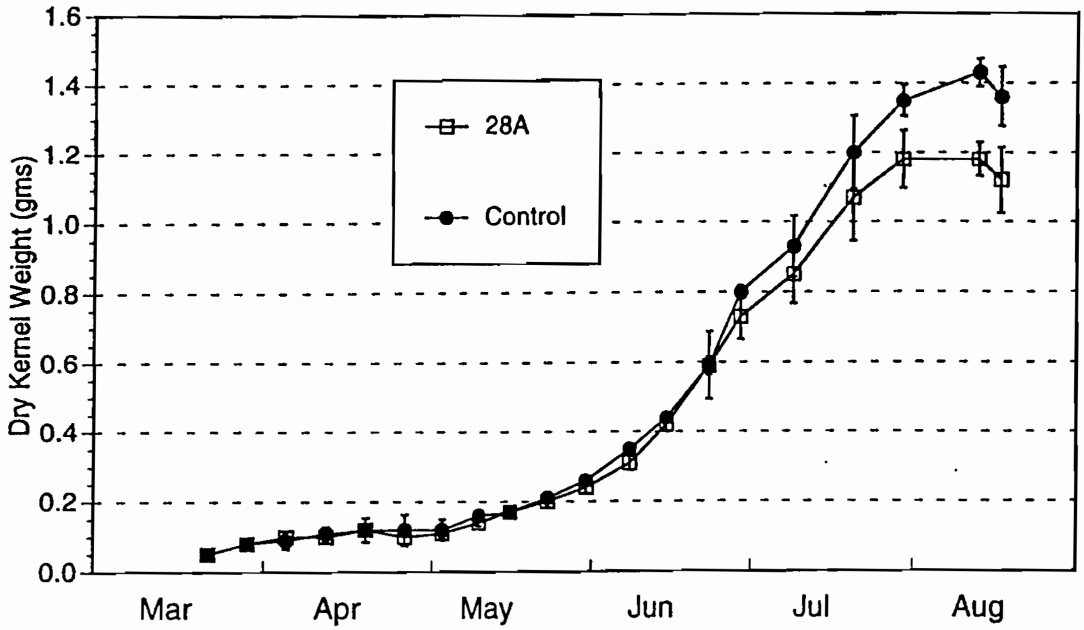

Fig. 1. **Almond kernel dry matter accumulation. Vertical bars are ±1 standard deviation.**

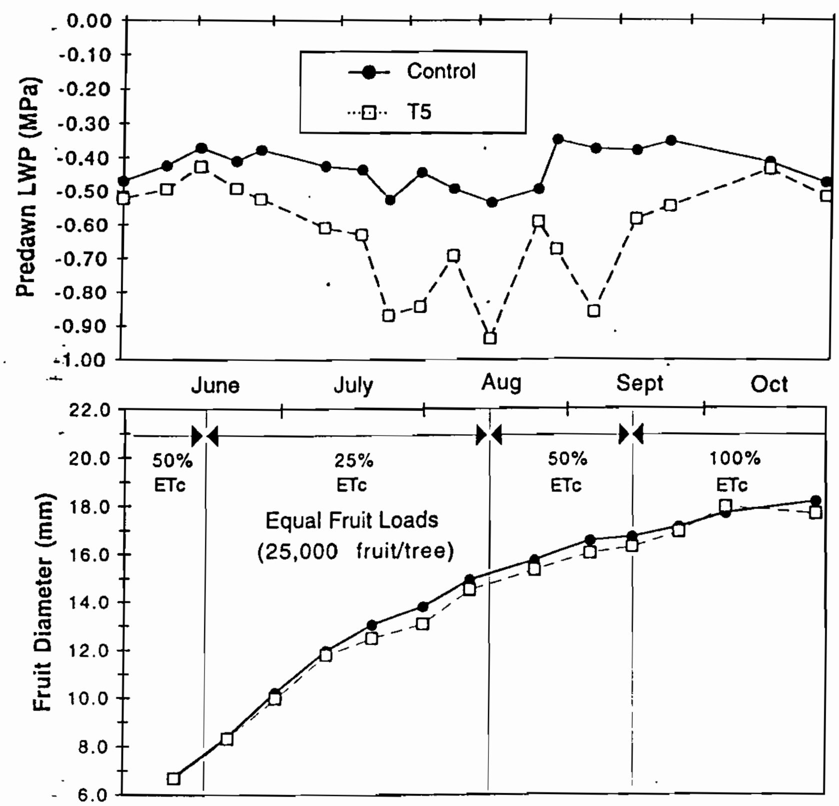

Fig. 2. **Olive predawn leaf water potential and fruit growth with time in 1994. Growth comparison is for equally cropped trees.**

Irrigation Insights for Fall and Winter Planted Field Crops

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INTRODUCTION:

Mild winter climate in the San Joaquin and Sacramento Valleys enable farmers to produce annual field crops nearly year-round. Rotational patterns include summer crops such as cotton, processing or fresh market tomatoes, corn, dry beans, rice and others. Summer crops are commonly planted in April and May and harvested between July and October. After summer harvest, a winter planted crop may follow such as wheat, barley, or garbanzo bean or an early spring planted crop such as safflower. Plantings occur from late October through February and harvests occur between May and August depending on the specific crop.

Rotational crops introduce biological diversity and interrupt monocultural cropping practices which often lead to intensified insect, weed, soil tilth, and soil fertility problems. This paper reviews available information on irrigating winter rotational crops. It discusses seasonal trends in crop evapotranspiration for winter grains, garbanzo bean, and cites limited information for safflower. It also discusses critical stages of crop growth and development, and harvest timing as it pertains to irrigation and irrigation cutoff. Lastly, it examines an important role that winter rotational crops may have in managing farmlands with shallow water table.

Trends in Seasonal Crop Evapotranspiration:

Seasonal crop evapotranspiration (ETc) is the total water used by the crop to produce sufficient yields that are profitable at the farm level. Water is either evaporated from the soil surface or consumed by the crop through transpiration or evaporated from the soil surface. Surface evaporation is a significant component of the seasonal ETc from germination until the seedling crop has grown a canopy which shades 60 to 70 percent of the soil surface. At that point, transpiration becomes the primary component of ETc.

Seasonal ETc is not the same as the total applied water required to produce a crop. It will be less than the total applied water because of non-uniform applications of water that are apparent with any irrigation system. Water applied with a well designed and managed furrow or flood irrigation system may only exceed the seasonal ETc by 15 to 25 percent. Whereas, a lesser designed and managed system may exceed the seasonal ETc of a crop by 25 to 50 percent or more.

Table 1 summarizes published levels of seasonal ETc for winter planted crops of wheat, barley, garbanzo bean, safflower and for a grass reference pasture crop.

Table 1. Reasonable crop evapotranspiration estimates for the central SJV.

	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Season Total
Crop	**Evapotranspiration (inches/month)**												**inches**
Wheat Forage[1]				0.1	0.5	1.1	3.5	6.2	3.9				15.3
Wheat Grain				0.1	0.5	1.1	3.5	6.2	7.8	3.0			22.1
Barley Forage				0.4	0.7	1.6	4.1	5.8	2.3				15.4
Barley Grain				0.4	0.7	1.6	4.1	5.8	4.6				17.2
Garbanzo Bean[2] (1900 lb/ac Yield)				0.3	0.7	1.4	2.0	3.2	3.0	0.2			10.8
Garbanzo Bean (2800 lb/ac Yield)				0.3	0.7	1.4	2.0	4.0	7.2	2.9	0.4		18.9
Safflower[3]						0.3	0.7	3.9	11.3	11.9	3.0		31.1
Grass[4] Reference	5.3	3.4	1.4	0.7	0.8	1.5	3.3	4.9	6.6	7.8	8.2	7.2	51.1

Closer examination of the monthly evapotranspiration values in Table 1 for a grass reference pasture that has a healthy, well watered canopy growing and transpiring water year-round illustrates the potential for less water demand by rotational crops grown in the winter. The reference ETc for pasture totals only 12.6 inches (25 percent of the annual reference ETc) for the

[1] Estimates of ETc for wheat and barley grain and forage crops are based on crop coefficients published in UC Publication 21454. Goldhamer and Snyder. 1989.

[2] Estimates of ETc for garbanzo bean are findings from two years of research sponsored by the California Dry Bean Council at the UC Westside Research and Extension Center. Fulton, Roberts, Frate, and Mueller. 1994/95. Publication in progress.

[3] Estimates of ETc for safflower from Westlands Water Conservation Handbook. 1984.

[4] Data from California Department of Water Resources Report. 1986.

six months of November through April. In contrast, 38.5 inches of ETc accumulates (75 percent of the annual ETc) for a pasture during the six months of May though October.

Thus, the issue becomes selecting field crops that can germinate successfully and develop during the coldest winter months. Wheat, barley, garbanzo bean, and safflower are crops with this potential.

Crop Specific Considerations Related to Irrigation:

Wheat Forage and Grain:

The acreage of wheat grown in the San Joaquin Valley fluctuates from approximately 500,000 to 1,000,000 acres annually. The planted acreage depends on current year prices of wheat and alternative crops. Wheat is a multi-purpose crop; it is grown for milling uses, domestic seed and feed supplies, and dairy forage. Approximately one-third of the planted acreage is commonly harvested for dairy forage and the remaining two-thirds is harvested for milling grain and domestic feed and seed.

Table 1 provides a comparison of seasonal ETc for wheat harvested as grain or seed versus dairy forage. It is a common practice to harvest wheat for forage at the soft dough stage of grain development. This typically occurs between April 25 and May 10 depending upon whether it is a late October/early November planting or a late November/early December planting. Harvesting for forage at the soft dough stage of grain development opposed to producing grain will reduce the seasonal ETc by about 7.0 inches of water per acre per year (refer to table 1). Usually the rainfall season coincides with the growth and development of wheat, so it is possible to grow wheat for forage with only one or two irrigation (6.0 to 10.0 inches of irrigation water per acre) in a season, except during very dry years.

A shift from harvesting wheat at the soft dough stage of grain development to harvesting wheat (and perhaps triticale) at the boot (pre-heading) stage of development may occur over time. The motivation behind the change may be the ability to harvest a higher protein forage that could be substituted for alfalfa in rations of milking dairy cows. Currently, soft dough wheat forage is primarily fed to dry cows and heifers. Two factors currently prevent this shift: wheat forage prices do not adequately reward farmers to grow higher quality boot stage forage; and absence of varieties that mature later and in turn give higher boot stage forage yields and reduced risk of rainfall at harvest. In the event that this shift should happen, the seasonal ETc for wheat forage would be less than suggested in Table 1.

With respect to wheat for grain production, Table 1 shows that approximately 25 percent (5.0 inches/ac) of the crop water use occurs from planting in November/December through March. This is commonly supplied by rainfall, thus the first crop irrigation is often not considered until late March or early April, except during unusually dry years. The majority (14.0 inches/ac) of the crop water use occurs during the months of April and May. This period coincides with when heads of wheat emerge from the leaf sheath through grain development. It also correlates with 1100 cumulative growing degree days after first heading using a 32° F minimum and 90°F maximum temperature. Irrigation cutoff ranges from the last week of April on finer textured soils with higher water holding capacities and as late as the second week of May on courser textured soils with lower water holding capacities.

Barley for Grain and Forage:

Patterns of crop ETc for barley grain or forage are similar to wheat (refer to Table 1). Its main difference from wheat is when it is grown for grain. Barley varieties have a condensed period of grain development which results in earlier maturing crops and reduced ETc (about 20 percent less). This is of most value where barley is grown for grain on marginal soils with limited production potential and where the goal is to produce a crop with minimal inputs. Barley is not the preferred crop for forage because of a greater tendency to lodge on soils with higher nitrogen fertility, lower forage yields, and inferior forage quality.

Garbanzo Bean:

Garbanzo bean is an attractive alternative to wheat and barley especially when wheat prices are low. Presently, it is a minor crop in the SJV, typical planted acreage is under 20,000 acres annually.

Table 1 illustrates the range in seasonal crop ETc for the crop depending on the yield goal. Seasonal ETc may range from about 11.0 to 19.0 inches for bean yields ranging from about 1900 to 2800 lbs/ac. It may be possible to achieve yields as high as 3200 to 3400 lbs/ac when sufficient water is supplied to meet 20.0 to 22.0 inches/ac of seasonal ETc.

Like wheat and barley, ETc is low during the four months from December through March and the primary months of ETc are April and May. Two years of research revealed that it is possible to attain yields of about 1900 lbs/ac with just one irrigation either applied as a preirrigation or irrigation after planting to germinate the crop plus rainfall. Added yield was attained with additional irrigation in March, April, and early May. Research also revealed a significant interaction between irrigation and nitrogen fertilization. Although garbanzo bean is a legume and rhizobium inoculated seed was planted, a modest addition of nitrogen applied at planting (60 lbs N/ac) increased yield while slightly reducing ETc.

Safflower:

Seasonal ETc for safflower has been studied less than the other winter crops discussed above. A study in the early 1960's at UC Westside Field Station (Pomeroy and Knowles) showed that seed yields of 2900lbs/ac could be achieved with 25.5 inches/ac applied water and yields of 3800 lbs/ac could be achieved with about 38 inches of applied water. They also reported no yield response and a slight yield suppression when applied water exceeded 38 inches/ac. However, this study did not discern the difference between applied water and seasonal ETc.

Table 1 provides seasonal ETc values developed by Westlands Water District. ETc patterns show extraordinary water consumption by safflower in June and July. This demand is primarily supplied by a preirrigation or irrigation after planting, rainfall, and an expansive root system that extracts water from deep subsoils. It is risky to supplement safflower with irrigation in the warmer months of April and May because phytophthora root rot diseases can seriously infect the crop.

Winter Cropping Farmlands with Shallow Water Table:

Long term monitoring of shallow water table In regions of the SJV with poorly drained soils show that water table levels fluctuate within a year. Water levels are nearest the soil surface in the spring (March/April) which reflects regional preirrigation practices and they are the deepest in the fall (Sept/Oct) which reflects regional irrigation cutoff for harvest of crops. Winter rotational crops fulfill a positive role in shallow water table management because their maximum crop growth and water demand coincides with periods of when shallow water table is nearest the soil surface.

Wheat, barley, garbanzo bean, and safflower all have the potential to use water from shallow water table to meet a portion of their seasonal ETc, thus reducing their irrigation requirement. The extent of which the crop can acquire water from a shallow water table will depend on its tolerance to salinity and root development. Studies have shown that up to 50 percent of the seasonal ETc can be supplied by water from the shallow water table when it is within the salinity tolerances of the crops.

The semi-dwarf type hard red wheat varieties such as Yecora Rojo and barley are the most salt tolerant of these crops. Research has shown that they can tolerate salinity in excess of 5.3 dS/m in the water table with no affect on the crop and that they can tolerate salinity of 10 dS/m in the water table with modest affects on production. Durum wheat has been shown to be significantly less tolerant of salinity than the hard red, semi-dwarf type wheats. Research indicates that durum wheat can tolerate salinity of about 4.0 dS/m in the water table without any affect on yield.
While wheat and barley are the most salt tolerant of these crops they have a fibrous root system which may be more restricted by differences in soil texture and structure within a rootzone. Thus, while they may tolerate more salinity in the water table they may not be as effective at attaining water from the shallow water table as safflower and garbanzo bean which both have taproots.

Safflower is not as tolerant of salinity in shallow water table as wheat and barley. However, it is considered moderately tolerant. It is reported to tolerate salinity in the water table in excess of 4.5 dS/m with no affect on the crop and can use water from shallow water table with 8 dS/m salinity levels with only modest affects on crop production. Safflower has been shown to have the most expansive root system of these crops. It can establish roots effectively in fine textured soil in excess of 6 feet deep.

Garbanzo bean is the least tolerant of salinity in the shallow water table among these crops. Garbanzo bean can tolerate salinity of about 3.3 dS/m in the shallow water with no affect on production and may be able to acquire water from shallow water table with salinity of about 5.0 dS/m with moderate affects on yield. Garbanzo bean can also develop an expansive root system. Research has revealed significant levels of water extraction from soils 4 and 5 feet deep.

Conclusions:

Winter rotational crops (wheat, barley, garbanzo bean, and safflower) have long been recognized to introduce biological diversity into a cropping system from insect, weed, and soil management perspectives. They also have positive roles in farming with limited water supplies and managing soils with shallow water table.

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IMPROVING WINEGRAPE QUALITY USING DEFICIT IRRIGATION TECHNIQUES

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Winegrapes are grown in all areas of California ranging from the North Coast, Central Coast, Delta Region, Central Valley to the desert and south areas of the state. Each of these areas produce distinctive wine products. That is not to say a given variety can be successful in all parts of the state. Since winegrape yield and quality in each region is largely determined by climate, soil and irrigation management practices. Additionally, the use of rootstocks as well as canopy management can significantly influence the end product of wine quality. Winegrape fruit quality is of importance consequence since consumption is greatly influenced by perceived quality. The fruit composition largely determines grape quality and subsequent wine quality. Fruit quality is most often related as sugar content, organic acid level and distribution, pH and wine color. Some of the quality parameters may be of greater or lesser concern in each variety and high levels of some parameters may not be attainable in all viticultural regions.

Water Deficits

Water deficit achieved through irrigation management has been observed to significantly affect fruit and wine quality parameters. However as stated by Webb in 1981, supplemental irrigation is recognized as a factor in determining grape composition, the solutes that impact varietal character and high fruit quality are not well understood.

The probable reason for this dichotomy is that irrigation scheduling research has been hampered by the inability to define quality goals and secondly to link these with specific irrigation management practices. This situation has improved using the previously stated fruit and wine quality parameters and the use of advanced instruments to measure soil moisture, vine water status and estimate climatic water demand.

On a practical basis, growers and vintners understand irrigation management can be a powerful tool which in controlling vegetative growth and fruit quality. The difficulty is in predicting the outcome of irrigating management decisions on a wide range of soils and climatic conditions. Irrigation water management includes control with both the volume of vine water use and the timing of water applications. Controlling irrigation application by supplying water causing less than full water use results in vine water deficits.

Study to Evaluate the Effects of the Timing and Severity of Water Deficits

An experiment designed to evaluate the timing and severity of water deficits on the vine fruit and wine quality of Cabernet Sauvignon was conducted for five years. The mature cabernet vineyard is on Dogridge rootstock and bilateral, cordon trained at 7½ x 11 ft spacing. All treatments are pruned alike at 20, 2-bud spurs per vine. The soil at the site has a moderate water-holding capacity with a root limiting layer near six feet. A full coverage micro-sprinkler irrigation system is used to supply water to each replicated treatment independently. The well water supply is of good quality and contains less than 150 ppm total dissolved solids. The experimental design is a randomized block of 5 treatments containing 4 replications of each treatment. The experimental site is located near Lodi, California, and the research funded by the Lodi-Woodbridge Winegrape Commission.

Project Chronology

The study was initiated in 1992 with the imposition of 5 irrigation strategy treatments. Treatment 1 was supplied with adequate water so as to maintain favorable vine water status throughout the season. Vine water use was measured by soil water disappearance using a neutron probe. Water use of this treatment was considered full or 100 percent potential water use.

Treatments 2 and 3 were managed in a fashion to consume near 70 percent of the full potential water use (treatment 1) through harvest. Treatment 2 experienced a moderate pre-veraison water deficit followed by a more severe post-veraison through harvest period water deficit (Table 1). Treatment 3 experienced a more severe pre-veraison deficit followed by a moderate deficit in the post-veraison through harvest period.

Treatments 4 and 5 consumed 50 percent of full potential water use through harvest. Treatment 4 experienced a moderate pre-veraison water deficit followed by a more severe post-veraison through harvest period water deficit. Treatment 5 experienced a more severe pre-veraison deficit followed by a moderate deficit in the post-veraison through harvest period.

All treatments, with the exception of the full water use, did not receive irrigation from first berry color through full cluster color. All treatments were postharvest irrigated.

Table 1
Imposed Irrigation Levels and Water Deficit Timing

Treatment	Pre Veraison	Post Veraison	Postharvest
T1 - 100%	0	0	0
T2 - 70% +-	+	-	0
T3 - 70% -+	-	+	0
T4 - 50% +-	+	-	0
T5 - 50% -+	-	+	0

+ = moderate water deficits
- = increased water deficits
0 = no water deficits

RESULTS

The first year (1992) of imposed treatments did not result in significant yield reductions. Results presented herein are an average of the years 1993 through 1995.

Yield Significant differences in yield were found between irrigation treatments (Table 2). The full potential water treatment (T1) produced the highest yield at 38.3 lbs/vine (10.1 tons/acre). Both 70% of potential water use treatments (T2 and T3) averaged 30.4 lbs/vine or 79% of the full potential water use treatment. The 50% of full potential water treatments were the lowest group at 25.6 lbs/vine or 67% of the full potential water treatment.

The timing treatments (T3 and T5, pre-veraison water deficits) resulted in a few pounds/vine increase over the post-veraison treatment. In each case, however, the difference is not significant.

Table 2. 1996 Harvest Data

Treatment	Yield (lbs/vine)	Clusters per vine	Cluster Wt (lbs)	Berries per vine	Berry Wt (gms)
T1 - 100%	38.3 a	131 a	0.293 a	13819 a	1.26 a
T2 - 70% +-	29.7 b	114 b	0.262 bc	13094 a	1.04 b
T3 - 70% -+	31.1 b	115 b	0.269 b	13468 a	1.05 b
T4 - 50% +-	24.6 c	108 c	0.224 d	11215 b	0.99 b
T5 - 50% -+	26.6 c	109 c	0.241 cd	11955 b	1.01 b
p =	0.0000	0.0000	0.0000	0.0000	0.0000

Common letters among means within columns denote no significant different at $P \leq 5\%$ using DMR mean separation.

Yield Component Analysis

An attempt was made to develop a relationship between the independent variables and the dependent variables, in this case, yield. The procedure quantifies the linear relationship between variables and measures the strength of the relationship. Using simple regression, the number of berries per vine explains the largest amount of the variability in yield at 60.1 percent (adjusted r^2). Berry weight by itself explains 55.1 percent (adjusted r^2) of the variation in yield.

Using multiple regression with both yield components in the model, an excellent fit is achieved (adjusted $r^2 = 98.7$). Yield can be described as:

$$\text{yield} = -28.0608 + 0.00224171 \times \text{berries per vine} + 27.572 \times \text{berry weight}$$

Vine Canopy Response

Each year resulted in slightly different total shoot growth and canopy light measurements. For brevity, the 1994 results are presented.

Vine response to water deficits are measured as maximum shoot length, the percent of land surface shaded by the canopy, the mass of prunings, and leaf cover of the fruit. Additionally, a relationship of yield per unit prunings was developed to assess the balance of vegetation to reproductive structures.

Total shoot length. The length of sixteen primary bud shoots per plot were measured on August 4, 1994. Shoots were significantly longer in the full water use treatment as compared to all other treatments (Table 3).

Land surface shading by the canopy was measured midday throughout the season. By midseason (July 8), the canopy size of all treatments, with the exception of full water use treatment, was maximized at near 55 percent (Table 3). It is important to note that while the rate of shoot growth for the full water treatment exceeded all others after July 8, the land surface shaded area only increased 3 percent to a maximum of 63 percent by harvest.

Prunings. The mass of prunings were significantly different between treatments. The full water treatment (T1) was greatest at 8.7 lbs/vine, followed by the 70 percent treatments (T2 and T3), and lastly by the 50 percent treatments (T4 and T5) (Table 3).

Table 3.

Treatment	Shoot Length 8/4/94 (cm)	Land Surface Shading 7/8/94 (%)	Mass Pruning (lbs/unit)	Yield/Pruning (lbs)
T1 - 100%	313 a*	60 a	8.7 a	5.3 a
T2 - 70% +-	170 b	55 b	7.7 b	4.3 b
T3 - 70% -+	168 b	55 b	7.6 b	4.8 ab
T4 - 50% +-	162 b	54 b	6.3 c	4.3 b
T5 - 50% -+	202 b	55 b	6.9 bc	4.3 b

* Common letters among means within columns denote no significant difference at $P \leq 0.05$.

PAR canopy penetrating light. Leaf cover of the fruit is probably best measured by the amount of light penetrating the canopy at the cordon level. Measurements of photosynthetically active radiation (PAR) were made using Sunfleck Ceptometer®. Measurements were made on top of the cordon for a length of one meter in each direction. Measurements were made just prior to harvest.

Juice Quality

An attempt was made to harvest all treatments at similar °Brix. Treatment sugar levels measured at harvest were not significantly different, averaging 23.6 °Brix. Differences between treatments were found in pH, TA, malate concentration, and potassium concentration. Levels of each quality component were higher (least desirable) in the full potential water treatment.

Table 4. Juice Analysis

	pH	TA	Malate	K+	°Brix
T1 - 100%	3.53 a	6.36 a	2935 a	1581 a	23.3
T2 - 70% +-	3.53 a	5.70 b	1939 b	1569 a	23.6
T3 - 70% -+	3.46 b	5.78 b	1663 b	1530 a	23.8
T4 - 50% +-	3.46 b	5.72 b	1595 b	1472 ab	23.6
T5 - 50% -+	3.41 b	5.86 b	1618 b	1386 b	23.7
p =	0.0000	0.0000	0.0000	0.0119	n.s.

Potassium concentration was higher and not significantly different in all but the lowest water level treatments. Malate concentration was dramatically decreased by nearly half in the deficit treatments when compared to the full potential water treatment.

Juice pH was found to be significantly higher in the full and 70% post-veraison deficit treatments. Treatments 2 and 3 consumed similar volumes of water. However, the timing of the deficit apparently reduced pH more if imposed pre-veraison as in T3.

Wine Analysis

As seen in the juice, water deficits reduce wine pH. Table 5 indicates an unadjusted wine pH difference between T1 and T3 of 0.22 units. The results indicate wine pH is reduced by increasing severity of water deficits. Additionally, pre-veraison water stress causes further reductions when compared to more severe post-veraison deficits. Titratable acidity and potassium content results are similar to that of pH.

Wine Color

Significant wine color differences were found as a result of imposed treatment. Increase color density measured at the 420 nm to 520 nm wavelength indicates a strong relationship between color and water consumed (Table 5). When comparing Treatments 2 and 3 to Treatment 1, the color density at 70% water level improved by 30% (420 nm), then to 70% for the 50% water level. At the 520 nm wave length, only the full potential water treatment was significantly different. All deficit treatments nearly doubled the color density.

Table 5. Wine Analysis

	TA	pH	K	520	420
T1 - 100%	5.23 ab	4.00 a	1667 a	2.09 a	1.66 a
T2 - 70% +-	5.17 a	3.88 b	1450 ab	4.73 b	2.14 b
T3 - 70% -+	5.57 bc	3.71 c	1333 bc	4.77 b	2.27 b
T4 - 50% +-	5.70 cd	3.67 c	1183 c	4.51 b	2.95 c
T5 - 50% -+	6.03 d	3.59 d	1092 c	4.44 b	2.74 c
p =	0.0038	0.0000	0.0038	0.0183	0.0013

SUMMARY

Five irrigation strategies were imposed on Cabernet Sauvignon winegrapes near Lodi, California. Treatments varied in controlling the timing and severity of water deficits experienced by the vine (with the exception of the full water treatment). Significant differences were found in yield, measured must and wine parameters. The results significant to the Lodi area are reduced pH and increased depth of color while producing an average 8.0 tons/acre on the Treatments 2 and 3.

Treatment 3, reduced water use by 30% through harvest and imposed early (pre-veraison) water deficits. This resulted in a significant reduction in wine pH, potassium, and a significant increase in wine color when comparing the sum of the 420 nm and 520 wavelength. This increase in quality was achieved at a 18% yield reduction.

Micro-irrigation for Tree Crop Production

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Introduction

Micro-irrigation systems used for irrigating tree crops include microsprinklers, surface drip, and subsurface drip irrigation systems. They are all characterized by being irrigation systems which are operated frequently and apply water at low application rates as compared to sprinkler and flood irrigation systems. They are also characterized by use of emission devices with small passageways; leading to clogging concerns which need to be considered in the design and management of the systems.

Use of a micro-irrigation system also results in an orchard which has only a portion of its surface wetted. Whereas a sprinkler or flood irrigation system wets the entire orchard floor and its underlying soil, micro-irrigation systems utilize only a portion (usually 40 - 60%) of the orchard's soil volume. Roots are concentrated in this wetted volume and frequent irrigations keep water constantly available to the trees; minimizing water stress. Orchards under sprinkler or flood irrigation go through a series of wetting and drying cycles with the potential for tree water stress if the soil becomes too dry. Proper irrigation scheduling will prescribe irrigation before the water stress results in yield reduction.

Micro-irrigation Systems Available for Tree Crops

As mentioned previously, surface drip, subsurface drip, and microsprinklers are all currently being used for irrigating tree crops. *Surface drip systems* utilize drip emitters, usually manufactured to discharge 0.5 gph or 1 gph, which are either punched into polyethylene tubing or manufactured as an integral part of the tubing (in-line emitters). Emitter discharge is a function of the irrigation system's operating pressure, with emitter discharge increasing as pressure increases. The exception being pressure-compensating emitters which discharge at a constant rate with pressure changes; as long as the pressure is above a threshold level. Drip irrigation systems are designed with multiple emitters per tree with the number of emitters being dependent on the emitter discharge rate, tree spacing, and the evapotranspiration (ET) demand of the orchard. The emitters per tree must be capable of supplying the tree's perk ET demand. Well designed drip systems can replace the tree's peak daily water uptake by operating no more than 16 to 18 hours per day. Most drip systems are designed to be operated daily during peak ET periods in order to minimize irrigation system costs. The number of emitters per tree selected may also be influenced by the consideration of wetting an adequate soil volume. This ensures adequate anchorage and provides a "reservoir" of stored nutrients and available water.

Subsurface drip systems share the same considerations previously mentioned for surface drip systems, but the water delivery is directly to the trees root zone. Subsurface drip products most frequently used for tree crops are drip tubing with in-line emitters or tubing with emitters manufactured integrally to the inside of the poly tubing. In very limited use are drip tape materials, which while less expensive do not have the structural strength of drip tubing.

Subsurface drip laterals are frequently buried quite deep; 16 to 24 inches being common. The laterals are placed this deep primarily to keep irrigation water from wetting the soil surface. A dry soil surface minimizes weed growth, allows orchard traffic and cultural practices even while irrigating, and even allows irrigation during harvest. For example, during harvest of nut crops like almonds and walnuts, surface drip or microsprinklers often cannot be operated while trees are being shaken, nuts are on the ground, or while they are being picked up. Subsurface drip systems which don't "sub" water to the surface allow irrigation to continue through much of these harvest operations.

Two disadvantages of use of subsurface drip systems are the inability to visually check for emitter clogging (discussed later) and the potential for root intrusion. Root intrusion is dealt with either by choosing a drip tubing product which has an herbicide impregnated into the emitters or by careful management including frequent irrigations and/or chemical injections.

Microsprinklers range from foggers, often used in citrus, which may discharge less than 3 gallons per hour (gph) to large fixed pattern or rotating microsprinklers which may discharge 30 to 40 gph. The fixed pattern micros (e.g. Bowsmith FanJet) throw water in particular shapes (e.g. half circles, butterfly patterns, etc.) and they can be selected based on their placement relative to the tree. Microsprinklers wet a larger area (diameters 8 to 30 feet) so they often readily cover at least the recommended 40-60% of the orchard floor.

While the orifices of the smaller microsprinklers are similar in size to the flow passageways of drip emitters, the larger micros have larger orifices and are therefore less likely to clog. The "jetting" velocity of microsprinklers also seems to reduce clogging. In most cases, they still need high quality filtration systems in order to continue operating properly.

Unlike drip irrigation systems, most microsprinkler systems, with their higher application rates, are not designed to be operated every day; even during peak ET periods. It is more common to have them designed to operate every 2 to 4 days during peak ET periods. The higher discharge rate of the microsprinklers often results in slightly higher initial costs due to the larger main / submain pipe sizes required.

Since they wet a larger area or volume of soil than do drip systems, microsprinklers seem to be particularly well adapted to use on sandier soils which have a lower waterholding capacity. Microsprinklers can be susceptible to wind drift and likely have higher evaporative losses than do drip emitters. This is particularly true in a young orchard.

Management of Micro-irrigation Systems

Irrigation Scheduling

Scheduling irrigations for micro-irrigation systems is different than that for sprinkler or flood irrigation systems. Sprinkler or flood system irrigation scheduling makes extensive use of the soil as a medium in which water is stored for use by the trees between irrigations, which may be two to three weeks apart. A large irrigation is applied to completely refill the tree's root zone. Under micro-irrigation, irrigation amounts (usually determined by ET estimates) are gauged to replace the soil water used since the last irrigation. For drip irrigation, this may be the amount of water used by the tree the previous day. Even with microsprinklers, it may only be the amount of water used in the last 2 to 4 days. Micro-irrigated orchards are therefore less dependent on the soil as a storage medium for water. This has allowed micro-irrigated orchards to do well under soil conditions which would cause significant problems under sprinkler or flood irrigation.

Micro-irrigation, because of its extensive hardware, allows the manager excellent control over where and how much water is applied; resulting in high potential irrigation efficiencies. Sprinkler and particularly flood irrigation are dependent on the water intake characteristics of soils - notoriously spatially and temporally variable.

Irrigation scheduling using soil moisture monitoring devices is complicated by the limited wetted soil volume, which makes their proper placement difficult. Their utilization to monitor whether the wetted soil volume is changing during the season, an indication of over- or under-irrigation, is very useful. They are therefore excellent tools to use in conjunction with ET estimate irrigation scheduling.

Maintenance

Micro-irrigation systems are particularly susceptible to *clogging problems* due to their small flow passageways. Clogging can be caused by physical particles, such as sand, in the water. This physical clogging can be controlled by proper filtration. Filters include screen filters, disk filters, and sand media filters; all of which can do an excellent job of removing the physical particles. The degree of filtration is often specified by the drip emitter or microsprinkler manufacturer.

Clogging by organic matter, such as algae, bacterial slimes, colonial protozoa, etc. is most frequently associated with use of surface waters. Surface water include water from natural streams or rivers, water delivered in open channels, and water stored in reservoirs or ponds. Management of organic matter clogging is accomplished through use of media filters and injection of a biocide such as chlorine. Sand media filters are most frequently used because of their greater filtering capacity which allows longer filtration times between required cleaning (backwashing). While screen and disk filters can be equally effective in removing organic matter, they tend to clog quickly and are difficult to clean or organic materials. Depending on the severity of the problem, injection of chlorine ranges from continual injection (1-2 ppm residual chlorine at the ends of the laterals) to periodic injections (every 2 to 4 weeks) at slightly higher rates (5-10 ppm residual chlorine).

Chemical precipitation of calcium carbonate, iron, manganese, calcium phosphate, etc. can result in clogging of micro-irrigation systems. Chemical precipitate clogging is most often associated with use of groundwater. Most of the calcium or magnesium compound precipitates can be prevented or remedied by lowering the water pH to 6-6.5. Iron and/or manganese precipitation is more difficult to deal with. The most frequent "treatment" is pumping the water into a pond or reservoir and allowing time for the oxidized iron or manganese to settle out.

Additional maintenance tasks include inspecting filters and pressure regulating valves to ensure they're working properly. Inspection of emitters to spot leaks or clogs is often done each time the micro-irrigation system is operated. This is most easily done with microsprinkler systems and very difficult with subsurface drip systems; although leaks usually show up readily.

Flushing of mainlines, submains, and laterals is very important. Silt and clay particles are small enough to pass nearly all filters and these particles usually end up at the end of the lateral lines. Flushing the system periodically, every 2-4 weeks, is often adequate.

Field Comparison of Micro-irrigation Systems

In 1990, a 9-hectare planting of almonds (referred to as the Marine Ave. orchard) was established at the Nickel's Soils Laboratory near Arbuckle, CA (90 km northwest of Sacramento, CA). The Nickel's Soils Laboratory is a trust, managed by the University of California, to investigate soil, water, and tree crop issues of concern to orchardists in the Sacramento and northern San Joaquin Valleys. While the facility's main objective is applied research, the facility is typical of grower-owned orchards and one which generates revenue from the sale of its tree crop yields (almonds and walnuts predominate).

The three types of micro-irrigation systems selected were surface drip, subsurface drip, and microsprinklers. "Which is the best micro-irrigation system for tree crops?" is a frequently asked question by those who are considering the purchase and installation of a micro-irrigation system. Information which compares the performance of trees irrigated by various types of micro-irrigation systems since establishment is scarce. An objective in evaluating the Marine Ave. orchard was to isolate any tree responses which could be attributable to micro-irrigation system delivery method. Variables such as irrigation amount, fertilizer application, and cultural practices were held constant between irrigation system treatments.

Irrigation Systems

As mentioned previously, surface drip, subsurface drip, and microsprinklers are used to irrigate the various plots of the Marine Ave. orchard. Fig. 1 shows the current layout of plots by irrigation treatment as well as by almond variety. The plot layout is a modified, randomized block design with 12 replications of each of the three types of micro-irrigation systems being investigated. The irrigation treatments have evolved since orchard establishment to account for information learned in the course of the experiment. Within each irrigation plot are 6 tree rows;

one row each of the Monterey and Carmel almond varieties, and two rows each of the Nonpareil and Butte almond varieties.

The water supply for the Nickel's Soils Laboratory is Sacramento River water, provided by the US Bureau of Reclamation Central Valley Project to a local irrigation district, which in turn provides it to its members. The surface water is drawn from open, concrete-lined canals and pressurized for delivery to growers via pipelines. The delivery pressure is insufficient to operate the micro-irrigation systems so the pressure is increased by a pump at the Marine Ave. orchard. The water is filtered using two, 120-cm sand media filters. Injection points are provided both upstream and downstream of the filters for chemigation. Injection is done using a positive displacement, diaphragm pump.

Separate mainlines and submains supply the drip treatments and the microsprinkler treatments so that they can be operated independently. Separate, pressure-regulating valves, operated by a controller, are used to control the irrigations. Separate flowmeters for the drip and microsprinkler systems are used to monitor applied water. In addition, smaller flowmeters are installed on selected, lateral lines at a dozen locations within the orchard.

The Marine Ave. orchard was established using surface drip emitters and microsprinklers. All drip treatments shown in fig. 1 (drip, double-line drip, and various sub-drip treatments) were irrigated for the first year using a single lateral per tree row, surface drip line. Initially, 2 drip emitters (4 l/hr Netafim, pressure-compensating, emitters), 120 cm apart, one located on each side of the tree were used. For the "drip" and "double-line drip" treatments, which are both surface drip irrigated, additional 4 l/hr emitters (120 cm apart) were added to the single lateral line per tree row, drip line the following year so that each tree (tree spacing = 4.9 m x 6.7 m) had four emitters per tree.

In the spring of 1995, 6 of the 12 original "drip" (surface drip - single lateral per tree row) plots were converted to "double-line" (two lateral lines per tree row), surface drip irrigated treatments. Soil moisture monitoring using gypsum blocks, tensiometers, and the neutron probe, along with backhoe investigations, provided evidence that under the soil conditions at Marine Ave. there was limited lateral movement of water (60 - 90 cm laterally from the drip line) in the single lateral line, drip treatment; thus limiting the root zone development. It was postulated that use of a double-line, surface drip system (one lateral line on either side of the tree row) would provide a greater wetted area and allow a more extensive root system to develop. The double-line, surface drip system uses Bowsmith, 2 l/hr., Tru-Flo emitters on a 1.2 m spacing. Thus, there are 8 emitters per tree. The drip system is operated at a pressure such that the double-line drip system applies water at the same application rate (mm/hr) as the single-line drip system.

The trees in the subsurface-drip treatments were irrigated for the first year using a single-line, surface drip system with two, 4 l/hr emitters per tree. At the beginning of the second irrigation season, the subsurface drip systems were installed. Two products are being used: Netafim RAM tubing and Geoflow tubing. Both products utilize a hard, polyethylene tubing with emitters built into the tubing. The RAM tubing utilizes pressure-compensating emitters. The Geoflow product has an herbicide (Treflan) impregnated into the emitters to prevent root intrusion. Installation depth was 40 cm with various combinations of distance from the tree row and number of lateral lines per tree row (see fig. 1) being installed (e.g. "Buried drip 2' single Netafim" = subsurface drip, Netafim RAM tubing / single lateral line, 60 cm from the tree row). All subsurface drip products were chosen so that their emitter discharge and spacing would result in the same application rate (mm/hr) as the surface drip treatments.

Irrigating orchards with subsurface drip irrigation is still relatively new and not widespread in California. Information on optimal placement (depth and distance from the tree row) is slowly being developed as growers install and utilize the systems. From the lessons learned at the Marine Ave. orchard and from monitoring and conversations with other tree crop growers using subsurface drip irrigation, the following guidance is appropriate: First, the decision of whether to use a single or double lateral line per tree row configuration follows many of the same "rules" as for surface drip-irrigated orchards. Larger trees, such as walnuts, planted on wider spacings frequently perform better with a double drip line per tree row configuration. For widely spaced plantings (e.g. 8 m x 8 m or greater), it may also be necessary to utilize a double lateral line configuration to meet orchard evapotranspiration demands.

Second, subsurface drip irrigated orchards are frequently established by using a single, surface-drip lateral during the first year after planting. Emitter placement, usually 1 or 2 emitters per tree, along this lateral line targets water to the young tree which has a limited root zone at planting. At Marine Ave., the subsurface drip lateral(s) were installed the second season and use of the surface drip line was discontinued. An alternative strategy, which appears from grower experience to work well, is to operate both the subsurface drip line(s) and the surface drip line during the first year. Use of the surface lateral line is then discontinued the second year. It should be noted that the irrigation system (filters, pipelines, etc.) must be designed to handle the higher flowrates, resulting from the use of the surface drip laterals during the first year.

Finally, a major advantage of use of subsurface drip irrigation can be the weed control and easy orchard access resulting from the dry orchard floor. Unfortunately, many subsurface drip irrigated orchards, including the Marine Ave. orchard, have experienced "surfacing" of water in which water moves to the soil surface and causes a wetted area above each emitter. This wet spot allows weed growth and can be a hazard to wheel traffic in the orchard. Surfacing has been a problem in systems with laterals installed as deep as 60 cm. Soil type and conditions play a role, but surfacing has not been restricted to heavier-textured soils, as the Marine Ave. orchard proves. An important factor in preventing surfacing seems to be keeping the emitter discharge rate as low as possible. At the Marine Ave. orchard, greater surfacing occurs in the treatments utilizing 4 l/hr emitters (single lateral per tree row) than. those using 2 l/hr emitters (double lateral lines per tree configuration).

The microsprinkler irrigation treatments utilize a single, 360°, Bowsmith Fan-jet microsprinkler. Water is discharged upward through an orifice, impacting on to a horizontal top plate which is configured to throw out the water in "fingers" or separate streams. Microsprinklers with various orifice sizes can be obtained. The orifice size, along with the operating pressure, controls the microsprinkler discharge rate. The top plate configuration controls the pattern of application. Patterns include full circles, half-circles, 270° patterns, butterfly" patterns, etc. Currently, each microsprinkler at the Marine Ave. orchard is placed midway between trees in the tree row. The wetted diameter is approximately 4 m. This keeps the crown of the tree dry, minimizing disease problems.

The trees in the microsprinkler treatment plots were established using the microsprinklers. For establishment, the microsprinklers were located close to the young trees and the microsprinkler heads covered with a piece of polyethylene drip tubing. This restricted the spray of the microsprinkler and caused the water to fall at the base of the microsprinkler, acting similar to a large bubbler. The system was run for relatively short periods of time to wet the soil surrounding the young trees. In following years, the microsprinklers were moved away from the trees to their present position - midway between trees. Establishment of the almond trees using this technique worked well. Following the first year, it was evident from visual observation that the trees in the microsprinkler plots were larger than those in the drip irrigated plots.

Irrigation System Management

The management of the Marine Ave. orchard is similar to that of commercially-operated, almond orchards in the vicinity. Irrigation scheduling is done using an evapotranspiration (ET) / soil moisture monitoring approach. Irrigation set times for the season are estimated based on historical ET information. Unusual weather conditions (either high or low ET), which is reflected in real-time ET information, is compensated for. In addition, monitoring of soil moisture using the neutron probe, tensiometers, and gypsum blocks is done to confirm the irrigation schedule.

Maintenance of the Marine Ave. orchard's irrigation system is typical for operation of micro-irrigation systems in the area. Media filters are flushed on a regular basis and secondary screen filters are cleaned when necessary. Periodic chlorination is done to control organic growth in the system. During chlorination, the objective is to get 5 - 10 ppm of chlorine to the end of the laterals for a period of approximately 6 hours. Chlorination is done monthly, or as needed. The mainlines, submains, and laterals are flushed on a regular basis. Due to the extensive irrigation system evaluation done in 1994 and 1995, the lateral lines were flushed frequently. While flushing is time-consuming (216 lines must be flushed in the Marine Ave. orchard's 9 hectares), it has been essential in maintaining the irrigation systems' high uniformities.

Irrigation System Performance

Installation of the Marine Ave. orchard, with its various micro-irrigation systems, offered an excellent opportunity to follow the performance of the various systems through time. Most growers using or considering use of micro-irrigation systems are interested in how long the irrigation system will last and if it will maintain its performance all through its operating life. With the assistance from a grant from the California Energy Commission, it was possible to do extensive irrigation system evaluations during the summers of 1994 and 1995, and limited evaluations during 1993.

Evaluation of the surface drip systems was done by collecting discharges from selected emitters in each plot. For example, in the 1995 evaluations, 44 emitters were selected within each drip plot and discharge collected from them for a set time period. From this information, the average discharge rate and irrigation uniformity were determined. Irrigation uniformity was measured using Emission Uniformity (EU) where:

$$\begin{array}{c}\text{Emission}\\ \text{Uniformity (EU-\%)}\end{array} = \frac{\text{Average discharge rate of low 25\% of emitters sampled}}{\text{Average discharge rate of all emitters sampled}} \times 100$$

Table 1 summarizes the average discharge rates and uniformities of the surface drip irrigation plots for the 1993 -95 seasons. In analyzing the drip-irrigated plots discharge and emission uniformity information in Table 1, it is evident that even after 6 seasons of operation the surface drip system is working well. Irrigation uniformities are high. For 1995, the overall emission uniformity for all the single-lateral, surface drip-irrigated plots was over 90%.

Those 6 plots listed in Table 1 as "surface drip / 2 laterals" are the surface drip irrigated, one lateral line per tree row, treatments which were converted in 1995 to surface drip irrigated treatments with 2 lateral lines per tree row. Thus, the 1993 and 1994 data shown for those plots is for a single lateral-line system while the 1995 data is for a double lateral-line system. While only its first year, the double lateral-line system shows high irrigation uniformity, both within plots and between plots.

The microsprinkler irrigated plots were also evaluated by collecting discharge from selected emitters for a set time period. The information for the 1994 and 1995 seasons and incomplete information for the 1993 season are contained in Table 1. The irrigation uniformities of the microsprinklers is high and has remained consistently high even after 6 years of operation. Microsprinkler discharge rates vary from plot to plot as well as from year to year for a particular plot. The microsprinklers are not pressure-compensating and the discharge rate is therefore dependent on the operating pressure. Emitter discharges for a plot from year to year are therefore likely to vary depending on management and operation. Consistent irrigation uniformity for a plot across the years is the desirable trait, and the data for the Marine Ave. orchard exhibits this characteristic. Variable discharge rates between plots during a year is not desirable, but is inevitable in a commercial orchard. At the Marine Ave. orchard, variations in microsprinkler discharge rates between plots is primarily a result of elevation differences within the orchard. Some of the pressure differences are controlled by valves in the orchard. The major drawback to non-uniform discharge rates between plots is that irrigation scheduling and operation times are adjusted to ensure that the areas with the lowest microsprinkler discharge rates receive adequate water. This results in some over-irrigation of other portions of the orchard with higher discharge rates.

Evaluation of the subsurface drip plots is difficult. Collecting discharge from emitters is impractical so two other methods have been used to gain information on performance of the subsurface drip system. First, pressures are monitored at the tail end of each subsurface lateral line. The lateral ends are left exposed above ground so that they can be opened for flushing. A pressure gauge connected to a drip irrigation fitting is placed on the end of the lateral temporarily to get the pressure at that point. Consistent end-of-lateral pressures throughout the orchard is an indication that submains and manifolds have been well-designed with minimal friction losses. Second, in 1995, a 19 mm (3/4") flow meter, adapted with drip fittings, was temporarily installed at the inlet end of each subsurface drip lateral line, and a flow measurement was taken over a time period (e.g. 10 minutes). While this procedure garnered some valuable information and is one of the few methods for detecting non-uniform discharge in subsurface drip laterals, is has its drawbacks. While providing information on lateral line discharge, it does not isolate any problems along the lateral. Use of the portable flowmeter evaluation technique is time-consuming and difficult. Disconnecting the lateral line can be difficult depending on the fittings used. Once the lateral line is disconnected and the flowmeter is installed, it takes a number of minutes for the lateral line to come back up to a constant pressure. In taking the flow measurement, a long enough time period must be allowed to get a reliable measurement; somewhat difficult when the flowrate is low (less than 4 l/min). It was found that a 10 minute measurement period provided adequate information.

Almond Tree Performance

As stated previously, one objective in establishing the Marine Ave. orchard was to investigate whether there were any differences in almond tree response which could be attributed to the type of micro-irrigation system used. To this end, variables such as amount of applied water, fertilizer, etc. have been held constant between irrigation treatments.

Almond Tree Trunk Diameter

During 1994 and 1995, trunk diameter information was collected. Trunk diameter measurements were taken 30 cm above the ground surface using a diameter tape. Table 2 lists the mean trunk diameters, by almond variety and irrigation treatment for 1994 and 1995. While complete statistical analysis has been done on the data to determine differences in mean trunk diameter, by irrigation treatment, for each of the almond varieties, only conclusions consistent across almond varieties will be discussed here. First, for both 1994 and 1995, microsprinkler irrigated trees had larger trunk diameters than did trees in any of the other irrigation treatments. Since applied irrigation water is the same for each irrigation treatment, the most likely explanation for larger, microsprinkler-irrigated trees is that a larger volume of soil is wetted by the microsprinklers, leading to a larger root volume (confirmed by backhoe investigations). It was this explanation which lead to addition in 1995 of the double lateral line, surface drip irrigation treatment to the experiment. It is unlikely that any growth differences resulting from adding the second lateral line would appear in the first year after conversion, and in fact there was no statistical difference between the 1995 measurements of mean trunk diameters of the single lateral line and double lateral line surface drip treatments.

Second, in general, there was no statistical difference in mean trunk diameter between any of the subsurface drip treatments or between any of the subsurface drip treatments and the surface drip treatment. From this information, there does not appear to be an advantage with regard to tree growth among any of the various methods of drip irrigation.

Almond Yield

The first year of harvestable yield for the Marine Ave. almond orchard was 1994. Yield information was collected on the Nonpareil and Butte varieties, by irrigation treatment, and is shown in Table 3. In 1994, there were greater average yields (statistically significant) in the microsprinkler plots versus the surface or subsurface irrigated plots. While not statistically significant, there appears to be a trend toward greater yields in the subsurface drip irrigated plots vs. the surface drip irrigated plots. Table 2 also contains preliminary information on average almond yields for the 1995 season. At the time of preparation of this manuscript, the 1995 yield information was still being statistically analyzed. The 1995 season was a poor season for almonds in much of California. Late winter rains fell during almond bloom and adversely impacted yields, particularly of the early varieties such as Nonpareil. Inspection of Table 3 and preliminary statistical evaluation indicates that there was no difference in almond yield between any of the irrigation treatments.

Plot No.*	Irrigation System	1993		1994		1995	
		Avg. q (l/hr)	EU (%)	Avg. q (l/hr)	EU (%)	Avg. q (l/hr)	EU (%)
1	Surf. drip / 1 lateral	3.79	94	3.94	91	4.06	87
7	Surf. drip / 1 lateral	4.24	91	4.05	89	4.16	91
14	Surf. drip / 1 lateral	4.39	91	4.13	90	4.15	88
21	Surf. drip / 1 lateral	4.62	85	4.28	84	3.95	95
31	Surf. drip / 1 lateral	4.01	96	4.05	92	3.95	93
36	Surf. drip / 1 lateral	4.16	95	4.20	91	4.02	92
6	Surf. drip / 2 laterals	4.01	96	3.97	94	1.84	96
12	Surf. drip / 2 laterals	4.54	96	4.24	88	1.87	94
17	Surf. drip / 2 laterals	4.09	95	4.54	84	1.89	94
24	Surf. drip / 2 laterals	4.54	92	3.97	89	1.77	95
27	Surf. drip / 2 laterals	4.09	95	4.05	91	1.91	94
29	Surf. drip / 2 laterals	4.16	94	4.01	92	1.82	92
2	Microsprinkler	29.9	87	38.1	90	40.3	89
4	Microsprinkler	33.3	98	42.1	92	43.5	90
8	Microsprinkler	39.0	95	41.0	93	41.6	93
10	Microsprinkler			38.5	94	41.5	94
15	Microsprinkler			38.0	80	38.9	86
18	Microsprinkler			39.9	88	39.7	88
20	Microsprinkler	37.7	85	37.1	94	39.2	92
23	Microsprinkler			36.8	94	39.3	94
25	Microsprinkler			40.8	89	46.6	90
30	Microsprinkler			39.5	90	41.4	93
32	Microsprinkler	36.7	94	37.5	92	40.1	93
35	Microsprinkler	46.6	94	43.3	97	48.3	94

* Note: See fig. 1 for plot locations within the Marine Ave. orchard

Table 1. Field-measured mean discharges (Avg. q) and emission uniformities (EU) for the irrigation treatments at the Marine Ave. almond orchard.

Irrigation Treatment	1994 Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	12.04	13.50	12.91	13.18
Microsprinklers	12.58	14.13	14.13	13.36
RAM - single lateral	11.99	13.61	13.25	13.15
RAM - double lateral	11.74	13.46	13.28	13.28
Geoflow - double lateral	12.55	14.52	13.48	13.11
All Sub-drip	11.83	13.51	13.23	13.27

Irrigation Treatment	1995 Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surf. drip - single lateral	13.70	16.65	15.62	15.33
Surf. drip - double lateral	14.22	16.09	15.41	15.06
Microsprinklers	14.59	17.52	16.13	17.03
RAM - single lateral	13.85	16.12	15.30	14.96
RAM - double lateral	13.97	16.65	15.84	15.49
Geoflow - double lateral	14.33	17.32	15.38	15.51
All Sub-drip	14.20	16.76	15.55	15.85

Table 2. Mean almond tree trunk diameters (cm) by irrigation treatment and almond variety for 1994 and 1995.

Almond Yield (kg/hectare)

Irrigation Treatment	1994 Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip		1164	1182	
Microsprinklers		1738	1720	
Subsurface drip		1381	1386	

Irrigation Treatment	1995 Almond Variety			
	Carmel	Butte	Nonpareil	Monterey
Surface drip	723	836	1031	1610
Microsprinklers	846	815	1100	1560
Subsurface drip	969	983	1152	1465

Table 3. Almond nut yields (kg/hectare) by almond variety and irrigation treatment.

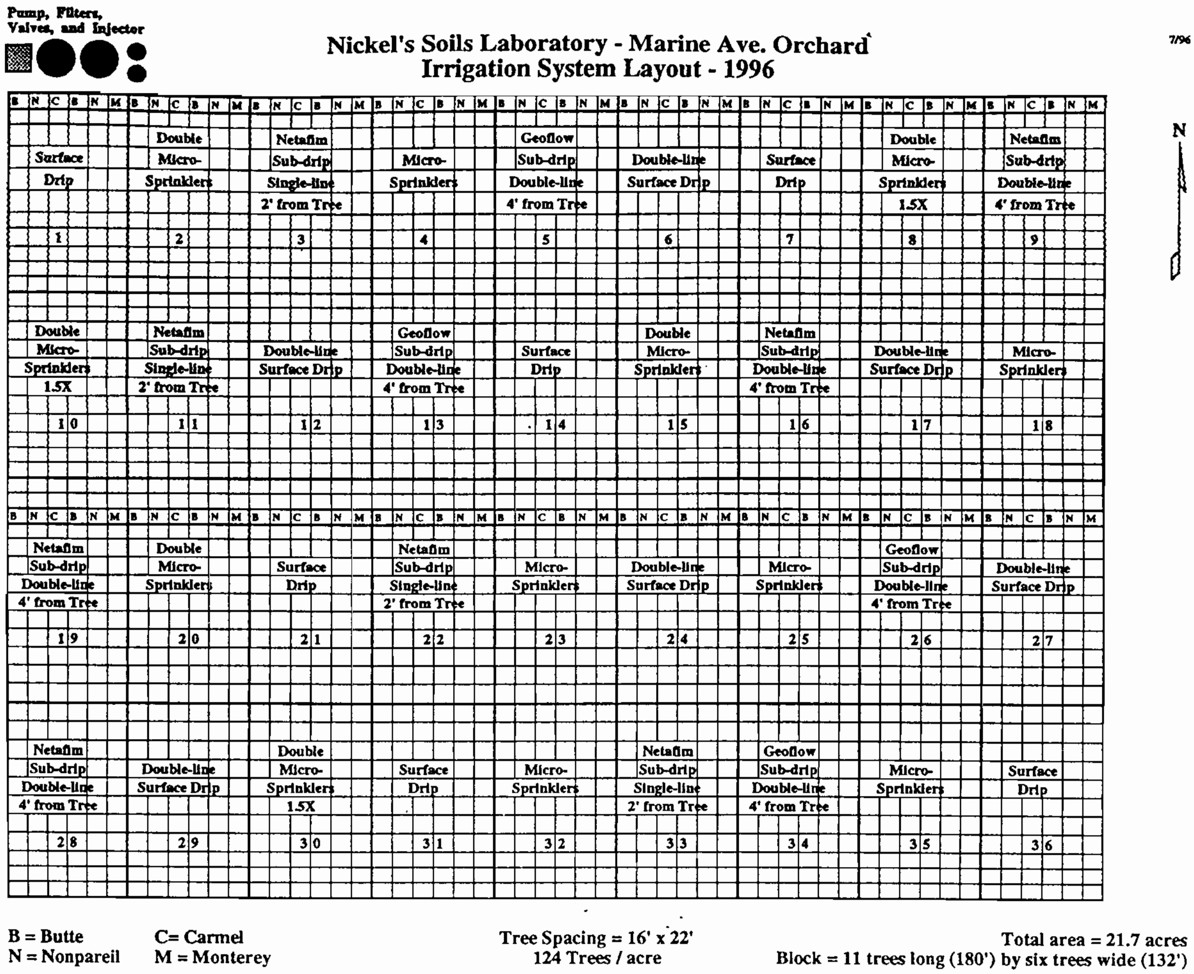

Fig. 1. Marine Ave. orchard layout showing irrigation system treatments and almond varieties.

STRATEGIES FOR UTILIZING SHALLOW GROUNDWATER IN ARID AREAS

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INTRODUCTION:

Shallow groundwater is a pervasive problem in arid irrigated areas. The west side of the San Joaquin Valley is one area which typifies the interaction between irrigation, shallow groundwater and the need for subsurface drainage. Since the closure of the Kesterson Reservoir, drainage has been eliminated as an alternative for managing shallow groundwater on thousands of hectares of irrigated land on the west side of the San Joaquin Valley. As the State of California revises the water quality standards in the San Joaquin River, the volume of drain water discharged into the river will be reduced because of the need to meet load requirements of salt and selenium. What then to do with shallow groundwater to prevent it from either becoming drain water or waterlogging soils.

The San Joaquin Valley Drainage Program Report (1990) listed several solutions to the problem of drain water and shallow groundwater. The first part of the solution was source control. This entails improved irrigation water management which results in less deep percolation losses and thus less shallow groundwater and drain water. The second part of the solution was to use the drain water for irrigation. The second proposal could be modified to include the goal of in-situ use of shallow groundwater by crops. This wasn't specifically addressed in the report but should be considered as an option in the solution alternatives being tested as part of the solution to the drainage water disposal problem. This abstract will discuss some management alternatives for utilizing shallow groundwater in arid irrigated areas and will present data from studies conducted on the west side of the San Joaquin Valley.

MANAGEMENT ALTERNATIVES:

Shallow groundwater management alternatives can be classified as passive without drains, passive with drains, and active with drains. Each of these alternatives has been given a limited evaluation in the San Joaquin Valley. Examples of each alternative will be given in the following sections. Supplemental irrigation using saline drainage water is also considered.

Passive without drains In this alternative the ability for a crop to use water from the shallow groundwater depends on the crop, the depth to the shallow groundwater, the groundwater quality, and the irrigation management as determined by the irrigation system in use. Hutmacher and Ayars (1991) used column lysimeters to demonstrate the effect of groundwater quality, depth to groundwater and age of the crop on groundwater use by cotton. The data in figure 1 show that as the groundwater became more saline the percentage of cotton evapotranspiration coming from the groundwater in the column lysimeters declined. The data also show that very little water is used from groundwater early in the season and the percentage increases as the season progresses and the rooting depth increases. The data in figure 2 for cotton grown in a column lysimeter show that for the same groundwater quality the percentage of water from the groundwater is reduced as the depth increases from 1.2 to 2 m (4 to 6.5 ft). Also, the time when use begins is delayed as the depth increases.

For management this means that the crop will have to be irrigated to meet the full water requirement during early growth and the irrigation interval will have to be extended as the crop develops and begins to use more water from shallow groundwater. This can be accomplished with irrigation scheduling which accounts for the soil water depletion and the uptake from shallow groundwater. Ayars and Hutmacher (1994) developed a crop coefficient for cotton which does this (Fig. 3). An alternative to the crop coefficient is to use leaf water potential to schedule the timing of irrigation and using a soil based measurement of soil water to determine the depth of irrigation. This has been proven to be very effective in cotton.

The depth to groundwater will depend on the management of both the pre-plant irrigation and the in-season irrigation. Excessive pre-plant will result in the water table being close to the soil surface at planting. If this is followed with a first seasonal irrigation which exceeds the soil water storage the water table will rise closer to the surface. As the growing season progresses the depth to water will increase due to crop water use, deep drainage, and lateral flow. There will be less deep percolation as the soil water depletion increases between irrigations. This is a scenario which is typical of cotton production in areas with shallow groundwater and no drains.

<u>Passive with drains</u> In this management scenario, the rate of flow from the drains is controlled with a a permanent device having operating characteristics which are not changed after installation. A potential device would be an orifice plate which is installed in-line in a lateral. The effect of the installation is to restrict flow below the maximum potential and reduce the rate of water table recession. With excess deep percolation early in the season this would result in the water table being close to the soil surface early in the season and receding ahead of the root development. This would increase the opportunity time for crop water use. This concept has been modeled and the results indicate that the water table position is maintained closer to the soil surface longer than for free drainage. The concept of a regulated flow still needs to be tested under field conditions.

<u>Active with drains</u> This management system uses adjustable control structures to regulate the depth of the water table. Control structures might include pumped drainage sumps, weir structures placed in the drain submain or laterals, and valves in the laterals and submains. Lord (1987) used DOS-IR[1] valves to regulate water table position in one study. In a study in the Broadview Irrigation District, Ayars (1996) used weirs and valves to control the water table

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[1] Trade names are provided for the benefit of the reader and do not imply endorsement by USDA-ARS.

position under cotton and tomato crops. Managing the water table resulted in 141 mm (5.6 in) less water being applied to a tomato crop in the test field compared to a companion field. Maintaining a higher than normal water table resulted in improved vine vigor later into the season which resulted in less damage occurring to the fruit.

Using drainage water for supplemental irrigation This technique has been extensively tested by researchers from the Agricultural Research Service, USDA and the University of California. In this strategy water is pumped from the drains and stored in an above ground reservoir and applied to salt tolerant crops during the growing season. In some instances the water is mixed with the surface water prior to application. Irrigation probably has the potential for the largest use of water compared to the other strategies. In part because it can be used earlier in the season and it can be used to meet the total crop water requirement after germination. When plants use water from shallow groundwater it is as a supplement after the better quality irrigation water is used from stored soil water.

Potential water use for management strategies In a study with active drains which were not controlled, Ayars and Shoneman (1986) found that over a three year period the average use of shallow groundwater by cotton was 66, 75, and 167 mm in 4 furrow irrigated plots with the maximum use being 239 mm. In a field study with no drains, cotton being grown with subsurface drip irrigation and scheduled with a modified crop coefficient used between 270 and 304 mm of water from shallow groundwater. In a project which used saline (7 dS/m) water for irrigation, Ayars et al. (1993) used between 336 and 573 mm of saline water for irrigation of cotton and 666 mm of saline water for irrigation of sugar beet. This demonstrates the larger potential for disposal of saline drainage when used for irrigation. However, there are drawbacks to using saline water for irrigation. There are additional costs associated with the storage of the water and managing it for application. The biggest cost is associated with the problem of adding salt and other elements to the root zone. Ayars et al. (1993) found that it would take as much good water to reclaim the soil from the boron added with the saline water during a 5 year project as was saved by using saline water for irrigation. When water is used from shallow groundwater the potential for salinizing the root zone and moving boron into the root zone is greatly reduced.

SUMMARY :

This paper reviewed several methods for managing shallow groundwater to reduce the volume requiring disposal. These included passive and active management schemes. The passive management was designed to induce crop water use from shallow groundwater through improved irrigation scheduling and control of the water table position to permit longer opportunity times for crop water use. Active schemes were designed to control the water table position to maximize crop water use in conjunction with improved irrigation scheduling and to directly apply saline drainage water. Schemes which use water in-situ have the advantage of not increasing the salinity in the root zone and not moving elements such as boron into the root zone. Potential in-situ usage of shallow groundwater is lower than use in direct irrigation.

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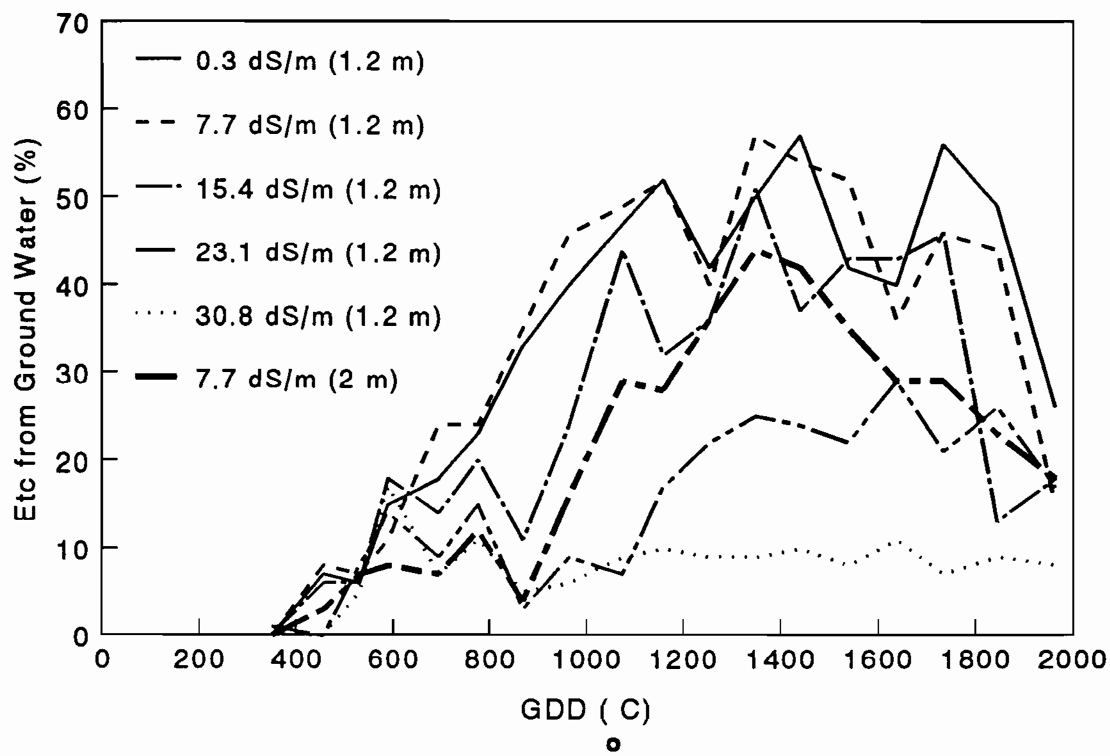

Fig 1. Percent of cotton evapotranspiration taken from shallow groundwater in column lysimeters as a function of depth to the water table and groundwater quality.

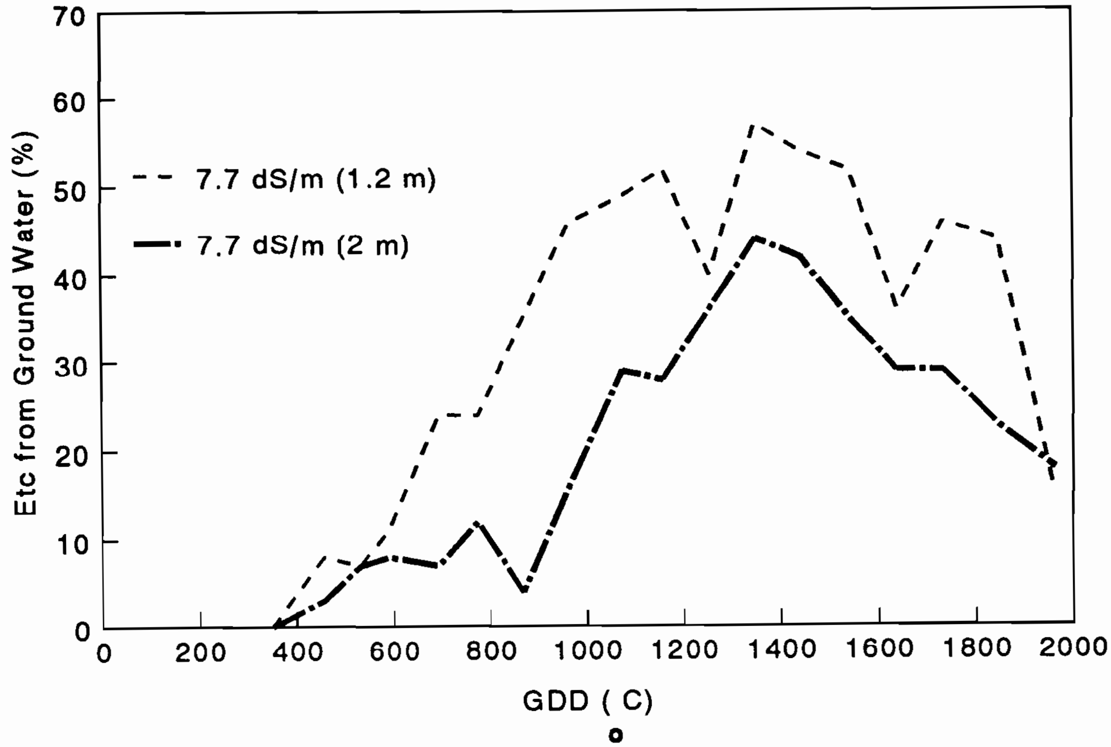

Fig 2. Percentage of cotton evapotranspiration taken from shallow groundwater in a column lysimeter as a function of depth to groundwater with an electrical conductivity of 7.7 dS/m.

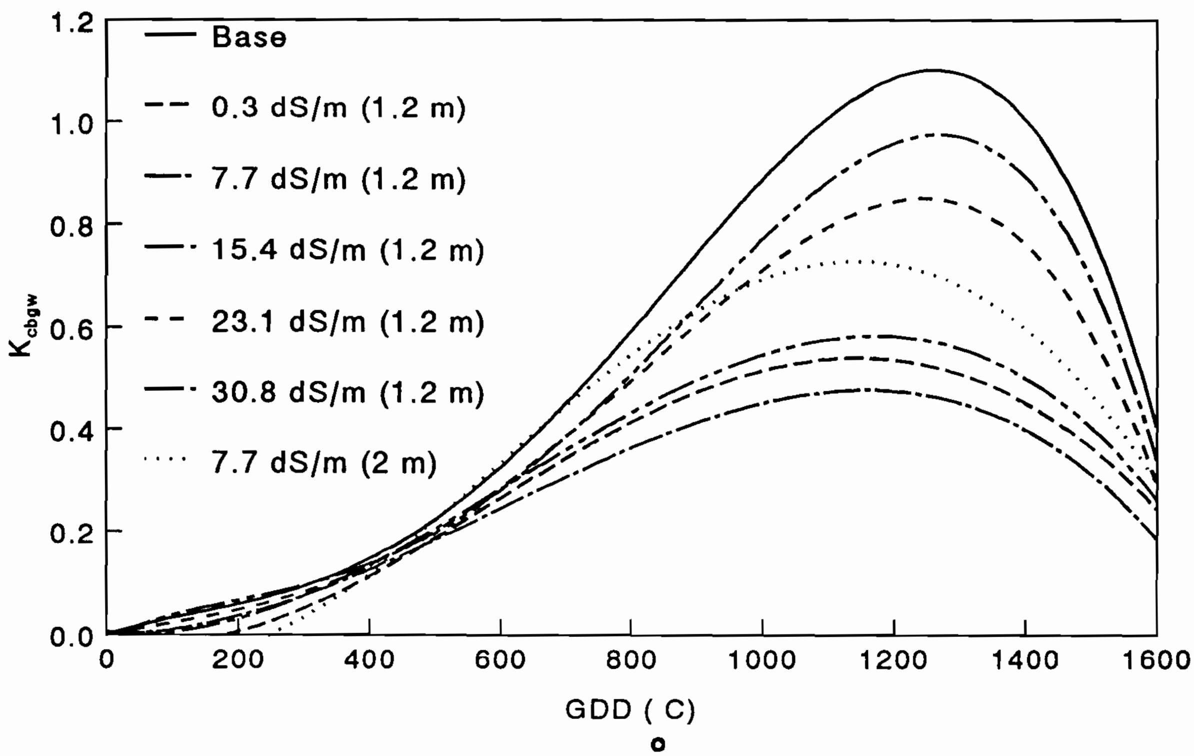

Fig 3. Modified cotton crop coefficient for use in irrigation scheduling in the presence of shallow groundwater of different electrical conductivities and depths.

Different Water Management Between Drip and Furrow Irrigation in Processing Tomatoes

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The most practical method to increase percent solids through water management was moisture stress before harvest (days water cut off before harvest).

A study at the University of California West Side Research and Extension Center showed .2 tons/acre/day loss of yield from 20 to 60 day cut-off, but solids increased .003% per day. Bostwick, or paste thickness, as well as days cut off, decreased with stress, Figure 1.

Stress during plant growth and fruit development is more risky for the grower to manage and results in about the same yield loss, but it did not improve solids or maintain paste thickness as well as days cut-off, Figure 2.

The best irrigation management for a grower to practice, as demonstrated in Table 1, was the 20% depletion which removed approximately 2.1 to 2.5 inches of water per week until 20-40 days before harvest, then irrigation was cut off. The 20-day cut off yields were 62 tons/acre, with solids 4.9%. Increasing cut-off to 40 days reduced yields to 56 tons/acre, a yield loss of 6 tons/acre, but increased solids .3% to 5.2%. This is very significant to the processor; he gets about the same tonnage of solids without buying, hauling or cooking off 6 tons of water, Table 1.

The four-year average of furrow irrigated trials at the WSR&EC is shown in Table 2. Four-year mean yields are reduced from the 20- to 40-day cut-off only 2 tons/acre, and solids are increased .3%. This data is a mean of all three moisture depletion levels during plant growth and early fruit development.

These trials were conducted on a Panoche clay loam which holds approximately 2.5 inches of available water per foot of depth with unlimited rooting. Adjustments must be made for lighter soil or soils with soil or irrigation problems that restrict rooting depths. On Panoche loam soils, water should be cut off 30-40 days before harvest to meet statewide average solids of 5.2%. Longer cut-off results in more percent solid increases, but significant yield losses.

Buried Drip Irrigation

Water management to meet processor demands of 5.2% solids, as is expected in furrow irrigation, is completely different than drip irrigation management. These trials, conducted at the University of California WSR&EC from 1991 to 1995, like the early furrow irrigation trials, have shown the type of adjustment in irrigation management that needs to be made when using buried drip.

The treatment of 110% of ETc was the highest yielding, but it also resulted in the lowest percent solids. The treatment that will bring grower and processor together is the reduced ETc of 75%, 60 days before harvest. This treatment reduced mean yields 2.8 tons/acre, Table 3, but soluble solids increased 0.25%. This treatment will be comparable to results from good furrow irrigation management. Increasing stress to 50% or 25% of ETc 60 days before harvest resulted in significant yield losses and solid increases (Tables 3 and 4). Water was cut off on the drip trial approximately 10 days before harvest.

Tomato yield differences varied between years due to our learning how to manage the drip irrigation system. In 1993, an error or lack of early fertilizer injection of nitrogen resulted in a N deficiency at third bloom and resulted in some yield loss. The 1994 season followed a dry winter and preirrigation was not sufficiently adjusted, thus the drier treatments ran out of water before harvest and resulted in severe yield loss. The late water deficit had a much larger impact on yield than percent solids (Tables 3 and 4).

Tons of solids are highest with the 75% ETc treatment. The increase in percent soluble solids compensates for red fruit yield losses. Here again, the processor would get the same solids without paying for 2.8 tons of water. The 50 and 25% reduced ETc treatments' yield losses are much larger and higher percent soluble solids do not compensate (Table 5).

The 1992 comparison of two irrigation trials at the WSR&EC would indicate the potential of drip irrigation. We were able to produce higher tonnage and higher solids with buried drip irrigation than with furrow, Table 6.

Preliminary trials on buried drip irrigation management, not reported, have indicated that some stress during first bloom to late second bloom is necessary to manage vegetative growth. By third bloom this loss of soil moisture should be replenished and 110% of ETc used.

The seven to ten-day frequency of furrow irrigation has a built-in stress between irrigations. This forces a good compromise between yields and solids.

Drip irrigation frequency of from daily to even three days per week removes all or much of the stress associated with furrow irrigation. Drip irrigation can develope a more restricted or lazy root system. Therefore, cutting water off 30 to 40 days before harvest has resulted in many disasters. The ability to continually add nitrogen fertilizers through the system has also complicated the water and nitrogen interaction, especially when using the same drip system more than one year.

Nitrogen management, when two to three or more tomato crops are grown, has not been resolved, but growers have used significantly more nitrogen than is needed, and have over-stimulated vegetative growth, usually after the second year of production.

Processors evaluation of drip irrigated processing tomatoes has not been good. Many prefer, or will not contract drip irrigated fields. These studies, and others in progress, indicate that with proper water and nitrogen management growers have the potential to supply not only higher yields but higher solids. Fields that can be properly lazer leveled, of one soil type with high water efficacy, drip irrigation will not likely improve water efficiency or improve yields.

In fields with too much slope to be efficiently leveled, or with wide range of soil types in the same field, drip irrigation should improve both yields and fruit quality if water management is done properly.

Installation costs and maintenance of drip irrigation are still high, but, as technology improves, they are being reduced. Long-term use of a buried drip system has reduced its annual cost significantly. Yearly maintenance cost of the buried drip system is a big question and will vary between users.

Figure 1 - Effect of cut-off irrigation days before harvest on yield and fruit quality

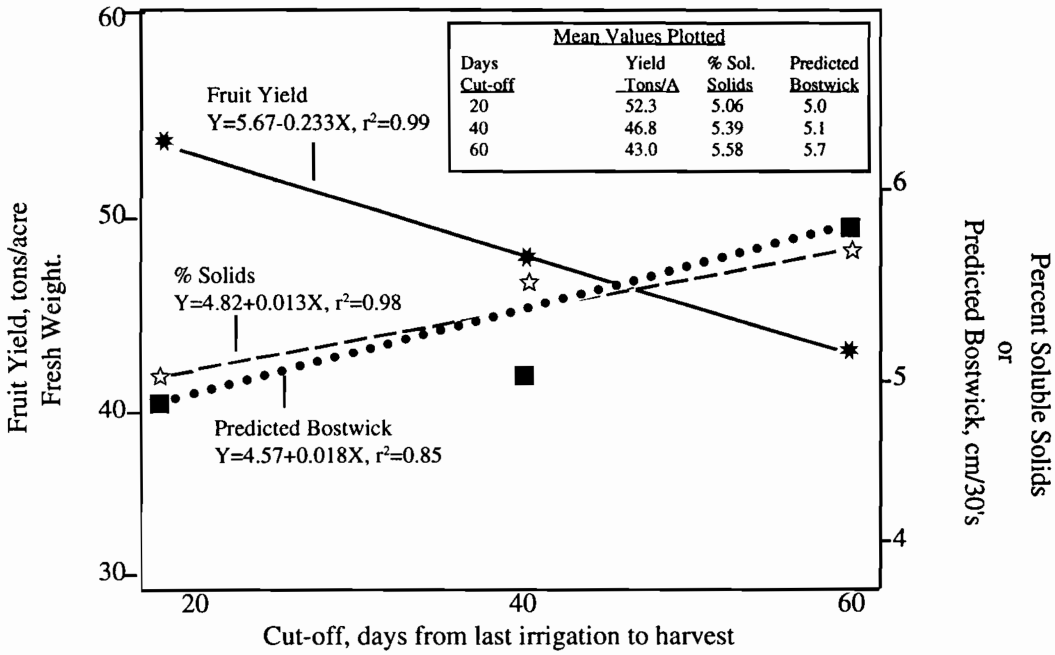

Figure 2 - Effect of percent moisture depletion on yield and fruit quality

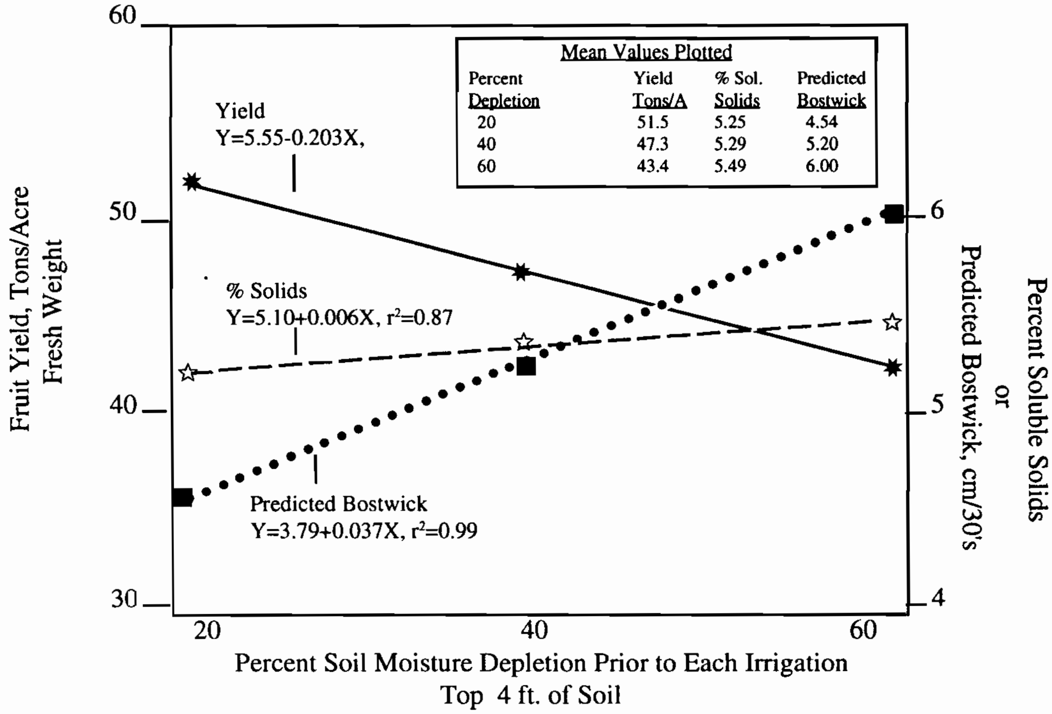

TABLE 1. **The effect of water depletion and time of cut-off on tomato fruit and solids yield, percent soluble solids, and predicted bostwick.**

% Water Depletion	Water Cut-off before harvest	Yield Fresh wt.	Solids Dry wt.	Soluble Solids	Predicted Bostwick
%	Days	------Tons/acre------		%	cm/30s
20	20	62	7.4	4.9	3.9
	40	60	7.1	5.2	4.5
	60	54	7.1	5.4	5.2
40	20	58	7.1	4.9	4.4
	40	57	7.1	5.3	4.3
	60	48	6.4	5.4	5.2
60	20	50	6.9	5.2	6.0
	40	49	6.4	5.4	5.8
	60	48	6.4	5.5	6.0
Significant Contrasts:					
Depletion		**	**	ns	***
D Linear		***	***	*	***
Cut-off		***	*	***	***
CO Linear		***	**	***	***

TABLE 2. **Four-year Summary of Results of Furrow Irrigated Tomato Yields and Fruit Quality**

Days Water Cut-off	Year of Study 1988	1989	1990	1991	Mean*
YIELD, Red Fruit			Tons/Acre		
20	43 a	47	53	52 a	49
40	43 a	44	47	53 a	47
60	38 b	40	43	47 b	42
LSD 5% - Linear		**	**		
SOLIDS			% Soluble		
20	5.0 b	4.8 c	5.1	5.2 b	5.0
40	5.3 b	5.1 b	5.4	5.3 b	5.3
60	5.6 a	5.4 a	5.5	5.8 a	5.6
LSD 3% - Linear			**		
SOLIDS*			Tons/Acre		
20	2.2	2.3	2.7	2.7	2.4
40	2.3	2.3	2.6	2.8	2.5
60	2.1	2.2	2.3	2.7	2.4
PASTE BOSTWICK			cm/30's		
20	5.2 b	4.5	5.0	5.1 ab	4.9
40	5.2 b	4.8	5.1	4.8 a	5.0
60	5.9 a	5.1	5.7	5.4 b	5.5
LSD 5% - Linear		**	**		

*Not statistically analyzed.

TABLE 3. **Buried Drip Irrigation Management Trial, Comparisons in Processing Tomatoes**

Reduced ETc Days Before Harvest	Yield - Tons Per Acre 1992	1993*	1994**	1995	Mean
ETc 110% 60 days	56.0	45.3 a	41.0 a	53.0 a	48.8
ETc 75%, 60 days	51.3	43.9 ab	39.6 a	49.1 b	46.0
ETc 50%, 60 days	52.7	42.3 ab	29.4 b	37.0 c	39.6
ETc 25%, 60 days	51.2	39.5 b	24.5 c	35.7 c	37.7
LSD level	NS	10%	5%	5%	

(ETc = ETo crop coefficient adjusted to % foliage cover.)

Note: Water applied by drip irrigation was started at first bud stage; soil profile was full of water; excess of 15" of available water at the time drip irrigation started, ETc was used to determine water needs. **This applies to all years except 1994 when soil profile was not full, which accounts for reduced yield. In 1993* the lower yield was attributable to lower ETc of 100% and plugging of drip system.

TABLE 4. **Buried Drip Irrigation Management Trial, Comparisons in Processing Tomatoes**

Reduced ETc Days Before Harvest	Percent Solids 1992	1993*	1994**	1995	Mean
ETc 110% 60 days	5.02 d	5.17 c	5.10 c	4.90 c	5.05
ETc 75%, 60 days	5.18 bc	5.33 bc	5.40 b	5.10 b	5.25
ETc 50%, 60 days	5.40 b	5.57 ab	5.90 ab	5.60 a	5.62
ETc 25%, 60 days	5.70 a	5.62 a	6.00 a	5.40 ab	5.68

LSD level 5%

(ETc = ETo crop coefficient adjusted to % foliage cover.)

Note: Water applied by drip irrigation was started at first bud stage; soil profile was full of water; excess of 15" of available water at the time drip irrigation started, ETc was used to determine water needs.

TABLE 5. Buried Drip Irrigation Management Trial, Comparisons in Processing Tomatoes

Reduced ETc Days Before Harvest	Yield-Tons Solids 1992	1993*	1994**	1995	Mean
ETc 110% 60 days	2.80	2.34	2.12	2.60	2.47
ETc 75%, 60 days	2.66	2.34	2.14	2.50	2.41
ETc 50%, 60 days	2.85	2.36	1.73	2.07	2.25
ETc 25%, 60 days	2.92	2.22	1.47	1.93	2.14

(ETc = ETo crop coefficient adjusted to % foliage cover.)

Note: Water applied by drip irrigation was started at first bud stage; soil profile was full of water; excess of 15" of available water at the time drip irrigation started, ETc was used to determine water needs.

TABLE 6. Processing Tomatoes, Comparison of Yield, Drip vs. Furrow Irrigation (1992)

Inches of	Tons/Acre		% Solids	
Water Applied	Furrow	Drip	Furrow	Drip
15″	51 a	56	4.9 c	5.0 c
9-10″	45 b	53	5.0 c	5.4 bc
6″	42 c	53	5.0 b	5.7 ab
4″	42 c	51	5.3 a	5.8 a
	5%	NS	5%	5%

Note: Approximately same water applied after first flower stage of growth. Two separate trials - no statistical comparisons between drip and furrow. Same planting date and soil type. Trials were located approximately 300 feet apart at the U. C. West Side Research and Extension Center.

Development and Promotion of Nitrogen Quick Tests for Determining Nitrogen Fertilizer Needs of Vegetables

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Introduction

The purpose of this work was to examine the feasibility of utilizing the Cardy specific ion electrode meter as a tool to assist growers to utilize nitrogen fertilizers more efficiently. These studies were funded by the Fertilizer Research and Education Program (FREP) of the CDFA. The following aspects of fresh sap analysis with the Cardy meter were investigated: 1) correlation between fresh sap analysis and traditional dry tissue analysis, 2) development of fresh sap critical levels for cabbage, cauliflower, lettuce, onion and sweet corn, 3) evaluation of plant-to-plant and in-field sampling variability, and 4) development of an integrated method fertilizer management in a drip irrigated broccoli field utilizing quick test for soil and tissue nitrate-nitrogen levels. The following are summaries for each area of investigation:

Correlation between fresh sap analysis with traditional dry tissue analysis

Table 1 contains the correlations between the dry tissue and fresh sap for the crops investigated in this study. Correlations developed in this project gave similar critical values to what has previously been reported cauliflower and broccoli; somewhat higher critical levels for lettuce; and much higher critical levels for celery. Data for cabbage, sweet corn and onions are newly developed.

Table 1. Correlations between fresh sap and dry tissue NO_3-N analysis

Broccoli	Fresh=.094 Dry + 209	$R^2 = 0.90$
Cabbage	Fresh=.056 Dry + 451	$R^2 = 0.84$
Cauliflower	Fresh=.087 Dry + 134	$R^2 = 0.94$
Celery	Fresh=.077 Dry + 91	$R^2 = 0.92$
Lettuce	Fresh=.048 Dry + 77	$R^2 = 0.89$
Onions	Fresh=.046 Dry + 93	$R^2 = 0.95$
Sweet Corn		
-Pretasseling	Fresh=.05 Dry + 190	$R^2 = 0.73$
-Tasseling	Fresh=.12 Dry + 76	$R^2 = 0.81$
-Silking	Fresh=.14 Dry + 81	$R^2 = 0.82$

Development of Fresh Sap Critical Levels

Table two contains the adequacy levels of nitrate-nitrogen in the fresh sap for the crops investigated in this study:

Table 2. Adequacy levels of nitrate-nitrogen in the fresh sap

Crop	Crop Developmental Stage	Fresh Petiole Sap NO_3-N (ppm) Adequacy Levels
Cabbage[1]	Cupping	1200 - 1500
	Early heading	1000 - 1200
	Mid heading	700 - 900
Cauliflower	Midgrowth	1000 - 1600
	Curd Development	700 - 1000
	Preharvest	500 - 800
Celery	Midgrowth	600 - 800
	Preharvest	400 - 600
Lettuce	Early head formation	400 - 600
	Preharvest	350 - 500
Onion[2]	Bulbs 0.5 - 1.5 inches	350 - 500
Sweet Corn	Entire season	600 - 700

1- Based on one year of data 2 - Long-day type of onions

Evaluation of Sampling Variability

Evaluations of plant-to-plant variability in celery fields indicated that in order to achieve a 10% margin of sampling error, from 13-42 samples would need to be collected from a field. Most tests however indicated that 20 samples per field would be adequate, and this is the common recommendation of sample size from other studies.

Nitrate-nitrogen in the fresh sap was intensively sampled on a 150' x 150' grid to obtain a measure of the in-field variability. Two celery and two broccoli fields ranging in size from 15 to 18 acres were sampled. Table 3 indicates the in field variability in tissue nitrate-nitrogen levels in the fields. All four fields were extremely uniform, with coefficients of variation from 7 to 9%. This in-field uniformity is very high. The high uniformity may be due to the following reasons: 1) small field sizes, 2) uniform soil types throughout the field and 3) high fertility (the nitrate levels in the plants do not increase once the maximum for a particular growth stage is reached). In fields with lower fertility or more soil variability, the nitrate levels in the plant tissue throughout the field will probably be more variable.

Table 3. Results of grid sampling in Four Vegetable Fields

		Mean	Minimum	Maximum		
Field	Crop	-----NO_3-N in the Fresh Sap (ppm)---			--	CV%
#1	Broccoli	2393	2100	2800	7	
#2	Broccoli	1410	1200	1700	9	
#3	Celery	1414	1200	1700	9	
#4	Celery	1082	900	1400	8	

Integrated method of managing nitrogen fertility under drip irrigation

With the integrated monitoring technique, residual soil nitrogen is monitored on a weekly basis and the plants are allowed to utilize the residual soil nitrogen before fertilization is begun. Once the crop grows to sufficient size, tissue sampling can begin and weekly samples can be collected. The information from the petiole samples is integrated with the soil nitrogen data to give an indication of when to begin fertilization and how much is adequate for the crop.

An 18-acre broccoli field near Soledad in the Salinas Valley was monitored utilizing soil nitrate-nitrogen quick tests and fresh sap nitrate-nitrogen tests at four sampling locations in the field. The soil nitrate-nitrogen levels increased between August 7th and 14th due to an application of ammonium nitrate for weed control (Table 4). This increase in soil nitrate-nitrogen levels was not reflected in the tissue samples collected on that date (Figure 1).

Table 4. Soil nitrate-nitrogen measured in an aluminum sulfate extract with EM Quant strips

Site	7/17	7/25	8/2	8/7	8/14	8/21	8/28
1	23	27	27	23	120	54	32
2	23	36	23	27	110	32	27
3	23	36	27	23	110	45	36
4	23	59	23	23	110	54	36

The petiole nitrate-nitrogen data was collected on a weekly basis. Samples were collected from the four quadrants of the field and plotted in figure 1. Fertilizer applications were withheld until the nitrate levels fell into the adequate range. During the week of August 20, fertilizer was applied at a rate at the low end of the suggested rates.

This application did not reduce the rate of decrease in petiole nitrate levels and a higher rate of fertilizer was applied the following week. For the rest of the season, fertilizer applications were adjusted each week to try to bring the tissue levels to the high end of the adequate range at harvest. Total nitrogen fertilizer application to this field was 192 pounds compared to a normal application of 295 pounds (Table 5).

Table 5. Comparison of normal fertilizer program and experimental program

Normal Fertilizer Program	lbs N	Experimental Program	lbs N
300# 13-13-13, preplant	39	600# 5-17-17, preplant	30
400# 28-0-05, spray band	112	700# 14-0-0-5, spray band	98
300# 32% N, sidedress	96	200# 32% N, injected in drip	64
150# 32% N, water run	48		
Total	**295**		**192**

There was a 103 lb/A reduction in nitrogen applied to the field in the test field compared to the normal fertilization. Some of this was due to a change in the preplant fertilizer and the banding application, but there was a reduction of 80 lbs/A in the sidedress and water run applications. With N fertilizer at about $0.38 per pound, the fertilizer reduction results in a savings of $30.40 per acre or $547.20 for this 18 acre field. In a report to the Iceberg Lettuce Research Advisory Board, Louise Jackson estimated the cost to a sample a 20-acre lettuce field to be $312.00 or about $15.60 per acre. Sampling costs for broccoli would probably be similar. The yield in this field was somewhat reduced due to a poor stand, but the quality was good and the grower thought the field was fertilized sufficiently.

[illegible] 8 am 2 pm
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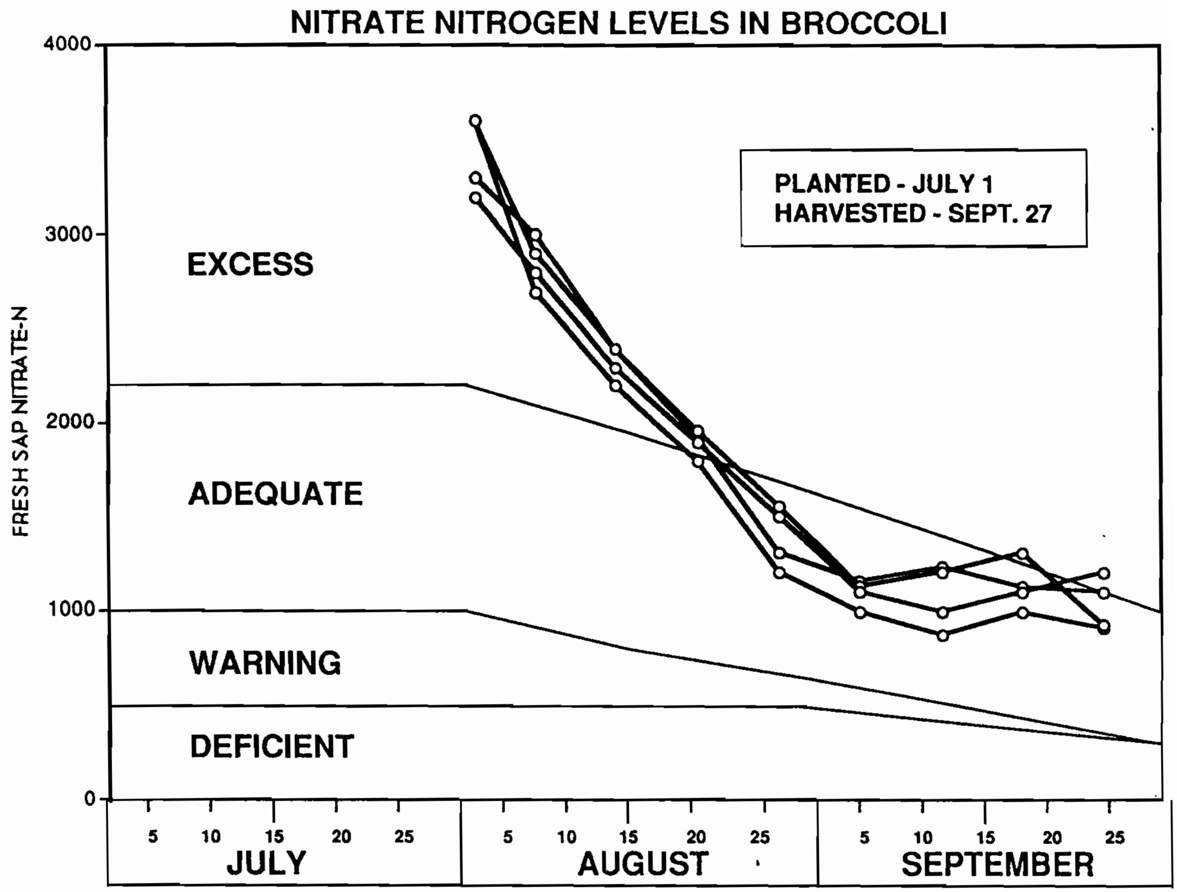
NITRATE NITROGEN LEVELS IN BROCCOLI
4000
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FRESH SAP NITRATE-N
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PLANTED - JULY 1
HARVESTED - SEPT. 27
5 10 15 20 25
JULY
5 10 15 20 25
AUGUST
5 10 15 20 25
SEPTEMBER

Figure 1.

1996 Strawberry Fruit Yields with Two Fertilizer Rates and Three Controlled Release Fertilizers in Combination with Fertigation

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Control release fertilizers can increase fruit yields by releasing a uniform amount of nitrogen throughout the growing season. Once the fertilizer prell absorbs moisture, the amount of soil moisture has little effect on the nitrogen release pattern. The major factor affecting the release of nitrogen from the controlled release fertilizer prell is temperature. The higher the temperature, the higher the amount of nitrogen released from the prell.

Most strawberry growers apply a portion of the fertilizer through the drip line (fertigation). The practice of applying both preplant sidedress fertilizer and fertigation allows the grower the best opportunity to balance strawberry requirements with fertilizer application.

PROCEDURES

A trial was established in a commercial strawberry field southeast of Santa Maria. Three controlled release fertilizers wore applied at two rates. The rates of 80 and 160 pounds of nitrogen per acre were applied on Oct. 12, 1995. The fertilizers were placed 5" below the bed surface and 2" to the side of the plants. Each fertilizer treatment was replicated four times on a randomized block design with plots 25 feet long and one bed wide (64"per bed).

The variety Camerosa was planted on Oct. 25, 1995. The plants were dug on Oct. 22, 1995 on the Lassen Canyon high elevation McArthur Nursery. Each bed had four rows of strawberries spaced 10" apart. The plants were spaced 16" apart within each row. The soil type in a Sorrento sandy loam. The fertilizer trial received the same irrigation, pest control, and picking schedule as the commercial field.

During April, May, and June the trial was harvested on a 3 or 4 day schedule and irrigated after each picking. During these months, an average of 0.7 pounds of nitrogen per day was applied through the drip tape. From July 10 to Aug. 8, the fruit was picked for the freezer and no additional nitrogen was applied,

The spring rains delayed the first harvest until March 17, 1996. The last fresh fruit harvest was July 4, 1996. The strawberries were harvested by the growers' commercial strawberry pickers. The fresh and freezer yields are based on the commercial high standards of the grower. The yield values are the average of the four replications from the 25' long and 64" wide plots.

RESULTS

The strawberry yields are shown in Table 1. There were no statistical strawberry yield differences between the three controlled release fertilizers. The controlled release fertilizers with 160 lbs of N per acre produced significantly higher strawberry yields than the plots with 80 lbs of N.

The commercial fertilizer at 160 lbs of nitrogen produced yields similar to the 80 lbs per acre rates of controlled release fertilizers.

The plot receiving nitrogen only through the drip line produced lower yields than the plot receiving preplant sidedress fertilizer application.

Supplying adequate fertilizer for early growth and establishment of the plants appears to be one of the important advantages of the preplant fertilizer practices.

There were no significant differences in the nitrogen concentration from the soil samples collected from the control, 80 lbs of N per acre, and 160 lbs of N per acre. The soil samples were collected from a depth of 0-3", 3-6", 6-9", and 9-12". The soil samples from 12" to 48" were collected at 6 inch increments.

Table 1. 1996 Strawberry Fruit Yields with Three Fertilizer Rates and Three Control Release Fertilizers in Combination with Fertigation.

	Company	Fertilizer		N Preplant	Fruit Yields*					
					Fresh		Freezer		Season Total	
				----------lbs/A----------						
1	Viridian Duration	24-8-15	urea	160	71,368	a	9,655	a	81,023	a
2	Scotts Agricote	22-7-11	urea	160	70,259	a	9,295	ab	79,553	a
3	Scotts Agriform	18-8-13	NH_4NO_3	160	69,744	a	9,172	ab	78,916	a
4	Viridian Duration	24-8-15	urea	80	65,804	b	8,672	ab	74,476	b
5	Scotts Agricote	22-7-11	urea	80	66,072	b	8,227	b	74,299	b
6	Scotts Agriform	18-8-13	NH_4NO_3	80	64,668	b	8,306	b	72,974	b
7	Growers Commercial	15-15-15		160	63,715	b	9,660	a	73,375	b
8	Control				56,747	c	8,618	ab	65,364	c
				CV%:	2.6%		7.4%		2.4%	

*Duncan's multiple range test - 5% level, yields with no letter(s) in common are statistically different.

Western States Proficiency Testing Program

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INTRODUCTION

This is a summary report of the Western States Proficiency Testing Program jointly developed by the University California Davis and Utah State University and supported by funds from the agricultural laboratory industry and the California Department of Agriculture Fertilizer Research Education Program. For 1995 and 1996 , 102 laboratories participated in the Western States Proficiency Testing Program across twenty-six states, Canadian provinces and foreign countries providing 26,700 analytical results. The program involves the quarterly exchange of three soil and three plant samples on which inorganic analysis of thirty-five soil and fourteen plant constituents are performed using established analytical methods. Quarterly statistical evaluations are provided to individual laboratory participants. The objectives of the program were: to provide an external measure of individual laboratory accuracy; develop a framework for improving the long term quality of agricultural analyses; and identify levels of accuracy and precision of specific analytical methods.

SOIL RESULTS

Soils used in the program were collected from the Western United States and represented a diverse range of chemical properties as illustrated by: salinity, 0.4 to 8.7 dS m^{-1}; pH, 5.2 to 8.5; and soil nitrate (NO_3-N), 2.0 to 110 mg kg^{-1}. Soil methods exhibiting the highest precision (based on reduced mean and standard deviation, outliers removed using the method of Dixon and Massey, 1951) soils were: saturated paste moisture %, pH (saturated paste and 1:2), NO_3-N, total Kjeldahl N, ammonium acetate extractable K (X-K) and Mg (X-Mg), and organic matter by Walkley-Black (OM-WB) method based on relative standard deviation (RSD), outliers removed. Methods displaying the greatest variability were: soluble cations, B (all methods), extractable phosphorus (all methods), ammonium acetate extractable Ca (X-Ca), DTPA extractable Mn and Fe, organic matter by loss on ignition (LOI), and cation exchange capacity (CEC). Soil salinity and pH had a RSD, of the reduced data set, of 19 and 3 %, respectively. Generally, saturated paste moisture content was reproducible within 9 %, RSD for the soils tested. Saturated paste soluble cations precision was 35 % for soils low in soluble salts ($EC_e < 1.0$ dS m^{-1}) and 20 % for soils higher in salinity. Soluble Cl and B precision ranged from 20 % on soils high is concentration of these ions to 50% for those extremely low. Soil NO_3-N concentrations were equivalent for cadmium reduction (Cd-Rd), ion selective electrode (ISE) and chromatropic acid methods (CTA) for individual soils (Table 1). The ISE method was consistently more variable than either of the former methods. Generally the RSD of the Cd-Rd and CTA soil NO_3-N methods was less than 10 % across all soils.

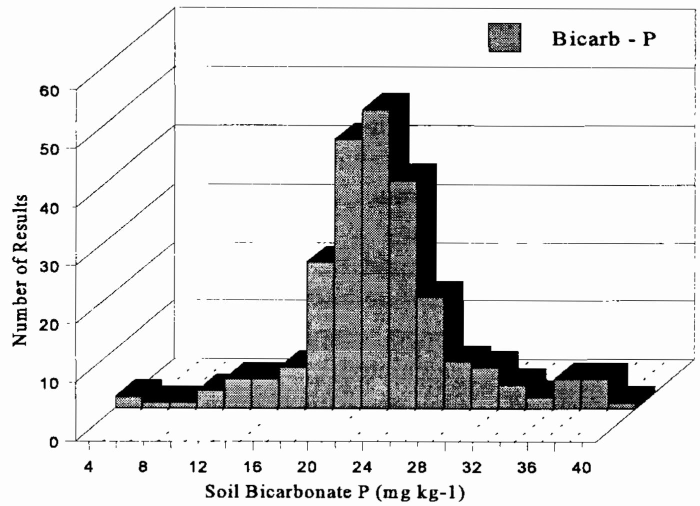
Table 1. Soil nitrate (NO_3-N) mg kg^{-1} for four soils by four methodologies, Western States Program.

Nitrate Method	95103	95104	95106	95111
	mean [1] ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI
Cadmium Reduction (Cd-Rd)	36.0 ± 0.6	16.4 ± 0.3	12.6 ± 0.5	41.0 ± 0.9
Ion Selective Electrode (ISE)	34.3 ± 2.3	17.1 ± 1.5	12.7 ± 1.1	40.1 ± 4.6
Chromatropic Acid (CTA)	35.0 ± 2.0	17.1 ± 1.3	13.1 ± 0.9	40.7 ± 2.8
Other Methods (Combined)	36.3 ± 5.6	20.6 ± 3.7	14.7 ± 2.2	40.6 ± 11.2

[1] Reduced mean and Confidence Interval based on reduced data set, outlier(s) removed using procedure of Dixon and Massey (1951).

Soil extractable PO_4-P was determined by five methods: sodium bicarbonate, Bray P-1, Mehlich 3, AB-DTPA, and Modified Morgan. Generally all methods exhibited very high RSDs (> 30 %) independent of soil. Results for soil bicarbonate PO_4-P were less skewed (Figure 1), depicting a high bias, as they were in 1994 for four of the 12 soils tested. Results from several laboratories in the program indicate that a portion of this bias is associated with differences in the absorbance of the phospho-molybdate complex between the 660 and 880 nm wavelengths. A comparison of sixteen soils ranging from 2.0 to 65 mg kg^{-1} PO_4-P supports this conclusion. Variability in Bray P-1 and Mehlich 3 extractable phosphorus increased with increasing soil pH (1:2), is likely associated with the dissolution of alkaline calcium phosphate minerals. The variability and high bias of extractable soil PO_4-P results remains a concern to the agricultural industry, since these methods are extensively used as the basis for phosphorus fertilizer recommendations in the United States.

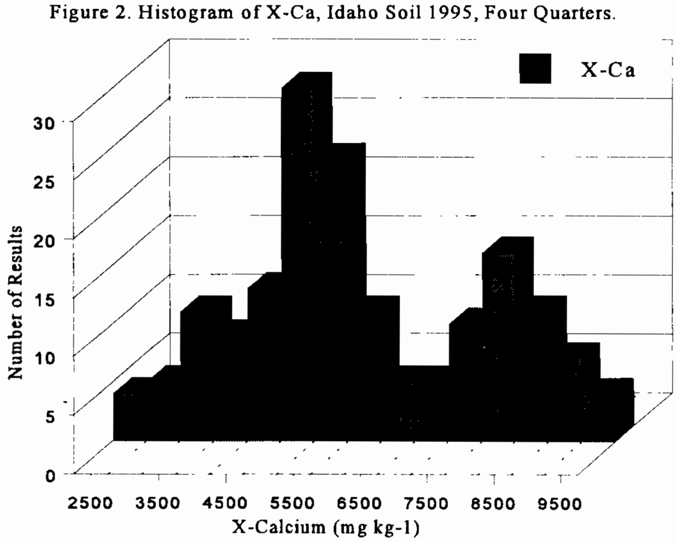
Figure 1. Histogram of Soil Bicarbonate P, Idaho Soil 1995.



Results for extractable cations and micro nutrients indicated that these elements have differing levels of precision. For ammonium acetate extractable X-K and X-Mg, variability ranged from 8-22 % across soils. Variability of ammonium acetate extractable X-Ca consistently exceeded 30 % on alkaline soils containing free carbonates and averaged 10% on other soils. It was noted for three of these soils that X-Ca concentration exhibited a distinct bimodal distribution (Figure 2). The basis for this bimodal population is likely associated with the presence of calcium carbonates in these soils. Extractable DTPA Zn and Cu were generally reproducible within 15-24 % of the mean with a decrease in precision as extractable concentrations fell below 1.0 mg kg^{-1} of soil. Soils containing less than 100 mg kg^{-1} X-Na, measurements were not precise, RSD > 50 %. Overall, precision of hot-water extractable soil B improved over 1994 for soils ranging from 0.32 to 8.5 mg kg^{-1}. With exception of soils exceeding 1.0 mg kg^{-1} B, the average RSD for hot-water extractable B was 34%.

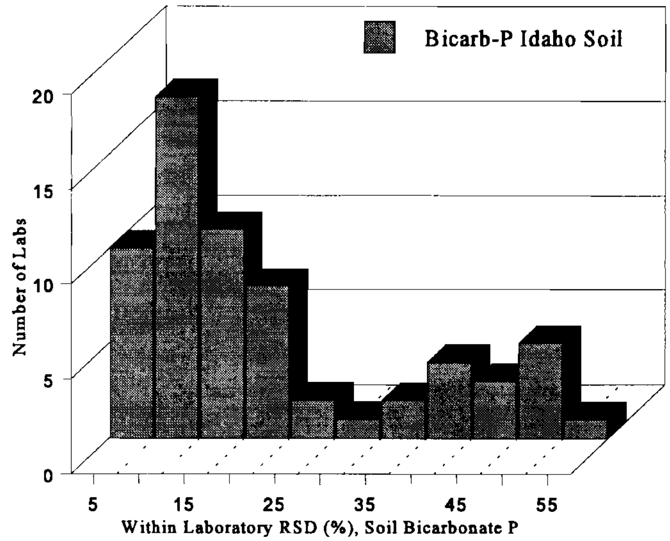
Results for soil organic matter show a large discrepancy between the Walkley-Black (OM-WB) and loss on ignition methods (OM-LOI). Consistently in 1994 and 1995 the LOI soil values were higher and less precise than the Walkley-Black method. These differences were independent of soil and were most pronounced on soils low in organic matter. Soil pH (1:2), SMP buffer pH, extractable soil NH_4-N and soil cation exchange capacity (CEC) were added to the program bringing the total to thirty-five soil analytical methods in the program. Generally soil saturated paste pH was approximately 0.25 units lower than that obtained by 1:2 soil:water extraction. Soil SMP buffer pH results indicate a precision level equivalent to that obtained by other pH methods. Soil extractable ammonium ranged from 4 - 6 mg kg^{-1} for all soils evaluated. Approximately thirty labs provided soil CEC results. Soil CEC was relatively imprecise, averaging an RSD > 40 % for the 1st quarter, but improved through the next three quarters of 1995.

Figure 2. Histogram of X-Ca, Idaho Soil 1995, Four Quarters.



The Idaho soil, collected by Dr. Janice Kotuby Amacher of Utah State University was replicated through all four quarters of 1995 as sample 95103, 95105, 95108 and 95110. Saturated paste percentage, pH (saturated paste and 1:2), EC, extractable X-K, extractable X-Mg, and DTPA-Zn mean values were reproducible within 3.0 % or less between quarters. Saturated paste soluble cations, B, soil NO_3-N, OM-WB and CEC precision was greater than 10 % between quarters. From quarterly replicates of the Idaho sample, within laboratory precision was calculated. Results for soil bicarbonate PO_4-P lab precision (Figure 3), indicate that a majority of labs could reproduce the PO_4-P value to within 15 %, however for several variation within lab exceeded 35 %. Within laboratory RSD values for X-K were substantially lower, with 65 % of labs having within lab RSD values less than 12 % on the replicated Idaho soil sample.

Figure 3. Histogram of Lab Precision, Soil Bicarbonate P



PLANT RESULTS

Plant tissue samples for the program were collected from vegetable, tree and cover cropped fields across the Western United States and represented a diverse range of chemical constituents based on: total nitrogen (N), 1.72 to 5.62 %; K 1.19 to 4.66 %; and Fe 101 to 1800 mg kg $^{-1}$. To evaluate absolute accuracy a National Institute of Standards and Technology Certified Reference Sample, NIST 1574, peach leaves, was submitted as a blind sample during the second quarter exchange as sample 95205. Results for total Ca, Mg, and B were highly accurate (Table 3). Results for total P, Zn and Cu, although comparable between methods, were slightly higher than the certified reference value. Results for total Fe were lower than the certified value of 218 mg kg^{-1} independent of the method. Results for total K and Mn were method dependent and slightly lower then the certified value. Precision, as based on standard deviation of reduced data set, is greater for all elements than the 95 % confidence interval, with the exception of B and Cu values reported for microwave digestion. As a group, microwave digestion analyte values were equal or greater precision than either the nitric/perchloric or dry ash digestion methods with the exception of Zn and Fe.

As in 1994, extractable plant nutrients exhibited a lack of precision relative to other plant elemental constituents, independent of method or sample. This was especially true for samples containing less than 1000 mg kg^{-1} of NO_3-N, RSD > 25 %. Samples greater than 2000 mg kg $^{-1}$ exhibited a level of precision of 15 % based on RSD. Consistently, both Cd-Rd and ISE, had similar levels of precision across samples. Extractable ortho-phosphate (PO_4-P) consistently was reproducible to within 10-15 %, with the exception of samples containing less than 700 mg kg^{-1} PO_4-P. Chloride concentrations ranged from 0.08 to 0.77 % across samples analyzed in the 1995 program with an average RSD of 28 %.

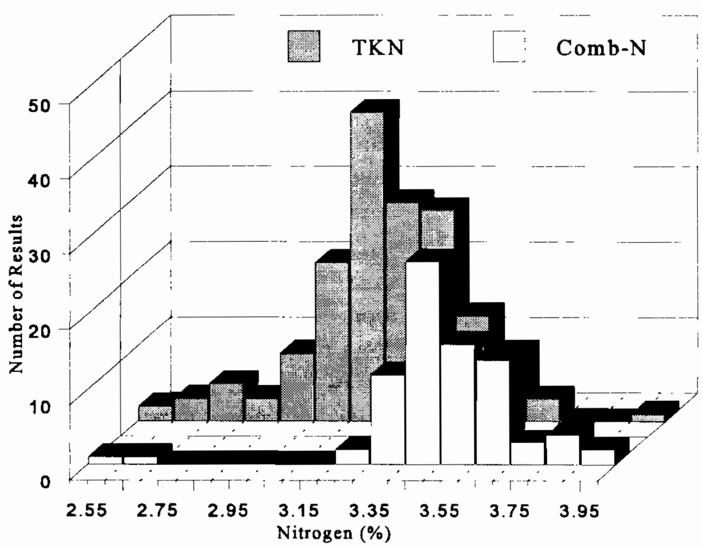
Table 3. Analyte recovery for NIST peach leaf sample 1574 submitted as plant sample 95205 in the 1995 Western States Program.

Analyte	NIST Certified Value	Nitric/Perchloric Digestion [1]	Dry Ash Digestion [1]	Microwave Digestion [1]
	mean ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI
P (%)	0.137 ± 0.007	0.143 ± 0.005	0.145 ± 0.004	0.144 ± 0.007
K (%)	2.43 ± 0.03	2.29 ± 0.07	2.41 ± 0.05	2.36 ± 0.13
Ca (%)	1.56 ± 0.02	1.57 ± 0.06	1.59 ± 0.04	1.55 ± 0.06
Mg (%)	0.432 ± 0.008	0.413 ± 0.011	0.435 ± 0.009	0.416 ± 0.016
B (mg kg^{-1})	29 ± 2	26.4 ± 1.3	28.7 ± 1.1	28.0 ± 1.1
Zn (mg kg^{-1})	17.9 ± 0.4	18.5 ± 0.8	18.5 ± 0.5	18.7 ± 0.7
Mn (mg kg^{-1})	98 ± 3	93 ± 2	93 ± 3	97 ± 5
Fe (mg kg^{-1})	218 ± 14	203 ± 8	200 ± 6	190 ± 14
Cu (mg kg^{-1})	3.7 ± 0.4	4.5 ± 0.6	4.0 ± 0.3	3.8 ± 0.2

[1] Mean and Confidence Interval based on reduced data set, outlier(s) removed using the procedure of Dixon and Massey (1951).

Nitrogen concentrations as measured by the combustion method were consistently higher and more precise than that measured by the total Kjeldahl method. The difference between absolute measured concentration between the two methods increased with increasing extractable NO_3-N indicating a poor recovery of reduced N forms by the total Kjeldahl N method utilized by the lab industry (Figure 4). Precision (as measured by RSD of reduced mean) of combustion N results approached 2.0 % for several samples and never exceeded 4.5 % for any of the samples analyzed based on the twenty-three participating laboratories. Sulfur concentration ranged from 0.15 to 0.59 % for the twelve samples utilized in 1995. Independent of sample the wet digestion method had higher S concentrations than the combustion method and has higher precision.

Figure 4. Histogram of TKN and Combustion N, Bell Pepper



Results for nitric/perchloric, dry ash and microwave total P were equivalent independent of the plant sample source with an average precision of 8.0 %. For samples with greater than 2.5 % K the dry ash method consistently recovered less K than either of the other two methods and was of lower precision (Table 4). Precision of total K results were consistently lower than either P, Ca or Mg analyses. Total Ca and Mg values were generally equivalent across methods of digestion independent of sample. For samples low in B the nitric/perchloric digestion method generally gave a higher recovery (Table 5). All methods

Table 4. Comparison of total K recovery by three methods for four plant sample materials, 1995 Western States Program.

Plant Sample	Nitric/Perchloric Digestion (% K) [1]	Dry Ash Digestion (%K) [1]	Microwave Digestion (% K) [1]
	mean ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI
95204 Vetch	4.44 ± 0.11	4.26 ± 0.31	4.41 ± 0.21
95207 Bell Pepper	4.61 ± 0.12	4.35 ± 0.13	4.63 ± 0.22
95209 Avocado Leaves	1.19 ± 0.03	1.11 ± 0.04	1.13 ± 0.06
95211 Bell Pepper	4.69 ± 0.09	4.23 ± 0.17	4.70 ± 0.14

[1] Mean and 95 % Confidence Interval based on reduced data set, outlier(s) removed using the procedure of Dixon and Massey (1951).

Table 5. Comparison of total B recovery by three methods for four plant sample materials, 1995 Western States Program.

Plant Sample	Nitric/Perchloric Digestion (mg kg^{-1} B) [1]	Dry Ash Digestion (mg kg^{-1} B) [1]	Microwave Digestion (mg kg^{-1} B) [1]
	mean ± 95 % CI	mean ± 95 % CI	mean ± 95 % CI
95203 Potato Stems	21.6 ± 2.7	20.1 ± 1.2	17.3 ± 0.4
95205 Peach Leaves	26.4 ± 2.1	28.7 ± 1.1	28.0 ± 1.0
95208 Potato Tubers	8.4 ± 0.7	7.6 ± 0.7	7.2 ± 0.7
95210 Oat Stems	11.9 ± 2.0	11.0 ± 1.0	10.0 ± 0.9

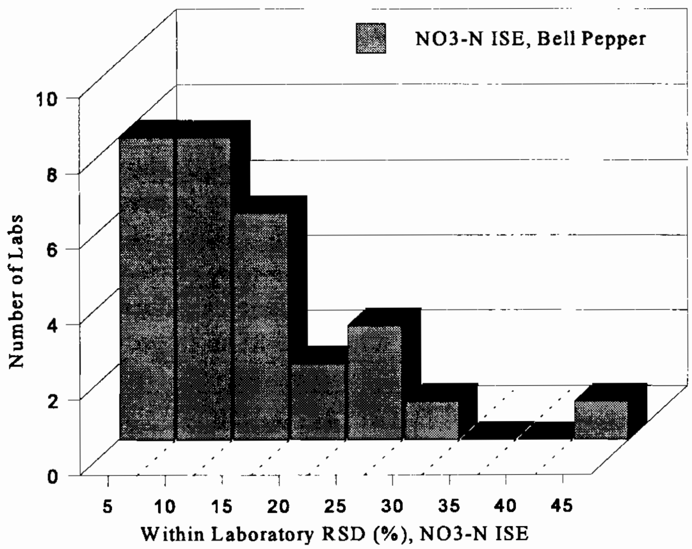
[1] Mean and 95 % Confidence Interval based on reduced data set, outlier(s) removed using the procedure of Dixon and Massey (1951).

were apparently effective at recovering B for samples high in concentration, greater than 20 mg kg^{-1}. Both the wet digestion methods generally gave equivalent Zn and Fe values independent of sample, and on specific samples the same was true for Cu. Manganese precision was less than 10% for both the nitric/perchloric and microwave digestion methods. With the exception of the first quarter, the microwave digestion method had a greater level of precision for P, Ca, Mg, B, Zn, Mn, and Cu than the other two digestion methods.

A bell pepper (*Capsicum annuum*) plant sample, collect by Dr. Tim Hartz of the University California Davis from the UCD agronomy farm, was replicated through all quarters of 1995 as sample 95202, 95206, 95207, and 95211 to evaluate reproducibility. Generally results for NO_3-N were highly reproducible for both the Cd-Rd and ISE methods. Soluble PO_4-P was reproducible within 2.6 % between quarters while Cl was 12 %. Based on quarterly averages, both total N methods were reproducible within 0.06 % N. Total P, Ca, and Mn were reproducible within 3.0 % between quarters. Across quarters, the microwave digestion had more reproducible analytical values than nitric/perchloric or dry ash digestion methods for P, Ca, Mg, B, and Cu.

From quarterly replicates of the bell pepper sample, within laboratory precision was calculated based on the RSD of the four sample exchanges for each laboratory. A majority of the labs could reproduce the NO_3-N value to within 15-20 % (Figure 5), and results for the ISE method were similar to the Cd-Rd NO_3-N method. Results

Figure 5. Histogram of Lab Precision, Plant NO3-N, ISE 1995



of extractable PO_4-P were similar to those obtained for NO_3-N while results for Cl were much higher. Within laboratory RSD values for TKN were substantially lower with 75 % of labs having RSD values less than 10 % on the replicated bell pepper sample. Results for combustion N were similar. Generally the level of within laboratory precision was similar for total P, K, Mg, and Mn across digestion methods with a median RSD value of 6 %. Within laboratory precision RSD values for total Fe by the dry ash method was highest of all methods evaluated. With the exception of Fe and Cu, the median RSD was lowest for the microwave digestion method. Generally precision within a laboratory was inferior for micro nutrients over macro nutrients.

LABORATORY ACCURACY

Approximately 12 % of the reporting laboratories provided soil results within established warning limits (two times the standard deviation based on reduced data set, outliers removed) and 4.0 % exceeding control limits (three standard deviations from the reduced mean) for 1995. Across all twelve soils the NO_3-N CTA, SMP buffer pH Mehlich 3 and AB-DTPA PO_4-P soil methods had the highest percentage of laboratory results within established warning limits. Approximately 13 % of all reporting laboratories provided plant results within established warning limits. Across all twelve plant samples, Cl had the fewest percentage of laboratory results within established warning limits, 76 %.

Table 6. Western States Program comparison of overall soil and plant analysis precision for 1994 and 1995.

Analysis	**Overall RSD (%)** [1]		**% of Labs Providing Results Within Warning Limits**	
	1994	**1995**	**1994**	**1995**
Soil NO_3-N (Cd-Rd)	17.5	9.1	83.6	85.6
Soil Bicab. PO_4-P	33.6	24.2	89.7	85.4
Soil Zn-DTPA	21.4	18.5	85.9	84.7
Plant NO_3-N (ISE)	32.1	22.3	82.9	84.2
Plant NO_3-N (Cd-Rd)	46.5	35.3	74.0	79.5
Plant TKN	9.2	5.8	87.1	87.5

[1] RSD and % of values within warning limits based on values for twelve samples.

Composite proficiency soil scores (sum total number of reported values exceeding warning limits divided by total number of analyses completed) indicate that 50 % of the laboratories reported 85 % or more of the values within warning limits. Plant proficiency scores indicate that 50% of the labs reported 88% or more of the values within warning limits. Generally, composite proficiency scores are similar to those in 1994 for soils and slightly lower for plant results.

Overall, significant progress has been made in the quality of laboratory analyses as measured by this program. Based on RSD, there has been a marked improvement in laboratory precision and an increase in percentage of values within warning limits since 1994 for soil NO_3-N (both Cd-Rd and ISE methods), saturated paste Ec_e, plant NO_3-N (both Cd-Rd and ISE methods) and total Kjeldahl nitrogen (Table 6). A majority of the remaining soil analyses showed a 1 - 9 % reduction in the RSD value. Although there was a general reduction in the percentage of values within warning limits between 1994 and 1995, this is attributed to an improvement in overall precision for all of the analyses.

SUMMARY

The focus of the Western States Proficiency Testing Program has been to provide an external measure of both accuracy and precision for the individual laboratory and address reliability of specific analytical methods. Although no certified soil sample is currently available, results of the 1995 program based on samples replicated with other programs, indicate that the accuracy of several soil analyses are very reliable. These include soil pH (1:2), EC_e, NO_3-N (cadmium reduction and chromatropic acid), ammonium acetate extractable K and organic matter Walkley-Black. Precision, results as measured by a replicated sample, indicate that a majority of laboratory participants are capable of reproducing analytical values within 10 % through a twelve month period. Accuracy of plant results, as evaluated by certified samples, indicate that a majority of the laboratories can accurately determine elemental plant constituents. Although precision, as measured by a replicated sample, is greater than 10 % for soluble anions (ie. NO_3-N, PO_4-P and Cl) that for total nitrogen as measured by the combustion method, is less than 4.0 %. Based on the results of 1994 and 1995, this program has demonstrated an overall improvement in both the level of precision of individual analyses, and the number of laboratories providing acceptable values within prescribed warning limits.

For 1996 the Western States Laboratory Proficiency Testing Program has added soil pH (1:1), extractable soil SO_4-S and plant SO_4-S methods. To improve the statistical evaluation of quarterly results the program will employ the median average deviation (MAD) robust estimator technique. Collaborative work will continue to address potential methodology problems associated with soil extractable bicarbonate PO_4-P, Bray P-1 PO_4-P, and ammonium acetate extractable Ca. Work will begin on developing certified reference soil materials. This program will continue in 1997 to address laboratory proficiency and issues related to the quality of soil and plant analysis in the agricultural laboratory industry.

ACKNOWLEDGMENTS

The authors of the Western States Laboratory Proficiency Testing Program would like to thank Dr. Ray Gavlak, Agronomy Specialist, Palmer Research Center, University of Alaska; Bryan Hopkins of Servi-Tech, Hastings, NE; Dr. Tim Hartz, Vegetable Crop Specialist, University of California Davis, CA; Tom Kearney, Farm Advisor Yolo County, CA; Richard Smith, Farm Advisor San Benito, CA for their assistance in providing soil and plant materials for the 1995 program. Additional thanks to Amy Sorenson, Merrit Coleman and Victor Huey, for their assistance with this program. This program is support by funds from the California Department of Agriculture Fertilizer Research Education Program.

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Revised Potassium Fertility Guidelines
for the San Joaquin Valley of California

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Irrigated cotton has been an important crop in California's San Joaquin Valley for many years and continues to hold its importance. There are more than 1 million acres of cotton valued at over I billion dollars. Guidelines for fertilizing cotton were developed in the late 1960's when different cultivars were grown and different culture practices were used. Yields now approach three bales of lint per acre and nutrients, water, and other inputs are needed more frequently or in greater amounts.

In particular, potassium (K) deficiencies have been identified in many areas of the valley. These deficiencies are due in part to the mineralogies of the subsoils and in part to the physiology of the cotton plant. Cotton root densities are significantly lower in the top five inches of soil, where K levels are usually high, than in the next ten inches of soil, where available K levels are lower. Late season K deficiencies are attributed to high vermiculitic clay content and low available K in subsoils as well as cotton root systems with a low number of surface roots.

Although K is required throughout all stages of cotton plant development, there is a dramatic increase in demand for K during boll set. Boll walls contain the highest concentration of K (about 4% dry weight), but seeds and other fruit parts are high in K also. To accommodate this need, a cotton crop may absorb from 1.9 to 3.0 pounds of K per acre per day during boll formation. The total elemental K requirement of a three bale crop is approximately 180 pounds (216 pounds of K2O). Since the entire plant is not harvested, much of the K is returned to the soil. An estimated 42 pounds of K (50 pounds of K2O) are removed in seeds and lint. However, rotational crops can remove even more from the soil. A corn silage crop yielding 30 tons per acre removes 250 pounds of K2O per acre while an eight ton per acre alfalfa crop removes 480 pounds of K2O per acre each year. To maintain soil K at sufficient levels it is sometimes necessary to supplement cotton fields with additional source of K.

Fields studies were conducted at 45 locations in 1993, 1994, and 1995 in Merced, Madera, Fresno, Tulare, Kings, and Kern Counties, to evaluate lint cotton responses to K fertilization. Fertilizer treatments were 0 and 400 pounds of K2O per acre as KCl banded to a depth of six inches in the shoulder of the beds. Applications were made during squaring and prior to the first irrigation. Preplant soil samples were taken at depths of 0 to 5 inches, 5 to 15 inches, and 15 to 30 inches, and evaluated for available K by eleven different laboratory methods. Soil K fixation potential was also measured.

Cotton petiole samples were collected at three times during the season beginning at first bloom and analyzed for total K.

The determination of whether, and how much, supplemental K fertilizer is required rests heavily on information obtained from both petiole and soil test levels. Ammonium acetate or Mehlich 3 soil test levels below 80 ppm indicate a high likelihood of fertilizer K response. Potassium fixation tests greater than 60% are indicative of sites having lint yield increases with K fertilizer. These low test levels in combination with fixation levels above 60 percent are clear indications that high rates of K fertilizer will be required. Under these circumstances, a 400 lbs/acre application is recommended. If soil test levels lie between 80 and 110 ppm, the likelihood of a large yield response is reduced and 200 pounds K per acre is the suggested rate. Petiole K data from the previous season are important in the final decision to apply K.

Summary

- THE CRITICAL SOIL LEVEL FOR A 2.5 BALE CROP IS 110 PPM EXCHANGEABLE POTASSIUM.
- IMPROVED K FERTILIZER PREDICTIONS ARE MADE FROM SOIL SAMPLES TAKEN FROM 5 TO 15 INCH DEPTH
- IF SOIL LEVEL IS 110 TO 120 PPM - APPLY 100 POUNDS K2O PER ACRE.
- IF SOIL LEVEL IS 80 TO 110 PPM - APPLY 200 POUNDS K20 PER ACRE, UNLESS K FIXATION IN GREATER THAN 60%, THEN APPLY 400 POUNDS K2O PER ACRE.

- IF SOIL LEVEL IS LESS THAN 80 - APPLY 400 POUNDS K2O PER ACRE.
- CRITICAL PETIOLE LEVELS FOR 2.5 BALE CROP ARE:

  FIRST BLOOM: 3.5%

  BLOOM + 2 WEEKS: 2.75%

  CUTOUT + 10 DAYS: 1.5%
- SUPPLEMENTAL K CAN BE APPLIED AS FOLIAR OR WATER RUN AFTER FIRST BLOOM

Developing Site-Specific Farming Information for Cropping Systems in California

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Site-specific farming is defined as the management of inputs on a smaller scale than the whole field. Variable-rate fertilizer, lime, and herbicide applications are examples of site-specific farming currently being used in some regions of the USA. The premises behind site-specific farming are (1) that agronomically significant variability in plant growth, yield, soil type, pest pressures, etc. exists within fields, (2) such variability can be measured, and (3) the information obtained can be used to modify management for the betterment of farm profit and the environment. Little research has been done in California's diverse irrigated cropping environment to test these ideas. The initial focus of research must be on collecting and analyzing information that in turn might provide the basis for site-specific farming practices.

In the fall of 1995, a team of U.C. scientists and Cooperative Extension specialists and advisors began working with Yolo County grower Tony Turkovich to attempt to relate within-field variation of crop yield and quality to variations in soil, pest pressures, plant tissue nutrient content, etc. The team's intent is to relate environmental variables (such as soil drainage class) and manageable factors (irrigation, fertilizer) to crop yield and quality using relatively low-cost information obtained through aerial photography and yield mapping. A key question is: Can variability and its causes be mapped without over-reliance on more expensive information such as grid soil and plant sampling?

The project is supported by a two-year grant from the California Department of Food and Agriculture Fertilizer Research and Education Program. Also, U.C. is contributing a significant amount of technician time. Team members bring a wide range of expertise to the project including in crop modeling and plant physiology, agronomy, irrigation, soils and plant nutrition, engineering, remote sensing, and geographic information systems.

Procedures

The team is collecting information from three fields in Yolo Co. ranging in size from 77 to 108 acres. These fields were cropped to irrigated wheat in the 1995-96 year and will be rotated into processing tomatoes in 1997. Wheat grain yield was measured in June 1996 with a commercial yield monitor/global positioning system package installed on the grower's combine. Yield and grain moisture content were recorded in a data logger once per second, corresponding to two to four feet travel by the combine. Color infrared aerial photographs were taken before crop emergence in December, 1995, at early jointing in

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March, and during grain fill in May. Photographs were digitized, and a vegetation index was derived for the growing season images. Soil properties, plant nutrient status, and crop/weed/disease visual ratings were collected on a 200 x 200 ft grid -- about 1 sample per acre. All data were compiled and color yield maps were generated using ArcView software.

Results and Conclusions

A large amount of data (yield, photographic, and plant/soil sample) was obtained during the wheat crop in the project's first year. Analysis of this information is in progress. Collected information from one of the fields will be used here to show the potential for obtaining useful results.

The net grain yield in this 77-acre field was 2,944 lb/acre – less than half of a typical "good" wheat yield in the southern Sacramento Valley. The average yield recorded by the yield monitor was 2566 lb/acre. The 13% discrepancy between yields obtained from the truck weights and the yield monitor was probably due to insufficient calibration of the latter. The great variability of the yield across the field is seen in Figure 1. Yield in the southwest corner exceeded 4,000 lb/acre but was less than 1,000 lb/acre in the north-central area of the field. Additional smoothing and processing of yield data-- for example, to remove data noise caused by short-range fluctuations in the flow of grain through the combine--is still required before an accurate characterization of yield variability can be obtained.

The main factor contributing to low yield was saturated soil conditions resulting from poor soil drainage and heavy winter rains. Apparently, growing the wheat on five-foot beds did not compensate for the slow drainage characteristics of the soil. Yield was highest in the southern one-third of the field where the soil was lower in silt content and higher in sand (Fig. 2). The lowest grain yields were observed in the northeast quarter of the field where the surface soil was higher in silt and clay and where a restricting layer (> 50% clay) was present at a depth of three to five feet. This area of the field also displayed the darkest color in the December bare soil aerial photo (not shown), taken shortly after a rain.

A second cause of low yields was competition from grassy weeds. The density of the weeds varied greatly across the field. In some areas, there were no weeds. In a few areas, there was almost no wheat, only weeds. Weed ratings shown in Fig. 3 were obtained by one person walking the entire field. The weed species that caused the biggest problem were wild oats, canarygrass, and ryegrass. Because these species are equal in height or taller than the wheat and possess a different color seed head, they are easily seen in the May aerial photograph (not shown). We plan to further analyze these data. It may be possible to produce a weed density map from the aerial photograph and--by comparing that to the yield map--determine the grain yield and economic loss caused by lack of weed control.

An unanticipated finding was the presence of dark green (darker red in the color IR) streaks in the May aerial photograph. These streaks run in a north-south direction and are about 70 feet apart. We believe the streaks are the result of non-uniform aerial application of N fertilizer topdressing on February 25. The streaking is also faintly visible on the March 8 aerial photograph and on the yield map. Even in the greatly degraded version of the yield map produced for this summary paper (Fig. 1), there is a north-south pattern visible in a few places, although without further analysis we cannot be certain that it is the same pattern seen in the aerial photographs. We will analyze the yield monitor data for the presence of an east-west cyclic pattern in grain yield and moisture content and will compare that to the color pattern in the aerial photograph. This example shows the tremendous potential for using within-field variability – in this case caused by an unintended non-uniformity in fertilizer application – to conduct experiments that could otherwise only be done with expensive small-plot experimentation. A further benefit of this whole-field approach to research is that the effects of fertilizer N can be observed across the range of conditions present in the field. A single, compact small-plot experiment would probably cover only one soil type; in fact, the researchers would try to place the small plots in the most uniform, problem-free area of the field. This example also shows how yield mapping technology used alone or in combination with aerial photography can enable a grower to conduct his or her own experiments at a relatively low cost.

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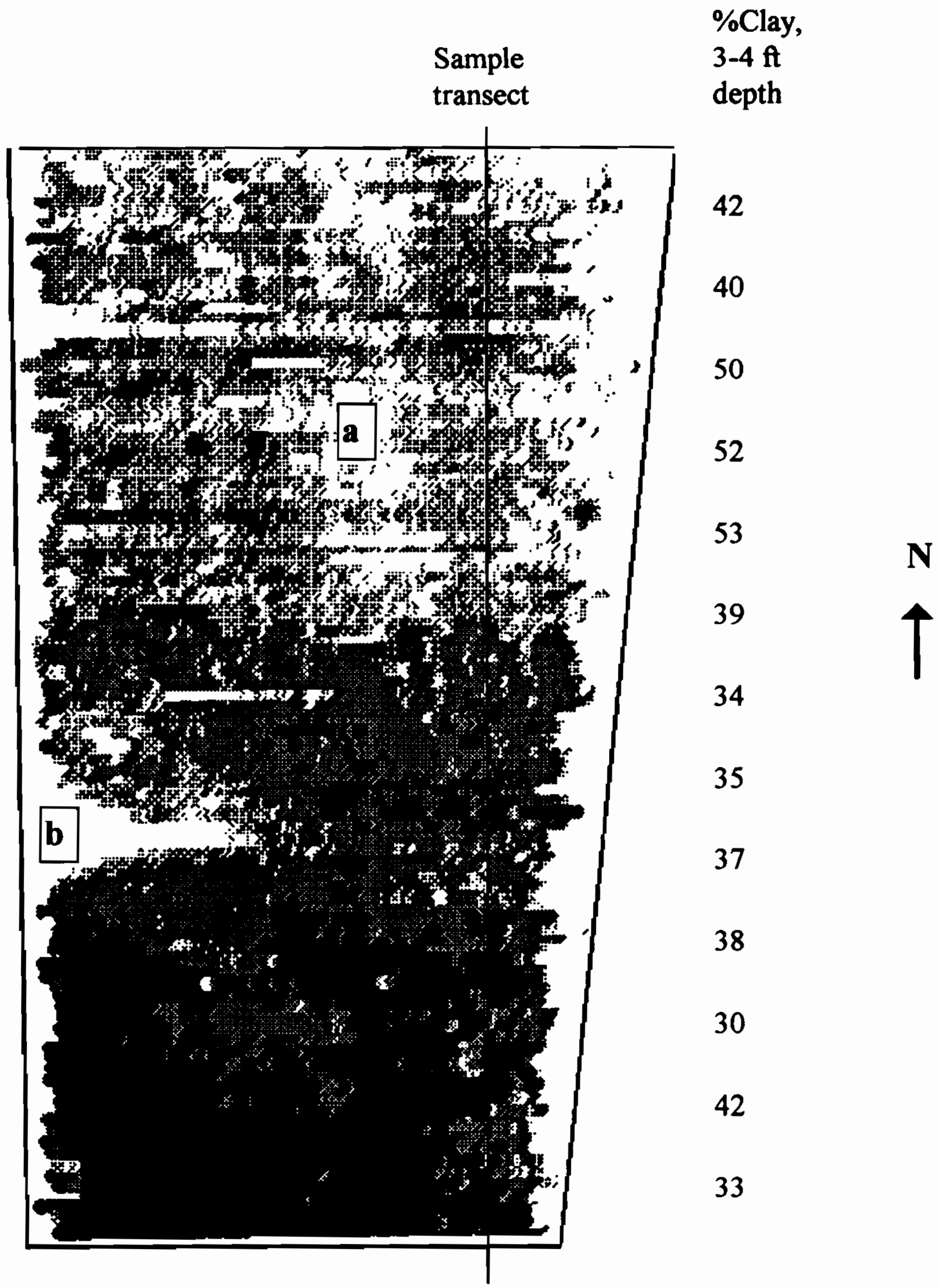

Figure 1. Wheat yield in a 77-acre field. Higher yield = darker shade. a = area with poor drainage. b = severe grassy weed infestation. Clay contents (3-4 ft depth) are shown for samples taken along a north-south transect indicated by the solid line.

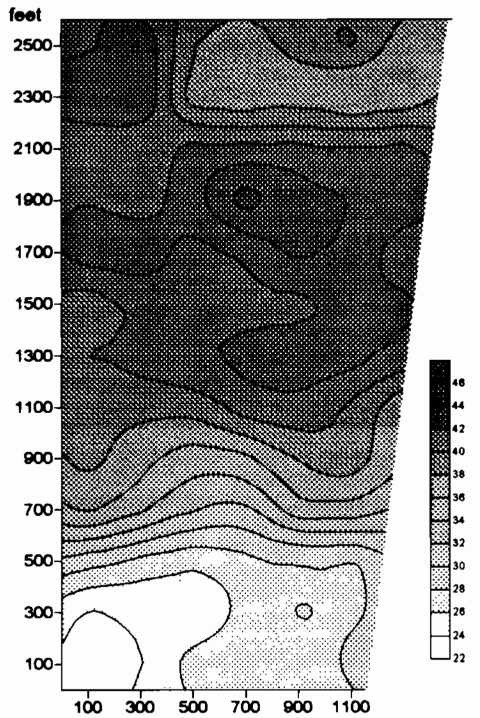

Figure 2. Silt content, 0-6 inch depth.

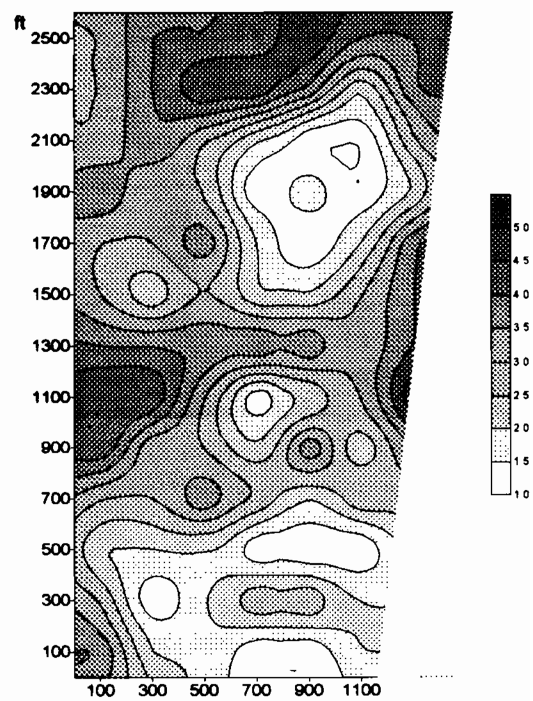

Figure 3. Visual weed rating, 1=low.

Using Foliar Urea to Supplement
Soil-Applied Fertilizer in Early Maturing Peach Trees

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Foliar urea provides a method for introducing nitrogen directly into plants. This has tremendous environmental implications since soil applied, leachable nitrogen could be eliminated or substantially cut back thus greatly reducing the potential for groundwater pollution by nitrates (Embleton et al., 1986). Foliar urea has been demonstrated as an effective way of providing nitrogen to a number of plants including citrus (Embleton et al., 1986), mungbean (Ghildiyal, 1992), cereal grains (Gooding & Davies, 1992) and apple (Titus, 1972)

In our last presentation to the California Plant & Soil Conferences (Johnson & Andris, 1995) we reported studies on peach trees showing efficient uptake of urea by leaves, rapid mobilization of N out of the leaves and subsequent distribution to other plant organs including the roots. There is no question that foliar urea can effectively supply N to the tree. However, there is a question of whether the long term productivity of peach trees can be maintained by foliar urea alone. Reduced fruit size in treatments receiving only foliar urea have suggested a physiological problem. Perhaps an imbalance in the root-to-shoot ratio, carbon-to-nitrogen ratio, nutrient interactions or phytohormone levels could be induced when the "normal" process of root nitrogen uptake is bypassed.

Subsequently, we have reevaluated our approach and are now pursuing the idea of supplementing soil fertilization with a single foliar urea spray in the fall of about 50 lbs N/acre. We are interested in not only reducing the amount of soil applied N but also in developing a very practical approach that fruit growers can easily adopt. Therefore, another aspect of this project is to look at the feasibility of applying the urea with a zinc sulfate spray in October which is a standard cultural practice for many growers.

Early Maycrest Peach Experiment

In a block of Early Maycrest peach trees at the Kearney Agricultural Center, we set up an experiment comparing different combinations of soil and foliar fertilizations. The four treatments are as follows:

1. Unfertilized control
3. Soil N only - 50#N/acre in April, 50#N/acre in September
3. Soil - 50#N/acre in April, Foliar - 50#N/acre in October
4. Soil - 50#N/acre in September, Foliar - 50#N/acre in October

Each plot consists of 2 trees and is replicated 5 times per treatment. The experiment was initiated in the spring of 1995.

By January, 1996, treatments 2-4 had all received 100#N/acre although at different times and by different methods. Sampling of dormant shoots and roots indicated the treatment which had received all its N in the fall (trt 4) had the highest level of stored nitrogen (Table 1). In December, this treatment also had the highest N concentration in its flower buds, although the other fertilized treatments caught up by January. These data support the conclusion that foliar urea, which contributed half the nitrogen in treatment 4, is effective at supplying nitrogen to all the organs of the tree.

Treatment 4 was also effective at maintaining fruit size compared to the soil fertilized control (trt 2). Flowerbud weight during the dormant season was the largest of any treatment, as was fruit weight at thinning time (Table 1). By harvest, treatment 4 had yields and fruit weight equal to the soil fertilized control.

Treatment 4 had the further advantage of reducing vegetable growth which can be quite excessive in an early maturing peach variety. Summer pruning weights taken in July, 1996, showed reduced growth in treatment 4 compared to the soil fertilized control (Table 1). In contrast, the other split application treatment (trt 3), which received foliar urea in the fall but a spring application of soil N, did not significantly reduce vegetative growth and had a tendency towards smaller fruit size. Therefore, based on just one year of data, it looks like the treatment receiving soil fertilization in September followed by foliar urea in October shows promise for maintaining fruit size while reducing vegetative growth at the same time.

Combining Urea Sprays with Standard Fall Zinc Sprays

Many peach growers spray zinc sulfate as a standard foliar treatment every year in their orchards. This is generally applied in October or early November as the leaves are just starting to senesce. Since our research studies have indicated this seems to be a good time to apply urea, we decided to initiate some experiments comparing these materials sprayed together or separately. We were particularly interested in testing for synergistic effects between the 2 materials which might lead to greater phytotoxicity, reduced flowering or abnormal fruit.

Under the leadership of Harry Andris, we set up 8 different treatments in 1994. All treatments were applied with a standard orchard speed sprayer to large plots (1/6 acre) and replicated 6 times. For simplicity, only the 4 treatments with relevance to this paper will be reported here. These treatments are an unfertilized control and the 2 materials applied separately or together. Zinc was applied as zinc sulfate (36%) at 10 #/acre and urea at 109 #/acre (50 #N/acre). A rate of about 100 gals solution/acre was sprayed for each treatment.

The combination of the 2 materials did not cause faster defoliation than each material alone (Table 2). In fact, zinc alone caused faster defoliation than when it was combined with urea. The differences in defoliation rates among the treatments was quite small, only amounting to a shift of a week or two. This would probably have insignificant physiological effects on the trees. No shoot dieback was observed in any of the treatments and flowering was not affected (Table 2). Unfortunately, we were unable to obtain yield data but there were obviously no problems with abnormal fruit. We have repeated similar treatments in other fields and have not observed any adverse effects. There are even reports of urea improving the uptake of heavy metals such as zinc and iron (Bar-Akiva & Hewitt, 1959; Hoffman & Samish, 1966). We are currently testing this idea using a zinc isotope.

Conclusion

These results suggest urea can be used to supplement soil fertilization in an early maturing peach variety. Also this material can be applied very economically by combining it with a standard fall zinc spray. To expand this work, we are currently pursuing two ideas. One is to test the same approach on later maturing varieties where the fertilization strategy might be a little different. The second is to determine the window during the fall period when foliar urea is most effective. Some preliminary results suggest November may be too late for much of the nitrogen to be mobilized out of the leaf before senescence. At the other end, September may be too early and the weather too hot for the tree to tolerate defoliation.

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Table 1. The effect of low biuret foliar urea sprays on Early Maycrest peach.

Parameter	Treatments				Significance
	1 Unfertilized Control	2 Soil Fertilized Control	3 Split April - Soil Oct. - Foliar	4 Split Sept - Soil Oct. - Foliar	
1/96 Shoot N (%)	1.02 d	1.28 b	1.16 c	1.40 a	.0001
1/96 Root N (%)	.70 d	1.33 b	.97 c	1.59 a	.0001
12/95 Flowerbud N (%)	4.49 c	4.59 c	4.76 b	4.95 a	.0001
1/96 Flowerbud N (%)	4.82 b	5.39 a	5.21 a	5.38 a	.0001
12/95 Flowerbud Weight (mg)	.34 b	.36 ab	.34 b	.37 a	.008
1/96 Flowerbud Weight (mg)	.73 b	.78 ab	.72 b	.81 a	.03
4/96 Fruitlet Weight (g)	1.70 c	2.50 a	2.10 b	2.70 a	.0001
5/96 Yield (kg/tree)	8.40 b	12.80 a	10.70 ab	12.60 a	.008
5/96 Fruit Weight (g)	97.70 b	114.80 a	110.30 a	113.50 a	.0004
7/96 Pruning Weight (kg/tree)	2.40 b	5.90 a	5.00 a	3.50 b	.0005

Table 2. The effect of foliar urea and zinc sulfate on defoliation and flowering of David Sun peach. Treatments applied October 24, 1995.

Parameter	Treatments				Significance
	Unfertilized Control	Foliar Urea	Zinc Sulfate	Urea and Zinc Sulfate	
Defoliation (%)					
11/3/95	1.1 c	5.4 b	13.1 a	7.9 b	.0001
11/10/95	3.8 d	18.2 c	62.9 a	36.7 b	.0001
11/17/95	15.7 d	60.0 c	82.8 a	72.1 b	.0001
11/22/95	24.2 c	66.9 b	86.3 a	77.9 a	.0001
12/1/95	57.9 b	89.9 a	94.1 a	92.4 a	.0001
12/8/95	95.7 b	97.7 a	97.5 a	97.2 a	.0001
Flower Density (#/cm)					
3/96	.46	.46	.44	.39	NS

COVER CROP SELECTION AND MANAGEMENT IN ORCHARDS AND VINEYARDS

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Potential Benefits of Cover Crops
Addition or conservation of nitrogen
Reduced soil erosion
Addition of organic matter to soil
Improved soil structure / water pen.
Improved wheel traction
Increased beneficial arthropods

Potential Problems with Cover Crops
Increased costs and management
Depletion of soil moisture
Increased frost hazard
Increased pests (insects, weeds, vertebrates, nematodes)

Tree and vine crop growers have several cover cropping systems from which to choose. The choice and performance of cover crops often depends on site-specific factors, so they should first be tested in a few rows before planting large acreages. The main factors to consider when selecting a particular species or mix are costs vs. benefits, irrigation method, tillage practices, nitrogen needs, frost concerns and harvesting practices (for nut crops). Understanding the basic cover crop types and management strategies can greatly improve the chances for success.

COVER CROP SPECIES AND BLENDS

Monocultures of sown cover crops are frequently used, but problems may occur with the use of the same species year after year. For example, continual plantings of 'Cahaba White' vetch may be affected by soil diseases; also, in some areas alfalfa weevil can be a serious pest of bur medic. Localized environmental niches, such as sand streaks or areas with differing soil nutrient availability, may also provide unfavorable growing conditions for a single species. Providing different species in a mix may enable one species to thrive in areas where another might be weak, increasing the chances for a healthy stand throughout the orchard or vineyard. Polycultures also attract a diversity of beneficial arthropods which may aid in pest management, although research in this area has provided mixed results.

Cover Crops for Disked Orchards and Vineyards. High-biomass cover crop species are often used in disked orchards and vineyards. Mixes which produce large amounts of biomass, or plant matter, can be used to add organic matter to the soil. The periodic addition of organic matter enhances soil microbial populations, improving soil structure and nutrient cycling. High biomass mixes contain large seeds and are usually quite easy to grow. In general, they are sown each fall and either disked or mowed in the spring; this is referred to as a "green manure" cover crop. Where furrow irrigation is used, they are disked before the soil dries excessively to enable the disk to penetrate the soil. Two basic types of high biomass mixes are often available from seed companies: pure legume and legume/grass blends.

Pure legume blends, usually containing bell beans, vetch, and field peas are used to add a large amount of readily available nitrogen to the soil. Bell beans produce vigorous, upright growth and cannot be mowed closely. Field peas are shallow rooted and therefore subject to drought on sandy soils; they also produce the far majority of their biomass and nitrogen in the spring. Vetches are frequently used, but may twine up vines, trees, or sprinklers if planted too close. Also, if allowed to reseed they may become a weed problem in the rows. 'Lana' woollypod is one of the most vigorous vetches in the spring and flowers and matures earlier than purple vetch. Common vetch has extrafloral nectaries on the stipules, which provide nectar to beneficial insects. 'Cahaba White' vetch has been shown to suppress root knot nematodes.

Various legume/grass blends are also available. The addition of grasses, such as barley, oats, or cereal rye in a mix imparts several benefits. The fibrous roots of grasses greatly enhance soil tilth and water penetration. Grasses also take up excess nitrogen from the soil, improving the growth and nitrogen-fixing ability of the legumes. Lastly, grasses provide structural support for the twining vetches and peas. Typical blends often consist of bell beans, vetch, peas, and oats or barley. Barley/vetch or oat/vetch blends are relatively inexpensive and are frequently used.

Cover Crops for Nontilled Orchards and Vineyards. With the increasing trend toward nontillage, many growers sow winter annual species that reseed and die in the spring and regenerate each fall--preferably with irrigation, but often with rainfall alone. Such species include annual clovers, burr medic, 'Blando' brome, and 'Zorro' fescue. If not replanted or if neglected, in time these species may simply become minor components of the ground cover. Periodic replanting every three or four years can ensure dominance by these species.

Burr medic is well adapted to California's climate and grows well in neutral to high-pH soils; it is occasionally a major component of resident vegetation. It effectively reseeds even under fairly close mowing and, because of its high percentage of hard seed, it usually reestablishes well even when tillage is used. For these reasons, it is an excellent cover crop for raisin vineyards. Subterranean clover, or subclover, usually performs best in acid to neutral soils. Early-maturing varieties, frequently used on range land, include 'Nungarin' and 'Dalkeith.' 'Blando' brome is often used for erosion control. 'Zorro' fescue is very expensive and is used mostly on hillside, serpentine, low fertility soils or where initial erosion control is required on cleared land.

Perennial Cover Crops. Perennial grasses and legumes provide a permanent cover that offers year-round traction and ease of management. Perennial clovers, such as white and strawberry, are low growing and add nitrogen, but are invasive and compete with trees and vines for water. Birdsfoot trefoil, a legume, is slow to establish but forms a low-growing, dense cover. Vigorous, summer-active perennial grasses, such as 'Berber' orchardgrass and tall fescue, devigorate trees and vines and should only be planted where vigor is excessive.

California native perennial grasses are currently popular among many grape growers in the North Coast and the San Joaquin delta area. Under drip irrigation they will almost completely shut down growth during the summer, and thus offer little competition with the vines. The seed is quite expensive initially, but can be relatively inexpensive over the life of the cover. It is important to select species that are adapted to the climate.

MANAGEMENT STRATEGIES AND CONSIDERATIONS

Planting. Winter annual and perennial cover crops perform best when sown by mid-October, but can usually be successfully grown if planted by mid-November. Establishing small-seeded cover crops in years with little fall rains may be very difficult, especially on sandy soils. In general, lower rates can be used for early seeding, and higher rates should be used for later seeding. For example, vetch sown in late September or early October may be seeded at 30 to 40 pounds per acre, while an early November seeding would require 40 to 80 pounds. Good seedbed preparation is essential, especially with native grasses.

Legume seeds must be inoculated with nitrogen-fixing *Rhizobium* bacteria to ensure nitrogen fixation. Small-seeded legumes are usually preinoculated, however large-seeded legumes (bell beans, vetch, and peas) must be inoculated by the grower, at least the first time they are sown. Use about one 8-ounce bag of inoculant per 100 pounds of seed. The most reliable method is the "wet" method, where a slurry of inoculum and adhesive are added to the seed and then allowed to dry before planting. However, the inoculant can also simply be layered (dry) with seed in the hopper. Inoculant or inoculated seed should be kept out of direct sunlight, so broadcast seed should be incorporated as soon as possible.

Mowing. Because cover crops can increase frost hazard, they are often mowed in late winter. Bell beans and peas do not perform well if mowed. Vetch should be mowed high--no lower than 8-10 in. High biomass blends can be killed in spring if mowed close to the ground. Nontillage clover mixes should be mowed in late winter to suppress tall weeds and encourage spreading. Subclover and burr medic can usually reseed even under fairly close mowing, while crimson and rose clovers flower above the foliage and therefore must not be mowed after about late March to allow for reseeding.

Nutrition. As with trees and vines, soil fertility is critical to cover crop production. Legumes fix nitrogen, so nitrogen should not be applied shortly before or during their growth. However, legumes do require adequate sulfur (which is plentiful in most vineyards) and phosphorus for good growth. Annual grasses require nitrogen additions if grown alone, and will respond well to up to 50 pounds of nitrogen per acre. Perennial grasses may require even more than this amount. In general, grasses predominate on highly fertile sites, while legumes will usually grow best in soils with low nitrogen content. Many poor solid legume plantings (especially clovers and medics) that are overtaken by grasses and mustards may be a result of excessive soil nitrogen, so broadcast fertilization should be avoided from fall until late spring.

In general, vetches and peas can fix far more nitrogen than clovers and medics. A green manure cover crop disked in April can add 150 pounds or more of nitrogen per *planted* acre, which may cause excessive vigor in grapevines, especially on highly fertile soils. Nitrogen production in orchards may be reduced due to shading and the use of wide herbicide strips. Management options in vigorous vineyards include alternate row planting and mowing instead of disking. When residues are mowed and left on the soil surface, a portion of the nitrogen will volatilize into the atmosphere. With about 80 percent of the nitrogen in leguminous cover crops contained in the above-ground portion, volatilization losses can be high--perhaps as much as half. Nontillage clovers and medics may add only about 30 to 40 pounds of nitrogen per planted acre.

Cover Cropping in Almond and Walnut Orchards. Because almonds and walnuts are harvested from the orchard floor, excessive cover crop debris at harvest could be problematic, particularly in nontilled orchards. However, most winter annual cover crops can be grown successfully if properly managed. Legume cover crops have a low carbon-to-nitrogen (C/N) ratio and therefore break down fairly rapidly after mowing, usually causing no residue problems at harvest. Grass residues have a high C/N ratio and can persist until harvest, but they are usually not a problem if mowed closely by June, followed by periodic mowing until harvest. Under drip or microsprinkler irrigation, breakdown of residues is slower, so mowing should start in late spring.

COVER CROP DATABASE AND RESEARCH INFORMATION

An on-line database of individual cover crop species and summaries of recent research is available on the World Wide Web. The web site is that of the UC Sustainable Agriculture Research & Education Program in Davis; the location is *http://www.sarep.ucdavis.edu*. The database includes descriptions and characteristics of dozens of species, along with color photographs. Over 40 cover crop research projects are also summarized on this web site.

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Seeding Rates And Costs For Cover Crops - 1996

Common Name	Scientific Name	Common Seeding Rate[1] (lbs./acre)	Approximate Cost[2] (price/lb.)	(price/seeded acre)
WINTER ANNUALS – LEGUMES				
Bell Beans	*Vicia faba*	140	$0.31	$43.40
Burr Medic	*Medicago polymorpha*	20	1.80	36.00
Clovers	***Trifolium* spp.**			
Berseem	*T. alexandrium*	20	1.50	30.00
Crimson	*T. incarnatum*	25	1.50	37.50
Rose	*T. hirtum*	15	2.20	33.00
Subterranean	*T. subterraneum*	25	2.35	58.75
Field Peas	*Pisum sativum*	100	0.38	38.00
Vetches	***Vicia* spp.**			
Common	*V. sativa*	80	0.50	40.00
'Cahaba White'	*V. sativa* x *V. cordata*	80	0.94	75.20
Purple	*V. benghalensis*	60	0.65	39.00
'Lana' Woollypod	*V. dasycarpa*	60	0.85	51.00
WINTER ANNUALS -- GRASSES				
Annual Ryegrass	*Lolium multiflorum*	25	0.50	12.50
Barley	*Hordeum vulgare*	100	0.15	15.00
'Blando' Brome	*Bromus mollis*	12	3.50	42.20
'Merced' Rye	*Secale cereale*	100	0.32	32.00
Oats	*Avena sativa*	100	0.23	23.00
'Zorro' Fescue	*Festuca megalura*	12	7.85	94.20
PERENNIALS				
Legumes				
Birdsfoot Trefoil	*Lotus corniculatus*	12	3.25	39.00
N.Z. White Clover	*Trifolium repens*	12	2.70	32.40
Strawberry Clover	*Trifolium fragiferum*	12	3.75	45.00
Grasses				
Perennial Ryegrass	*Lolium perenne*	30	1.25	37.50
Fescues	***Festuca* spp.**			
Chewings	*F. rubra commutata*	25	1.50	37.50
Creeping Red	*F. rubra*	25	1.20	30.00
'Covar' Sheep	*F. ovina*	15	4.00	60.00
Hard	*F. ovina duriuscula*	20	3.25	65.00
MIXES				
Organic Builders (grass/legume)		100	0.36	36.00
High Nitrogen Mixes (legume)		100	0.48	48.00
Perennial Sods (grass)		35	1.80	63.00
Reseeding Annual Clovers and Medics		25	2.20	55.00
California Native Perennial Grasses		20	Variable	$150-300

[1] *Seeding rates are for monocultures only; use reduced rates for individual species in mixes. Optimal seeding rates may differ from those listed depending on time of seeding, desired benefit, etc.*
2 *Prices often vary greatly among seed companies and from one year to the next. Check with local seed supplier for exact prices.*

(Prepared by Fred Thomas and Chuck Ingels)

Greenwaste-Derived Compost For Ornamental Nursery Crops Production

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Introduction

A variety of organic materials are used to produce ornamental plants in containers in California. The container nursery industry has traditionally used peat moss, firbark and other byproducts of the forestry industry as components in their growing media. These materials are lightweight, porous and relatively inexpensive. Greenwaste-derived compost has also been used as a component in nursery production. Compost has many of the same horticultural qualities as the traditional materials, and at the same time is a highly renewable resource. The purpose of these trials was to determine the optimum concentrations of compost for growing five species of woody ornamental crops.

Materials and Methods

Trials were established at Grover Nursery, Modesto, California, and at Modesto Junior College Nursery, also in Modesto. Five commonly planted landscape plant species were used in the study, including Fraser's Photinia (*Photinia fraseri*), Chinese pistache(*Pistacia chinensis*), Gold Coast Juniper (*Juniperus chinensis* 'Gold Coast'), Pink Indian Hawthorn 'Springtime' (*Raphiolepis indica rosea*) and Belgian indica azalea (*Rhododendron indicum*). The compost used in the trials was produced by Grover Environmental Services, Inc., Modesto, California. The compost was blended with each grower's standard potting soil mix to produce the following five treatments: 100% compost; 75% compost/25% grower's mix; 50% compost/50% grower's mix; 25% compost/75% grower's mix; and 100% grower's mix (control). The standard mix at Modesto Junior College Nursery consisted of a combination of sand, sawdust and fir bark for all species but azalea; for azalea, the standard mix consisted of a combination of perlite and peat moss. The standard mix at Grover Nursery consisted of a combination of forest humus, sawdust and sandy loam. Each of the five test species was grown in the five compost/grower mix combinations, using a randomized complete block experimental design, with 40 replications per treatment (1000 plants total at each nursery location).

Plants were transplanted from liner stock into 1 gallon nursery containers by both nurseries in June, 1994. The plants were grown to marketable size using each nursery's standard irrigation, fertilization, pest management and other cultural practices. In 1995 ten plants per species and per treatment (250 plants total) were harvested at each nursery location. Plants at the Modesto Junior College site were harvested on April 11, 1995, and at the Grover Nursery site on April 20, 1995. Unharvested plants were shifted (repotted) into 5 gallon containers using the same compost/grower mix treatments, and returned to the growing grounds. An additional 1000 plants (5 species, 5 treatments) were planted from liners into 1 gallon containers at both nursery locations as in 1994.

Plants to be harvested were first weighed in their containers; plants were then harvested by removing them from their containers and carefully removing the soil mix from their root systems.

Plants were then air dried for 4 weeks. An electrical scale was used to obtain whole plant weights, top (stems and foliage) weights, and root weights. Roots were separated from the plants at root crown level with pruning shears.

A second harvest using the same procedures was made in 1996, except that wet weights (plants in containers) were not obtained. As before, ten 1 gallon plants per species and per treatment were harvested; five 5 gallon plants per species and per treatment (125 plants total) were also harvested at each nursery location. Plants at the Modesto Junior College location were harvested on May 30, 1996, and at the Grover Nursery location on June 19, 1996. Plants were dried and weighed as before.

Soil samples were taken at the beginning and end of the trial at each nursery location; leaf tissue samples were taken at harvesttime in 1995 and 1996 at both nursery locations; composite samples were taken from each species and treatment. Leaf samples were analyzed for total nitrogen, phosphorous and potassium; pre-plant soil samples were analyzed for total nitrogen, ppm phosphorous and potassium, and for total salts (ECe) and pH; soil samples taken at harvesttime were analyzes for total nitrogen, phosphorous and potassium. The analyses were performed by the University of California Division of Agriculture and Natural Resources Analytical Laboratory in Davis, California.

Additionally, a visual evaluation of quality was made at Modesto Junior College Nursery, along with plant height measurements. The visual evaluation was a subjective measure of the test plants' appearance and marketability, and took into consideration leaf color, bloom where appropriate, and overall conformation; evaluations were done by Mark Bender and Ed Perry, two of the project's principal investigators. The plant heights were made as a further test of marketability. Plants were measured from soil surface to the uppermost leaves.

Results

Measurements of plant heights and visual determinations of plant quality were made at MJC Nursery just prior to harvest. Table 1. shows that azalea and Chinese pistache grew taller in the 0, 25 and 50 percent compost treatments. Average heights of Indian hawthorn and juniper was similar for all treatments, while photinia grew tallest in the 0 percent compost treatment. Table 1. also shows that for Chinese pistache and Indian hawthorn, the best commercial quality was obtained in the 0 and 25 percent compost treatments; photinia attained best visual quality in the 0 percent compost treatment, although the compost treatments were uniformly good; visual quality of juniper was best at 25 and 75 percent compost, but still good in the other treatments; none of the treatments produced visually outstanding azaleas, although the 0 and 25 percent treatments produced good plants; the 75 and 100 percent compost treatments produced unsatisfactory azalea and Chinese pistache plants from a visual standpoint.

Table 2. shows the average weights from two harvests of the test species growing in one gallon containers at the MJC Nursery. For azalea and Chinese pistache, there is a trend towards higher plant weights at the 0 to 50 percent compost levels. Highest plant weights for juniper and photinia occur at the 25 percent compost level, and at the 75 percent level for Indian hawthorn. Table 3. shows the average weights from two harvests of the test plants growing in one gallon

containers at Grover Nursery. For azalea and photinia, plant weights were generally higher at the 0 and 25 percent compost levels. Highest juniper weights occurred at the 75 percent level, and at the 0 percent level for Indian hawthorn. There were only slight differences in weights of Chinese pistache over the five treatments.

Table 4. summarizes the harvest data from the two nursery sites for the two years of the trial; data from both one and five gallon containers are taken into account. In nearly half of the cases (14 of 30), the 25 percent compost-containing mix produced the heaviest plants over the two year period of the trial. More specifically, a soil mix containing 25 percent compost produced the greatest plant weights in seven of the ten species grown in 1-gallon containers in 1995; the 25 percent mix produced the greatest plant weights in three of the ten species grown in 1-gallon containers in 1996, while the 0 percent compost mix produced the highest weights in five of the ten species grown at the two nurseries in 1996. A 25 percent compost mix produced the greatest plant weights in four of the ten plant species grown in 5-gallon containers at the two nurseries in 1996, while three of the ten species grew heaviest in the 0 percent compost mix.

Table 5. shows total nitrogen, phosphorous and potassium in the various compost/potting soil treatments at MJC Nursery in 1996. Taken from the five gallon containers, these levels represent the levels of the three nutrients remaining in the containers at the end of the trial. For the most part, there are only small differences in the levels of nutrients between treatments for the test species. However, for Chinese pistache, Indian hawthorn, juniper and photinia, percent nitrogen generally increases as percent compost increases. Table 6., which shows total soil levels of nitrogen, phosphorous and potassium from five gallon containers at Grover Nursery in 1996, shows increasing levels of nitrogen with increasing compost for all of the test species; there are only slight differences in levels of phosphorous and potassium. Table 7. shows the final leaf tissue analysis for the MJC Nursery trial; samples were taken from five gallon plants that had been growing in the various treatments for two years. There are only slight differences in percent nitrogen, phosphorous and potassium between the treatments among the five species. Table 8. shows the final leaf tissue analysis for the Grover nursery trial. As in the previous table, the nutrient levels shown are for plants that had been growing in the five treatments for two years. In this case, percent nitrogen and potassium generally increase as percent compost increases.

Conclusions

These trials showed that five species of ornamental nursery stock can be successfully grown in compost-containing potting soil. There was a great deal of variability in plant growth between species in the various compost mixes, as well as differences between the two nursery test sites. The variability was due in part to the different cultural practices between the two nurseries. For most of the plants tested, over the two year period at both nurseries, a 25 percent compost/potting soil mix performed well as a growing media, as shown by the harvest data.

Compost was shown to have several good qualities as a component of potting soil. Preplant soil tests showed that compost has greater nutrient-holding capability than non-compost-containing media. This remained true, especially for nitrogen, to the end of the trial. This is as a result of compost's fine texture. This feature also increases the water-holding capacity of compost-containing potting mixes, which, while not specifically studied in these trials, may have important implications for water savings. Visual evaluations showed that azaleas and Chinese pistache and Indian hawthorn grown in 25 percent compost were equal in quality to those grown without compost; junipers grown in 25 and 75 percent compost were visually superior to those grown without, although photinias grown without compost had better visual quality than any of the compost treatments.

(This study was supported by a grant from the California Integrated Waste Management Board. Cooperators included Grover Nursery and Grover Environmental Products, Modesto CA., Modesto Junior College, City of Modesto, Stanislaus County and University of California Cooperative Extension. The complete report, including statistical analyses of results, will be published by the CIWMB).

Table 1. Plant height and visual quality of five species grown in one gallon containers in five compost treatments in 1994-95 (MJC Nursery).

%	Azalea		Chinese pistache		Indian hawthorn		Juniper		Photinia	
Com-post	Ht. in cm	Quality	Ht. in cm	Quality	Ht. in cm	Quality	Ht. in cm	Quality	Ht. in cm	Quality
0	50.0	G	90.0	E	42.5	E	37.5	G	52.5	E
25	45.0	G	90.0	E	45.0	E	37.5	E	45.0	G
50	45.0	F	87.5	G	45.0	G	36.3	G	47.5	G
75	40.0	U	65.0	U	45.0	G	37.5	E	42.5	G
100	35.0	U	32.5	U	42.5	F	36.3	G	45.0	G

E = Excellent commercial quality **F = Fair**
G = Good **U = Unsatisfactory**

Table 2. Average weights in grams of five species grown in one gallon containers in five compost treatments in 1994-95 and 1995-96 (MJC Nursery).

% Compost	Azalea	Chinese Pistache	Indian Hawthorn	Juniper	Photinia
0	400	20	119	144	93
25	320	22	124	219	104
50	152	19	130	115	75
75	73	8	152	180	95
100	56	9	115	160	88

Table 3. Average weights in grams of five species grown in one gallon containers in five compost treatments in 1994-95 and 1995-96 (Grover Nursery).

% Compost	Azalea	Chinese Pistache	Indian Hawthorn	Juniper	Photinia
0	219	32	97	154	60
25	190	35	81	176	47
50	145	33	64	154	42
75	146	28	57	212	41
100	116	26	67	186	40

Table 4. Percent compost mix yielding highest plant weights by test site, year and species.

Test site	Year	Azalea	Pistache	Hawthorn	Juniper	Photinia
MJC	1995	25	25	25	25	0
Grover	1995	25	25	0	75	25
MJC	1996	0	25	75	25	25
MJC	1996	25	50	25	75	0
Grover	1996	0	0	0	75	0
Grover	1996	0	50	25	25	0

Table 5. Percent nitrogen, phosphorous and potassium in five compost/potting soil treatments used in growing five species in 1995-96 (MJC Nursery).

%	Azalea			Chinese pistache			Indian hawthorn			Juniper			Photinia		
Com post	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %
0	1.25	0.13	0.15	0.32	0.08	0.13	0.18	0.05	0.11	0.19	0.05	0.11	0.27	0.10	0.11
25	1.36	0.15	0.15	0.43	0.09	0.11	0.25	0.05	0.11	0.31	0.06	0.11	0.27	0.05	0.10
50	1.23	0.19	0.15	0.42	0.09	0.10	0.41	0.08	0.11	0.61	0.08	0.12	0.54	0.10	0.13
75	1.29	0.23	0.15	0.62	0.12	0.11	0.55	0.08	0.11	0.76	0.08	0.12	0.61	0.08	0.11
100	1.23	0.21	0.15	0.62	0.14	0.14	0.55	0.08	0.10	0.52	0.08	0.10	0.46	0.08	0.11

Table 6. Percent nitrogen, phosphorous and potassium in five compost/potting soil treatments used in growing five species in 1995-96 (Grover Nursery).

%	Azalea			Chinese pistache			Indian hawthorn			Juniper			Photinia		
Com post	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %
0	0.20	0.13	0.25	0.20	0.09	0.18	0.20	0.11	0.19	0.17	0.12	0.20	0.26	0.12	0.23
25	0.32	0.15	0.28	0.48	0.12	0.22	0.43	0.12	0.19	0.44	0.16	0.26	0.42	0.14	0.24
50	0.84	0.22	0.27	0.68	0.19	0.29	0.52	0.13	0.17	0.58	0.18	0.27	0.78	0.18	0.30
75	0.59	0.22	0.33	0.74	0.21	0.25	0.74	0.20	0.23	0.78	0.23	0.36	0.81	0.21	0.24
100	0.95	0.30	0.34	1.05	0.20	0.12	1.06	0.26	0.20	1.02	0.29	0.36	0.88	0.28	0.27

Table 7. Percent nitrogen, phosphorous and potassium in leaves of five species grown in five compost treatments in 1995-96 (MJC Nursery).

% Compost	Azalea			Chinese pistache			Indian hawthorn			Juniper			Photinia		
	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %
0	2.04	0.14	0.64	2.38	0.17	0.79	1.40	0.14	0.87	1.20	0.16	0.60	1.34	0.14	1.06
25	1.83	0.16	0.83	2.28	0.21	0.97	1.32	0.17	0.88	1.03	0.14	0.66	1.20	0.16	1.17
50	2.20	0.19	0.96	2.46	0.25	0.91	1.62	0.17	0.94	1.39	0.20	0.84	1.71	0.14	1.17
75	2.26	0.20	0.99	2.42	0.26	1.03	1.46	0.25	0.88	1.45	0.22	0.79	1.47	0.18	1.16
100	1.72	0.15	0.69	2.61	0.28	1.24	1.50	0.25	0.96	1.42	0.20	0.81	1.40	0.19	1.13

Table 8. Percent nitrogen, phosphorous and potassium in leaves of five species grown in five compost treatments in 1995-96 (Grover Nursery).

% Compost	Azalea			Chinese pistache			Indian hawthorn			Juniper			Photinia		
	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %	N %	P %	K %
0	2.26	0.19	1.15	2.00	0.38	1.53	1.01	0.27	1.46	1.25	0.19	0.81	1.48	0.44	1.82
25	2.41	0.18	1.40	2.33	0.34	1.69	1.16	0.30	1.59	1.29	0.21	0.91	1.60	0.49	2.08
50	2.44	0.17	1.38	2.11	0.32	1.46	1.35	0.28	1.59	1.28	0.20	0.85	1.99	0.47	2.64
75	2.43	0.16	1.61	2.39	0.48	1.78	1.29	0.24	1.74	1.40	0.24	0.99	1.91	0.38	2.04
100	2.54	0.15	1.95	2.64	0.42	1.95	1.32	0.23	1.78	1.59	0.27	0.97	1.93	0.24	2.25

Applications of Fully Composted Community Derived Green Waste Vegetable Demonstration Project in Stanislaus County.

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Introduction:
Government imposed regulations to California communities to reduce the amount of trash been deposited in landfills has brought officials and scientists together to work in finding sound alternative solutions to alleviate its impact to the environment. Most trash going to landfills is classified as community green waste (grass clippings, garden and pruning material). Therefore, pressure to local landfills can be relief if green waste could be collected by communities efficiently. Curb side collections of recyclable materials is already in place in many cities. Adding back yard prunings to the curb side should not be difficult to the citizenry for pick-up by public utilities.

Since, green waste can be successfully composted and crops can benefit when used to amend soils with little or no adverse effects on the environment. The team wanted to demonstrate its impact under controlled conditions. Some of the issues needing answers were the following: Will compost improved soil characteristics? Would the compost affect water holding capacity? Would it increase water infiltration? would it improve soil friability?

Demonstration projects were conducted at growers' fields in 1994 through 1996. Three crops with different root systems and growth patterns were selected to be included in the demonstrations. Sweet corn, a shallow rooted crop with an upright growth pattern was the first selection. Watermelons, has more of an intermediate to deep and extensive lateral root system with a postrate vine growth pattern. Fresh market tomatoes, the third crop has more of a medium to deep root system with a compact but dense bushy growth. These three crops were selected to have a representation of most vegetable crop root systems growing in the central San Joaquin valley.

The Central Valley of California produces a high percent of food and fiber in the United States. Yet, this highly productive area is under threat from city encroachment and environmental pressures to produce food with more organic materials soft to the environment. The farming industry has been practicing sustainability for a long time already and are been less dependent from synthetic pesticides to produce crops than ever before. Yet, in order for them to switch to a total organic practice, two things need to happen. First, the system must be proved that works, and secondly, the system must be economical feasible. Fully composted materials could be the first step in moving towards those goals. Healthy soils are the foundation for agricultural productivity. Therefore, they should be maintained and enriched with organic materials to preserve them for generations to come.

Application of compost: Compost was applied at the rate of 10 and 20 tons per acre and incorporated into the soil with a power rototiller at a depth of 4-6 inches. Compost applications were compared to a typical commercial synthetic fertilizer program. An untreated check plot was also used for comparisons in all three crops. After the first year, individual rows and furrows where marked with metal stakes to facilitate duplication of treatments on the same location the following year. Treatments on all three crops were randomized 4 times.

Plant and soil analysis: Soil analysis were taken before and after the compost or commercial fertilizer was applied to the site to determine initial levels of organic matter, soil EC, pH, nitrogen, potassium and phosphorous content. Samples where also taken at the end of the season for analysis to record soil changes.

Tissue samples were taken through out the growing season to monitor for nutrient content. Three samples were taken in the tomatoes. The first at first bloom, the second when the fruit reached an inch in diameter. The third was taken at first pink fruit. Samples where taken twice in sweet corn. One when plants reached 12 inches in height and the other at first tassels. Watermelons: two samples were taken there. The first at first fruit set and the second during fruit enlargement. All Samples were sent to the University of California, Davis Analytical Laboratory for analysis.

Harvest: Crops where harvested as soon as they reached maturity. They all required multiple harvest as the grower was picking only marketable vine ripe fruit for his fresh market. A 50 foot strip of the middle row was used for yields and evaluations.

Conclusions: The first conclusion after two years of compost applications to East side sandy soils of Stanislaus County did not seem to be enough to provide nutrition for growth and development of the vegetable crops in the evaluation. However, compost was starting to affect soil structure, which seems to have helped freeing nutrients tied up by soil particles to soil acidity and low organic matter conditions. Organic matter increased significantly in the compost treatments over both, commercial fertilizer and untreated check plots. Compost pH of 7.9 raised the soil pH significantly over the check and fertilizer plots both years. In fact, nitrogen fertilizer used made the soil more acidic.

Two years of compost applications affected crops in the evaluation plots in different ways. Production of fresh market tomatoes was increased by the addition of compost at 10 ton compost rate over the check and even the commercial fertilized plots. However, the 20 tons compost per acre rate did not resulted in increase production. In sweet corn,10 ton compost rate yielded similar results. However, this was not true in watermelons, which changes in production were affected by treatment.

Soil structural changes with compost take place over a long and continuous application of organic materials into the soil. Two years is not sufficient time to document the impact of compost to row crops in the study. Two years of evaluations can only provide limited information and we can only make some conclusions based on extrapolation of data obtained. More time will be necessary to learn and document changes of soil structure changes.

UTILIZING DAIRY MANURE IN A CROPPING SYSTEM

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INTRODUCTION:

California agriculture is rich in commodities. Many of these commodities have by-products associated with processing the commodities to a saleable form. Many of these by-products, as well as forages and grains, are fed to dairy cattle. The milk produced by California's dairy cattle is the state's leading agricultural commodity. Since milk production is not 100% efficient, another by-product is obtained: manure.

The average California dairy cow produces in excess of 22 tons of manure (feces and urine) annually. Some of this is handled in a wet form (diluted through a flush system). Other manure is air dried and handled in a dry form.

Manure is commonly land applied. Guthrie (1995) surveyed dairy producers in Fresno, Madera and Tulare counties on manure use. The producers reported that manure was applied primarily to forage crops (corn or cereal grains for silage) and cotton, but that manure (solid or liquid) was also applied to grapes, olives, tomatoes, sugar beets, sudan grass or pasture land.

The same survey addressed nutrient sampling of manures. Although many producers indicated that manure was applied to meet crop nutrient needs, none reported taking samples of manure liquids or solids for chemical analyses. Clearly, there is a need to incorporate nutrient content of manures applied in a cropping system. Also, one must integrate irrigation water management in order to help contain plant available, highly soluble and mobile nutrients in the crop root zone. Once these nutrients have leached beneath the root zone they are, depending on soil type, potentially destined for the underlying groundwater.

SOURCES OF MANURE NUTRIENTS

All manures aren't alike. Corral solids, composts and solids from a separator vary in nutrient concentration, moisture and bulk density.

Most solid manures (corral solids, compost or separated solids) can be sampled easily. A shovel or soil auger and a bucket are useful. Piles should be sampled prior to spreading. A sample should represent the entire pile or source. Many augerfuls or shovelfuls should be collected and mixed well in a bucket. Then a representative subsample can be taken and stored in a labelled ziplock bag. The collected sample should be stored out of the sun and transported to the lab for analysis as soon as possible.

Liquid manures are stored in earthen ponds. At this time, the recommended method of sampling liquids is as they go to an irrigation system. Ideally, samples would be taken every other day during the spring dewatering. Non-diluted samples can be retrieved as manure water drops into a standpipe. If the standpipe is too tall, or mixing occurs underground there may be other options. The preferred option is to sample straight manure water as it enters a standpipe. The first alternative is to run only manure water through lines and sample at a field valve. This is a common method when all plumbing is underground or the standpipe is too tall. Alternatively, if manure water from the pond used for irrigating is also used for recycled flush water, water can be collected from a flush at the valve.

Samples should be collected in the actual bottles that will physically go to the lab. An airspace of at least 1" is recommended if samples are to be frozen.

NUTRIENT ANALYSES

Solids should be analyzed for total N, ammoniacal-N, P, K, Ca, Mg, Na, Cl and EC. Also, moisture or dry matter (100%-Moisture%) should be determined. Dry manures are 15 to 5% moisture. Compost may have as much as 50% moisture. Solids straight from a separator can be 85% moisture. Table 1 lists average values for nutrient composition of solid manures.

Table 1. Nutrients applied (lbs/ton) from solid manures and compost.

Source	Moisture	Org-N	NH_4^+-N	P	K	Ca	Mg	Na	Cl
Freshly separated solids (n=56)									
	85.0	4.5	0.4	1.0	1.1	3.6	0.8	0.4	0.3
Fresh manure	(n=3)								
	84.2	7.5	0.3	2.0	1.9	5.8	1.7	0.4	1.1
Old dried manure	(n=16)								
	38.8	25.6	0.4	7.8	15.3	32.1	7.6	3.4	5.0

Manure liquids should be evaluated for the same chemical elements as the solids. However, an evaluation of moisture would be quite difficult and not necessarily useful. Also, it is helpful to know the flow rate of the manure water. Then, the results of analytical analysis can be calculated in terms of pounds of nutrients applied per hour of manure water application. Table 2 is a summary of such data evaluated during the summer of 996.

Table 2. Nutrients applied per (lbs.) hours of manure pump operation.

Concentration	Org-N	NH_4^+-N	P	K	Ca	Mg	Na	Cl
Low	9.0	7.9	1.7	10.8	8.5	1.8	4.8	2.3
High	9.97	115.5	33.2	202.3	90.7	39.9	69.4	98.3

Values calculated from nutrient concentration of sample and pump flow rates from 17 dairy operations.

DETERMINING APPLICATION RATE

Solid or liquid manures should be applied based on soil nutrient concentrations, crop needs and nutrient concentration in the manure.

It is important to consider the method of application when determining the application rate. For instance, if solid manure should be applied at 4 tons per acre. Can the manure spreader or truck apply that rate? Equipment used for spreading manure should be calibrated annually.

The method of application is important to consider. If the irrigation method is flood (versus sprinkler) then a non-uniform distribution of water and nutrients will occur. This is a particular concern in areas of poor soils and shallow water tables.

Commonly, a single pump is available to pump manure water. Therefore, alterations in application rate require the ability to alter the amount of fresh water commingled (dilution rate).

CHALLENGES IN USING MANURES

Fist and foremost, one must consider the nutrient content of the manure. Crops use much more N than P. As a result, if manure is applied to meet crop N needs, P and salts will be over-applied. Will this affect the crop or the soil? Two methods can be used to overcome this poor N:P ratio. The first is N conservation once manure is excreted from the cow. Current research efforts are focusing on techniques to accomplish N conservation. A second method to enhance N:P ratio included incorporation of fertilizer N.

A second consideration is distribution uniformity of nutrients. Spreaders that shoot out large clumps of manure may not distribute nutrients evenly. Is this acceptable in the particular farming scheme? Also, spreaders compact soil which can be detrimental to the cropping system. This practice may be undesirable in permanent crop systems. Although liquid manure does not compact soil, some producers have reported crop loss or damage, and poor water infiltration. Will water be able to infiltrate into the soil? This is an especially important consideration in orchards or vineyards where soil tillage is less than that of row crops. Crop loss or damage can be associated with high salt, high ammoniacal N, or high organic content (which as it decomposes removes oxygen from the oil resulting in crop death due to lack of oxygen). Also, it has been suggested that fines in manure water (bacteria and small particles) seal the soil surface -- prevent oxygen from entering and other gases from leaving the soil.

A third consideration is viable weed seeds. The inside of composted manure or stacked manure piles that have undergone static composting will be virtually weed-seed free. However, wind blown weed seeds may have been embedded in the pile surface. Corral manure and manure liquids will contain viable weed seeds. Organic growers and others may choose to further analyze manure utilization potentials based on the risk of broadcasting weed seeds. Weed control around piled manure is important to minimize plant maturation and further spread weed seeds. Solid liquid separators have not been evaluated on their ability to remove weed seeds.

Certain cropping systems are better suited to receive manure waters than others. Cropping systems that remove large amounts of N or that have deep roots are desirable. Deep rooted plants have a deeper root zone from which to remove nitrate. This may aid in reducing the amount of nitrate ultimately leached into underlying groundwater.

The nutrient availability of manure will depend on its chemical analysis, soil microbial activity (which depends on temperature) and the presence of cations and anions in the soil.

The solids in liquid manure can be a challenge. Most manure water is less than 1.5% solids. When thicker liquids are applied, solids will settle out of the liquid stream. Often, solids accumulate in the top 50 to 200' of check. The deeper the solids, the greater the probability the solids will hinder cultivation practices. A 1' deep solid build-up immediately after an irrigation will dry down to 2 to 4" of material. The soil under such a thickness of solids takes longer to dry to allow equipment use without getting stuck. Solids settle as a result of their particle size and density compared to the reduced flow velocity that occurs as water exits the valve onto a wide field. Flow rate can be increased or check width can be reduced in an attempt to distribute solids further down a field. Alternatively, the first third or half of the irrigation can be with fresh water, with manure water added toward the middle of the irrigation. One-half as much time running manure water will reduce total solids applied to the field, thereby reducing solids settling at the top of the field. Solid liquid separators can be effective at removing larger sized fiber particles (>2mm). Unfortunately, this size particle makes up a small portion of the total solids in liquid manure. To date, settled solids at the head of a field have not been evaluated for particle length. Application of manure solids to fields where solids from manure water irrigations have settled should be done in consideration of the solid settling pattern (e.g. apply solids in the solid form to areas of the field that didn't receive considerable amounts of solids from the liquid form).

Clearly, the organic component of manure can improve soil quality. However, the salt composition may hinder water utilization and crop productivity.

IRRIGATION EFFICIENCY AND UNIFORMITY CONSIDERATIONS

Irrigation water management considers both efficiency and uniformity of water use. Both are major components to consider under normal farming practices. Both become critical components of management when manure waters are used in the irrigations..

It can be a tremendous challenge to apply liquid manure with a flood irrigation system. The extent of the challenge depends on site specific characteristics that are difficult to modify, as well as management practices that can be modified. Soil type and depth and depth, to groundwater are physical characteristics an operator must consider in management. Cropping pattern, field slope, soil tillage, and field length are components that can be modified on an operation. When the practicality of modification is considered, costs as well as additional infrastructure necessary to accomplish modifications must be evaluated.

The amount of water applied that is beneficially used during an irrigation defines the efficiency of the irrigation. The primary beneficial use of irrigation water is to supply the crop with its water needs. Irrigation water ends up in one of three places: water stored in the crop's root zone; deep percolation (if there is over application of water); or runoff from the field surface (a tail water return system is very useful in such situations). Deep percolation of water can result in leaching of nutrients beneath the crop's root zone which can be undesirable.

The amount of water needed to refill the crop's root zone can be determined prior to an irrigation event. Irrigation scheduling should be used to plan irrigation events to meet crop water requirements. Techniques of evapotranspiration (ET) and/or soil moisture monitoring can be effective aids to determine when and how much water is needed.

Field characteristics (length, slope, soil type, and roughness) need to be considered when determining irrigation water scheduling. As an example: It takes an average of 5 inches of water per acre to irrigate a field. The ET for the crop is 1.5 inches per week. Irrigations should occur about every three weeks (this would apply 5 inches of water when the plants have consumed about 4.5 inches of water). Irrigations at one week intervals (application of 5 inches of water per week when only 1.5 inches are needed) would result in large over applications of water and deep percolation with potential nutrient leaching. However, careful consideration must be given to the crop's ability to sustain the longer interval between irrigations.

Flood irrigated systems confound the application of nutrients with the application of water. California research (Morse et al., 1994) has indicated that although some solids do settle at the head of the field during some irrigations with manure waters, most nutrients are carried with the liquid phase of the water throughout the field. In an ideal situation, the manure water would be distributed uniformly throughout the field, which would apply manure nutrients uniformly to the field. Unfortunately, flood irrigated systems have non-uniform distribution of water (and nutrients when manure waters are applied). Very detailed information of the importance of distribution uniformity and manure water nutrients can be found (Morse and Schwankl, 1995; Schwankl and Morse, 1995; and Schwankl et al., 1996).

Non-uniform distribution of water/nutrients can be detrimental to crop growth and to groundwater quality. If water and nutrients are applied in excess, deep percolation can occur. This can result in leaching of nutrients beneath the crop root zone. When water and nutrients are not applied in sufficient rates (under-irrigated) plant development may be hindered.

CONCLUSIONS

Manure solids and liquids are part of dairying. The nutrients and water can be used as a beneficial component of cropping systems. However, they need to be managed appropriately to minimize adverse impacts on other resources. Proper management of manure nutrients and water is key to successful farming practices. Minor alterations in current management practices may improve efficiency of manure nutrient utilization.

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EFFECT OF GROUND COVERS ON GRAPEVINE GROWTH AND VINEYARD MICROCLIMATE

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INTRODUCTION:

Cover cropping in grape vineyards is being promoted for a variety of positive benefits, including improvement of soil structure and water penetration, addition of nitrogen from leguminous covers, field accessibility in wet conditions, reduction of dust and improved pest management (Ingels and Klonsky, in press). We have found that ground covers (cover crops and resident vegetation) can sometimes lower numbers of vineyard pests such as leafhoppers (Costello & Daane 1995). The mechanisms involved in this finding are not understood, but possibly involve 1) increased activity by predators; 2) poorer host plant quality due to competition from the covers, making the vines less attractive and/or suitable for leafhopper feeding and development; and 3) alteration of the microclimate of the vineyard, thereby affecting growth, development or fecundity of leafhoppers and/or predators. Here we present vine growth and microclimate data from experiments conducted in commercial vineyards in the San Joaquin Valley, one managed for table grapes, the other for raisins.

MATERIALS AND METHODS:

One study took place in a table grape vineyard (cv. Ruby Seedless) near Reedley, CA. The grapes were cordon trained and spur pruned, and trellised with a 0.9 m (3 ft) crossarm with 2 catch wires. Rows were spaced 3.6 m (12 ft) wide and vines were spaced 2.4 m (8 ft) within the row. The experiment was designed as a randomized complete block, with blocks replicated five times. Plots were 8 rows wide by 80 vines long (0.6 ha [1.4 ac]). The entire site was seeded to a 4:1 mixture of purple vetch (*Vicia benghalensis*) and barley (*Hordeum vulgare*) at a rate of 11 kg/planted ha (25 lb/planted ac) in November 1992 and 1993 and a 1:1:1 mix of fava beans (*Vicia fava*), austrian winter peas (*Pisum sativum*) and common vetch (*Vicia sativa*) at a rate of 23 kg/planted ha (50 lb/planted ac) in November 1994. Cover crop was seeded in a 1.5 m (5 ft) swath in the row middle. The two treatments were: 1) no cover crop during the growing season (no cover) and 2) maintenance of cover crop/ground cover during the growing season (ground cover). In the no cover treatment, the cover crop was disked under in late March of each year, and kept free of vegetation through mid-August. In 1993 this was accomplished by "chemical mowing", i.e., spraying the ground cover with glyphosate and creating a "dead mulch", and in 1994 and 1995 this was accomplished by cultivating the middles and french plowing in-row. The no cover treatment was kept free of vegetation through August. In the ground cover treatment the cover crop was allowed to mature, go to seed and be replaced by summer resident vegetation of cupgrass (*Echinochloa* species author), large crabgrass (*Digitaria sanguinalis* [L.] Scopoli), knotroot foxtail (*Setaria gracilis* Kunth) and bermuda grass (*Cynodon dactylon* author). Resident vegetation was allowed to grow in the vine row, and was mowed accordingly. Therefore, this was a "100% cover" treatment, i.e., 100% of the vineyard floor was covered by vegetation. In 1993 and 1994 the ground cover was maintained by mowing through September; in 1995 the ground cover was removed in mid-July by spraying with glyphosate.

Another study is being conducted in a raisin vineyard (cv. Thompson Seedless) near Del Rey, CA. The grapes were head trained and and cane pruned, and trellised with a 0.6 m (2ft) crossarm. Rows were spaced spaced 3.6 m (12 ft) wide and vines were spaced 2.1 m (7 ft) within the row. The experiment was established in a randomized complete block design, with blocks replicated four times. Plots were eight vines by 100 vines long (0.6 ha [1.5 ac]). The entire site was seeded to a 4:1 mixture of purple vetch (*Vicia benghalensis*) and barley (*Hordeum vulgare*) at a rate of 11 kg/planted ha (25 lb/planted ac) in November 1993 and 1994. Cover crop was seeded in a 1.5 m (5 ft) swath in the row middle. Treatments were 1) cover crop disked under in early July (cover through June) 2) cover crop disked under in early June (cover through May) and 3) cover crop disked under in March (no cover). The in-row vineyard floor was treated in February of each year with 0.45 kg/ha (1 lb/ac) each of simizine and oxyfluorfen for weed control. Therefore, the cover crop represented 42% floor cover.

Temperature and relative humidity were monitored with hygrothermographs at the table grape site in 1993 and 1994 and at the raisin grape site in 1994. At the table grape site, one unit was placed on the crotch of a vine in the middle rows of three randomly selected plots of each treatment. At the raisin grape site, units were place on the crotch of three randomly selected vines between two adjacent plots of the no cover and cover through June treatments (pseudoreplicated). The hygrothermographs were left at each site for approximately a week at a time.

Vine nitrate-nitrogen status was measured by taking petiole samples at bloomtime (mid-May) in 1995 at each site. From the middle two rows of each plot, one petiole (opposite a cluster) was taken from 30 randomly selected vines. Petioles were dried at 40°C for two days, ground, nitrate extracted using 2% acetic acid extraction (Johnson & Ulrich 1959) and analyzed using the zinc reduction and conductimetric analysis (Carlson 1978).

Grape berry sugar (°brix) at harvest was measured by selecting berries from the top, middle and bottom of clusters from 33 randomly selected vines from each plot (100 berries).

Sampling dates were 31 Aug. 1993, 6 Sept. 1994 and 7 Sept. 1995 at the table grape site and 1 Sept. 1995 at the raisin grape site. Sample berries were homogenized in a blender, the juice filtered and °brix read with a Leica Brix30 temperature compensating refractometer.

As a measure of vine vigor, winter prunings were weighed at the table grape site. In each plot two 2-vine sections and three 6-vine sections were weighed in 1994 and 1995, respectively.

All data were analyzed by analysis of variance (ANOVA), using $P=0.05$ as a level of significance (SAS, 1995).

RESULTS AND DISCUSSION:

Results from berry sugar, pruning weight and petiole nitrate show that maintaining 100% ground cover throughout the season increases vine stress. Grape berry maturity was more rapid when the cover crop was maintained throughout the season, as was the case at the table grape site in the first two years of the study. °Brix were 0.32 and 0.38 points higher in the cover vs. the no cover treatment in 1993 and 1994, respectively ($P<0.05$, Table 1). Accelerated sugar accumulation can be associated with increased vine stress; this finding suggests that the maintenance of ground covers in close association with the vines throughout the growing season contributed to increased vine stress. In 1995, °brix did not differ significantly between treatments at the table grape site (Table 1) nor among treatments at the raisin grape site (Table 2), indicating that if ground covers are removed by mid-season (mid-July) they should not increase vine stress. This is corroborated by the pruning weight measurements at the table grape site. In 1994, pruning weights were reduced by 20% with ground covers compared to no cover ($P<0.05$, Table 1), whereas in 1995 there was no significant difference in pruning weights between treatments (Table 1).. At the table grape site, 1995 bloomtime petiole nitrate levels in the ground cover treatment were 80% lower than with no cover ($P<0.05$, Table 1), reflecting the competition between ground covers and vines for soil nitrogen during the 1993 and 1994 growing seasons. No significant difference in bloomtime petiole nitrate levels was found among treatments at the raisin grape site in 1995 (Table 2).

Temperature was little affected by the presence of cover crops at either site. At the table grape site, there were almost no significant differences in 1993, but in 1994 there was a trend toward slightly cooler late-season temperatures where ground covers were present. In August and September 1994 low temperatures were 1.3°C and 1.4°C cooler and and high temperatures were 2.2°C and 1.8°C cooler with ground covers compared to no cover, respectively ($P<0.05$, Table 3). That there were no significant differences in 1993 appears to indicate that the "dead mulch" served to reflect incoming solar radiation. At the raisin grape site temperature did not differ significantly between treatments except in mid-July when the high temperature was 2.2°C higher in the cover treatment compared to no cover ($P<0.05$, Table 4). Remember that when the July temperatures were recorded the cover crop had just recently been disked under.

Relative humidity was not consistently affected by the presence of cover crop, but during certain periods the difference between treatments was dramatic. At the table grape site no differences were seen in 1993, but in 1994 the ground cover treatment daytime RH was 33.5 and 23.1 points lower than no cover, and nighttime RH 20.9 and 12.2 points lower than no cover in July and August, respectively ($P<0.05$, Table 5). The explanation for this phenomenon can only be that the July and August measurements were taken during periods of irrigation; the presence of ground covers allowed for higher rates of water infiltration, whereas the water remained standing on the soil surface of the no cover treatment. A similar situation can be seen at the raisin grape site. No differences in RH between treatments are recorded in March, April and May/June, but in July daytime RH was 38.0 points lower and nighttime RH 23.2 points lower where cover crop had recently been disked under compared to no cover ($P<0.05$, Table 6). This again suggests that water infiltration was highest because of the improved soil structure due to the cover crop. At the table grape site in September, when irrigation was not taking place, the ground cover treatment daytime RH was 7.5 points higher than no cover ($P<0.05$, Table 5).

CONCLUSIONS:

It appears that maintaining a 100% ground cover throughout the grape growing season increases vine stress and decreases vine vigor compared to clean cultivation, as indicated by increased berry sugar, lower pruning weight and lower petiole nitrate concentration at the table grape site. However, when ground covers were removed by mid-season, as happened at the raisin grape site and at the table grape sites in 1995, increased vine stess was not found. Temperature did not differ much between ground cover and "dead mulch" treatments (table grapes 1993), but mean daily canopy temperature during the warmest part of the season was reduced by about 1.5°C with ground covers compared to clean cultivation (table grapes 1994). RH was dramatically increased in the clean cultivated treatments at both the table and raisin grape sites during periods of irrigation, suggesting that ground covers increased the rate of water infiltration.

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Table 1. Berry sugar (°brix), brush weight (kg), and nitrate-nitrogen concentration in ground cover and no cover treatments, table grape vineyard.

	Brix		Brush Weight		N03-N	
Year	Cover	No Cover	Cover	No Cover	Cover	No Cover
1993	20.12 (0.26)	19.80 (0.30)	---		---	
1994	20.52 (0.26)	20.14 (0.36)	2.74 (0.11)	3.44 (0.19)	---	
1995	19.70 (0.05)	19.96 (0.18)	0.65 (0.06)	0.62 (0.05)	28.0 (4.9)	142 (36.0)

Table 2. Berry sugar (°brix) and nitrate-nitrogen concentration in cover and no cover treatments, raisin grape vineyard.

	Brix			N03-N		
	Cover through June	Cover through May	No Cover	Cover through June	Cover through May	No Cover
1995	21.20 (0.35)	21.77 (0.33)	21.27 (0.72)	585 (108)	545 (160)	500 (112)

Table 3. Temperature (°C) in ground cover and no cover treatments, table grape site 1993-94.

Year	Period	Low		High		Daily Mean	
		Cover	No Cover	Cover	No Cover	Cover	No Cover
1993	19-21 April	6.4 (1.1)	6.4 (0.8)	22.2 (2.8)	22.8 (2.8)	17.8 (1.0)	17.9 (0.9)
	30 Apr.-5 May	8.7 (0.5)	9.9 (0.5)	28.8 (1.1)	28.7 (1.1)	17.9 (0.6)	18.3 (0.6)
	21-26 May	13.8 (0.6)	11.9 (0.4)	32.5 (0.7)	32.9 (0.6)	23.0 (0.4)	23.0 (0.3)
	16-22 June	15.8 (0.8)	15.2 (0.6)	32.3 (0.4)	32.0 (0.4)	24.0 (0.3)	23.5 (0.3)
	2-8 Aug.	16.5 (0.5)	16.7 (0.5)	33.4 (0.5)	33.1 (0.7)	25.2 (0.5)	25.1 (0.5)
	19-25 Aug.	15.0 (0.4)	13.4 (0.4) *	31.4 (0.4)	31.6 (0.7)	22.8 (0.4)	22.3 (0.5)
1994	13-18 April	10.5 (1.0)	10.3 (0.7)	32.3 (0.8)	30.8 (0.9)	19.5 (0.8)	18.7 (0.8)
	12-19 May	11.6 (0.4)	11.6 (0.4)	26.5 (1.3)	27.7 (1.4)	19.0 (0.4)	19.2 (0.5)
	14-21 June	13.3 (0.7)	11.0 (.05) *	31.4 (0.9)	33.4 (0.4)	22.3 (0.5)	22.2 (0.6)
	18-25 July	16.5 (0.5)	17.8 (0.4) *	28.9 (1.5)	32.1 (0.8) *	23.0 (0.4)	24.8 (0.4) *
	10-17 Aug.	15.6 (0.2)	17.0 (0.2) *	32.3 (0.8)	34.1 (0.5) *	23.3 (0.5)	24.6 (0.4) *

* P<0.05

Table 4. Temperature (°C) in cover and no cover treatments, raisin grape site 1995.

Year	Period	Diurnal Mean		Nocturnal Mean		Daily Mean	
		Cover	No Cover	Cover	No Cover	Cover	No Cover
1994	22-29 March	6.3 (0.5)	6.1 (0.6)	20.4 (1.0)	21.9 (1.0)	12.35 (0.15)	13.11 (0.18)
	18-24 April	11.4 (0.6)	10.8 (0.5)	24.8 (1.5)	25.4 (1.5)	17.75 (0.22)	18.13 (0.22)
	27 May-3 June	13.7 (0.9)	13.8 (0.5)	33.4 (0.6)	33.0 (0.5)	23.40 (0.41)	23.60 (0.31)
	4-11 July[1]	16.6 (0.4)	17.0 (0.4)	37.1 (0.5)	34.9 (0.5) *	26.60 (0.29)	25.30 (0.30) *

[1]Cover crop was disked under just prior to this period of measurement.
* P<0.05

Table 5. Relative humidity (%) in ground cover and no cover treatments, table grape site 1993-94.

		Diurnal Mean		Nocturnal Mean		Daily Mean	
Year	Period	Cover	No Cover	Cover	No Cover	Cover	No Cover
1993	19-21 April	39.4 (4.4)	37.6 (4.7)	66.1 (4.0)	62.2 (3.8)	54.8 (3.3)	50.8 (3.3)
	30 Apr.-5 May	51.8 (3.0)	57.2 (3.6)	81.8 (2.7)	73.9 (2.8)	67.4 (2.3)	66.4 (2.4)
	21-26 May	44.1 (2.7)	41.7 (2.7)	79.7 (2.1)	81.5 (2.1)	61.7 (2.2)	61.5 (2.8)
	16-22 June	43.1 (2.2)	39.0 (2.9)	83.5 (2.5)	85.3 (2.5)	63.3 (2.2)	65.4 (2.6)
	2-8 Aug.	62.9 (2.5)	64.0 (2.5)	83.7 (2.2)	80.4 (2.1)	73.4 (1.8)	72.3 (1.7)
	19-25 Aug.	58.2 (2.4)	58.3 (2.5)	79.3 (2.0)	83.0 (2.2)	68.9 (1.7)	70.8 (1.9)
1994	13-18 April	42.4 (4.4)	55.4 (6.9)	71.3 (3.2)	65.4 (5.1)	58.1 (3.0)	61.2 (4.15)
	12-19 May	50.9 (2.6)	50.7 (3.8)	71.1 (2.4)	68.9 (3.9)	61.0 (1.9)	59.5 (2.9)
	14-21 June	33.9 (1.8)	67.4 (2.6) *	65.6 (2.2)	86.5 (2.2) *	50.5 (1.8)	77.4 (1.8) *
	18-25 July	67.0 (1.8)	89.7 (1.2) *	80.6 (1.2)	92.5 (1.0)	74.2 (1.1)	91.5 (0.7) *
	10-17 Aug.	73.9 (1.7)	66.4 (2.0) *	88.7 (1.1)	89.2 (1.0)	81.8 (1.1)	89.2 (1.0) *

* P<0.05

Table 6. Relative humidity (%) in cover and no cover treatments, raisin grape site 1995.

		Diurnal Mean		Nocturnal Mean		Daily Mean	
Year	Period	Cover	No Cover	Cover	No Cover	Cover	No Cover
1994	22-29 March	44.6 (2.6)	39.9 (2.4)	76.5 (2.2)	82.1 (2.0)	61.4 (2.0)	61.8 (2.1)
	18-24 April	45.4 (2.6)	51.3 (2.6)	62.5 (2.6)	62.8 (2.4)	54.0 (1.9)	57.2 (1.8)
	27 May-3 June	34.2 (3.4)	30.1 (3.3)	62.5 (3.7)	69.9 (4.9)	48.7 (2.9)	51.0 (3.8)
	4-11 July[1]	43.8 (2.3)	81.8 (2.0) *	71.2 (2.5)	94.4 (1.2)*	58.4 (2.0)	88.6 (1.2) *

[1]Cover crop was disked under just prior to this period of measurement.
* P<0.05

Alfalfa Responses to Phosphorus and Potassium Applications–Yield and Quality

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REDUCTION OF PHYTOPHTHORA DISEASES BY APPLIED NUTRIENTS

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INTRODUCTION:

Members of the genus Phytophthora are devastating fungal pathogens of a wide variety of crops including potato, tomato, cucurbits, peppers, soybeans and alfalfa. Chemical fungicides have been the traditional means of control. As resistance to these fungicides has developed, an understanding of alternative control methods becomes critical.

Several non-chemical methods such as crop rotation, soil amendments and fertility programs have been employed to reduce diseases caused by Phytophthora (3, 4, 19). Based on published information the use of nutrients has proven beneficial as part of the program for control of Phytophthora capsici that attacks peppers in southeastern Arizona.

The objectives of this presentation are to provide a foundation for increased control of Phytophthora diseases using nutrients, and to connect the cellular functions of these nutrients to plant resistance and disease reduction.

RESEARCH BACKGROUND:

In 1982 Petri published an extensive literature study on the effects of nitrogen, phosphorus and potassium on plant diseases (14). Generally, potassium was implicated most frequently in the reduction of plant diseases. High nitrogen was implicated in the increase of plant diseases. Phosphorus fertilization generally decreased disease incidence. Due to the complexity of interactions the information cannot be applied specifically to all pathogen, host, and environmental situations, but does provide insight about reducing diseases.

The study by Petri provided the following information about potassium (14).

"Potassium fertilizer has long been associated with increased disease resistance. An in-depth review of the literature with 534 references provides a unique evaluation of the relationship between potassium fertilizer use and plant diseases. Eight general conclusions are evident from this review of the literature.

1.) Potassium improved plant health in 65% of the studies and was deleterious 23% of the time.
2.) Potassium reduced bacterial and fungal diseases 70% of the time; insects and mites 60% of the time, and nematodes and virus influences in a majority of the cases.

3.) Fungal disease infestation was reduced by potassium an average of 48% where soils tested low in potassium and 14% where soil test levels were unknown. Where the soils tested low, 88% of the studies showed crop response to applied potassium. Crops responded 60% of the time where soil test levels were undefined..

4.) Potassium's influence upon crop yield varied according to the parasite group. The average increase for yield or growth was 48% of fungal diseases, 99% for viruses, 115% for nematodes, 14% for insects and mites, and 70% for bacteria.
Crop yield and growth increases were greatest for nematodes and viruses even though these pathogens were often increased by potassium.

5.) The mode of action is primarily through plant metabolism and morphology. Accumulating N compounds, sugars, etc., are frequently accompanied by improved conditions for parasite development. Tissue hardening, stomatal opening patterns, etc. are closely related to infestation intensity.

6.) Crop response was not consistently different for potassium carriers.

7.) N balanced with potassium is significant to disease susceptibility of plants.

8.) Benefits were noted more frequently in the field than in laboratory and greenhouse experiments."

Recent information relating potassium to suppression of Phytophthora diseases is presented in Table 1. Phytophthora diseases were reduced in 50% of the studies. One study of the eight listed indicated an increase in potato late blight when potassium was applied to soil.

Table 2 contains information from earlier studies relating potassium application to disease incidence (19). Over half of the studies indicate a reduction in Phytophthora diseases (19). In five of the 23 studies listed, potassium increased diseases. High nitrogen did decrease the effect of potassium in disease reduction in one study (19) as previously noted (14).

Recent research on the effects of nitrogen and phosphorus on Phytophthora diseases is reported in Table 3.

Earlier work supports the general trends indicated from the data presented in Table 3 (19).

Calcium has been shown to decrease certain diseases such as P. cinnamomi of eucalyptus (4) and avocado (19), black pepper attacked by P. palmivora (9), and P. parasitica of citrus (7). Increases in diseases by adding calcium have been shown in at least six other diseases caused by Phytophthora (19).

Note that external additions of calcium (foliar applications) increase some diseases; whereas, calcium in the cell cytoplasm aids in disease resistance (11). Experimental work should define sources of calcium as from within the cell (soil applied) or foliar applied.

Copper has been shown to reduce late blight of potato, and root and foliar rot of pepper caused by P. capsici (6, 12, 14, 19).

CELLULAR FUNCTIONS OF IONS IN DISEASE REDUCTION:

Kunoh and Doke (5, 11) have provided a cellular model depicting the functions of the various nutrients in defense of plants against attack by pathogens (Diagram 1).

Specific cellular functions of nutrients (ions in the plant cell) have not been thoroughly described for all host/pathogen interactions. A general understanding of the disease response can be obtained from specific interactions but this information cannot be applied to all situations.

The literature is not always clear whether or not an ion (nutrient) was applied to the soil or to the foliage. This is critical since it is known that ions such as CA++ and K+ serve as nutrient sources for the pathogen when applied exogeneously (5, 6, 11). Therefore in some instances, foliar applications enhance the infection.

Plant resistance to infection may be as simple as a thickening of the cuticle. However, upon penetration, a dynamic process is initiated that involves much of the biochemical machinery of the cell and the aggregation of necessary materials including ions toward the site of attack (5, 6, 11).

Nitrogen and phosphorus are involved in general ways; whereas, potassium, calcium, copper and boron are involved in the specific defense mechanisms. Other ions such as silica are involved, but time and space do not allow their discussion (5, 6, 11).

Nitrogen is required as building blocks for a vast number of molecules involved in resistance. However, high nitrogen levels in plant tissues reduce polyphenyloxidases' activity. Polyphenyloxidases are essential enzymes in the formation of many molecules toxic to pathogens (5, 6, 15). This may partly explain the increase in disease when nitrogen is applied.

Phosphorus is found in high concentrations near the infection site. It is required for energy. High energy demand is characteristic of the infection process. Phosphorus is also used as a building material for molecules needed for repair of plant tissues and structures (5, 6, 11).

Potassium is critical for the cytoplasmic movement of biochemical machinery toward the site of penetration by the pathogen (5, 11). Mitochondria, endoplasmic reticulum, and golgi bodies all move toward the site of attack over microtubules and actin filaments mediated by potassium (11). Potassium is also involved in the activity of over 40 enzymes, many of which are necessary to fight infection.

Potassium along with calcium is involved in formation of the wound plug, a physical barrier to infection (5, 6, 11).

Formation of the cuticle, one of the plant's first defenses, is imported by both copper and potassium (6, 11).
Cellular calcium has a wide variety of functions in the resistance phenomenon (5, 6, 11). A few of the most important functions are:

1.) provides added structural integrity as calcium pectate;
2.) responsible for deposition and attachment of the wound plug (3);
3.) glues the glycoside to the polyphenolics that make the wound plug (gels);
4.) increases the production of phytoalexins, the anti-pathogen polyphenolic compounds produced in response to infection; and
5.) aids in the formation of other insoluble glycophenols that resist pathogen penetration.

Copper is the coenzyme necessary for polyphenolic oxidase activity (6). As such, it is important in the formation of polyphenolic compounds that are directly toxic to the pathogen as pre-infection materials (5, 6, 11).

Copper as a coenzyme to polyphenoloxidases is involved in post-infection phytoalexin production (5, 6, 11).

High levels of polyphenols stop pectolytic activity of many pathogens thus halting tissue degradation. Since copper is involved in the production of these polyphenols and quinones it is involved and necessary for the plants' response to infection (11).

The hypersensitivity reaction, the rapid browning and death of tissue resulting in a barrier to pathogen ingress, requires the production of polyphenols and similar molecules such as quinones and thus requires copper (5, 6).

Boron is involved in many plant processes (3), an important role in resistance may be the metabolism of polyphenols responsible for plant resistance (6).

The understanding of the relationship among plant nutrients and their cellular participation in reduction of plant disease provides a foundation for field experiments. Future studies involving the reduction of diseases using nutrition should begin with the knowledge of how the nutrients function in plant resistance.

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TABLE 1. EFFECT OF POTASSIUM ON PHYTOPHTHORA DISEASES.

PATHOGEN	HOST/PATHOGEN	EFFECT*	REFERENCE
P. megasperma	Alfalfa root rot	-	Grau 1989 (8)
P. megasperma	Soybean root rot	-	Vasilas 1988 (21)
P. palmivora	Piper betle wilt	-	Rabindran 1987 (16)
P. palmivora	Cocoa root rot	0	Ahenkorah 1987 (1)
P. megasperma	Alfalfa root rot	0	Alva 1985 (2)
P. ingfestans	Potato late blight	+	Phukan 1989 (15)
P. parasitica	Piper betle rot	-	Nema 1990 (13)
P. megasperma	Soybean root rot	0	Rehm 1993 (17)

* Disease Decrease/Yield Increase (-).
Disease Increase/Yield Decrease (+).
No Effect (0).

TABLE 2. EFFECTS OF POTASSIUM (K) ON PHYTOPHTHORA DISEASES (19)

PATHOGEN	HOST AND DISEASE	FACTORS	EFFECTS*	REFERENCES
P. infestans	Potato late blight	K	-	Alten and Orth (1940)
				Awan and Struchtemeyer (1957)
		K	0	Herlihy and Carroll (1969)
		K	+ -	Szczotka et al (1973)
		High K, high N	+	Weindlmayr (1965)
P. capsici	Pepper blight	K	-	Elenkov and Bakharieva (1975)
P. drechsleri	Pigeon pea blight	High K, low N	-	Pal and Grewal (1976)
P. parasitica	Tobacco black shank	K	0	Apple (1961)
				Dukes and Apple (1968)
				McCarter (1965)
			-	Kincaid et al (1970)
	Tomato stem lesions	K	0	Weststeijn (1973)
	Roselle stem rot	K	-	Olunloyo and Adeniji (1976)
	Philodendron leaf spot	K	0	Harkness and Reynolds (1964)
	Betelvine wilt	K	+	Thyagarajan et al (1972)
	Citrus gummosis	High K, low Ca	+	Chapman and Brown (1942)
P. cinnamomi	Avocado root rot	K	-	Bingham et al (1958)
	Pine little leaf	K	0	Roth et al (1948)
	Pineapple root rot	K	-	Anderson (1951)

* Disease increased (+), decreased (-), was highly variable (+ -), or did not change (0) with high levels of K.

TABLE 3. EFFECTS OF NITROGEN AND PHOSPHORUS ON PHYTOPHTHORA DISEASES.

PATHOGEN	HOST/DISEASE	FACTOR	EFFECT*	REFERENCE
P. parasitica	Tomato root	N	+	Workneh 1993 (20)
P. cinnamomi	Rhodendron root rot	N	+	Hoitink 1986 (10)
P. infestans	Potato late blight	N	0	Sawicka 1993 (18)
P. palmivora	Cocao root rot	N	+	Ahenkorah 1987 (1)
P. parasitica	Piper betle wilt	N	+	Nema 1990 (13)
P. megasperma	Alfalfa root rot	P	0	Grau 1989 (8)
P. parasitica	Citrus root rot	P	0	Graham 1988 (7)
P. palmivora	Cocao Root Rot	P	0	Ahenkorah 1987 (1)
P. megasperma	Alfalfa root rot	P	0	Alva 1985 (2)
P. megasperma	Soybean root rot	P	0	Rehm 1993 (17)
P. parasitica	Piper betle wilt	P	-	Nema 1990 (13)

* Disease Decrease/Yield Increase (-).
Disease Increase/Yield Decrease (+).
No effect (0).

Diagram 1, Kunoh, H. 1990. Ultrastructure and mobilization of ions near infection sites. Annu. Rev. Phytopath. 28:93-111.

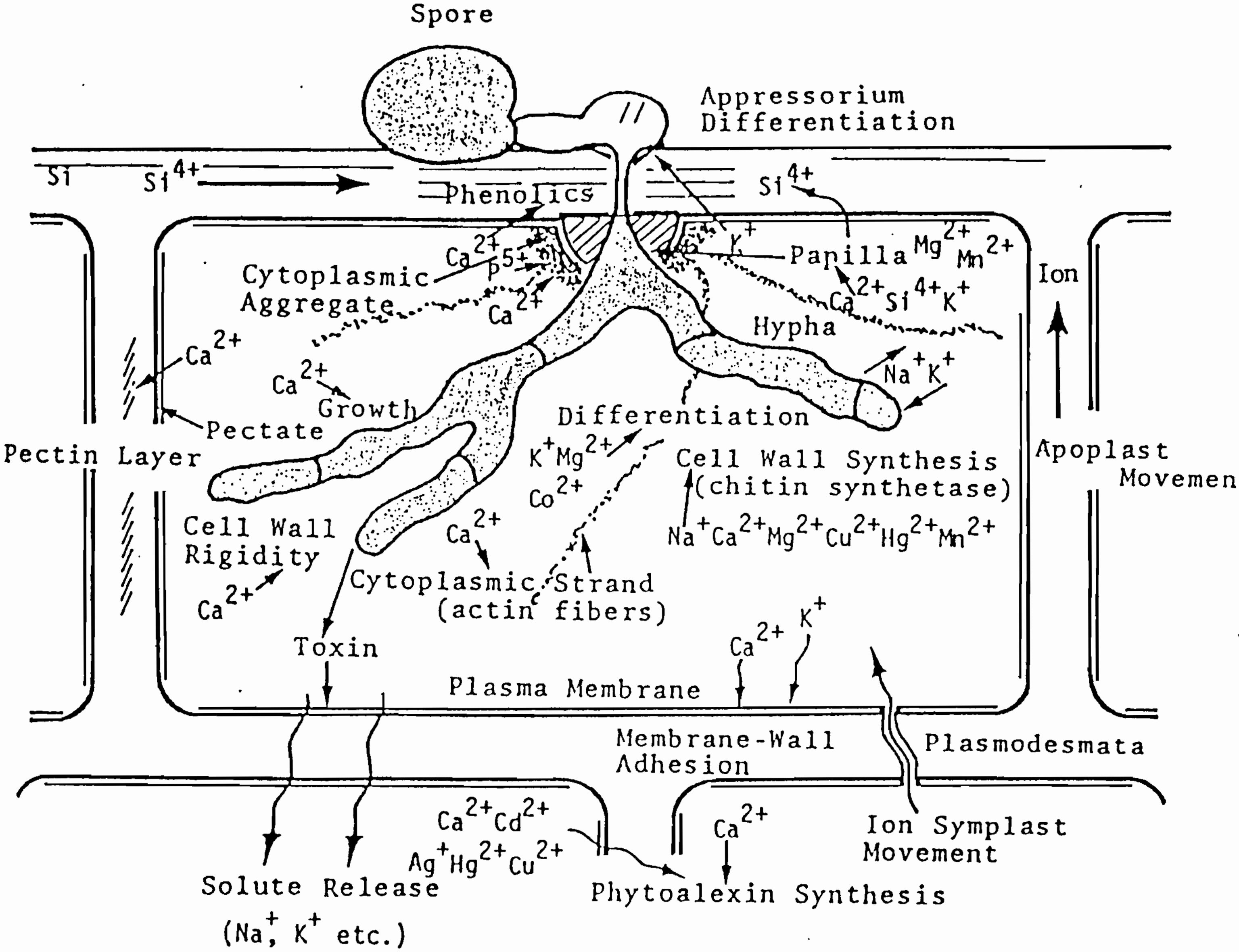

Figure 1. Possible involvement of various ions in events at the encounter site of a pathogen and a host cell. Ions accumulated near infected and neighboring cells through apoplast or symplast translocation may interfere with resistant responses of host cells and growth and differentiation of a pathogen.

CHLORIDE TO REDUCE DISEASE AND PHYSIOLOGICAL LEAF SPOT

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Chloride containing fertilizers have been used in crop production for many years. For the most part, however, Cl has been considered incidental to the associated salt which most frequently is potassium (K). In arid regions, such as the San Joaquin Valley of California, Cl is frequently considered undesirable since it is a component of soil salinity and also potentially toxic to Cl-sensitive trees, vines and woody ornamentals. However, in recent years there has been considerable research focus on the beneficial aspects of chloride, including its use to reduce disease and physiological leaf spot.

Chloride is an essential nutrient. It plays several key roles in plants, some being quite similar to K:

- Photosynthesis and enzyme activation. Some of the enzymes are involved in starch utilization which affect germination and in energy transfer
- Transport of other nutrients. Chloride aids in the transport of cations such as K, calcium (Ca) and magnesium (Mg). Its role is to maintain an electrical charge balance.
- Water movement in the cell. Concentrations of Cl in the cell aid in the movement of water into cells and its retention. This is especially important under water stress conditions.
- Stomatal activity. Both K and Cl are involved in the movement of the guard cells that control opening and closing of stomata on leaf surfaces. It is important in controlling water loss from the plant.
- Suppression of plant diseases. Many plant diseases, particularly of small grains, are temporarily suppressed by Cl.
- Reproductive development. Small grains grown with adequate Cl tend to form heads and complete head emergence sooner than low Cl plants.
- Nitrification inhibitor. Under certain conditions Cl may limit the conversion of ammonium to nitrate.

CHLORIDE IN THE SOIL

Chloride exists in nature only as the chloride anion (Cl^-). It should not be confused with chlorine gas (Cl_2) which is a manufactured product and is used for many industrial processes -- products of sanitation, pulp bleaching, disinfectants and textile processing. Common chloride sources include salts of sodium (Na) and K -- common table salt (NaCl), carnallite ($KCl.MgCl.6H_2O$), and sylvite (KCl).

Chloride is highly soluble in soil and is not held by soil organic matter or clay. It is, therefore, highly leachable. It is one of the first elements removed from minerals by weathering of soils which is why most of the world's Cl is either found in oceans or in salt deposits left by evaporation of old inland seas.

Many soils and crops receive an adequate supply of Cl from sea spray carried by rain/snow and wind. Amounts of about 90 lb/A/yr have been measured up to 5 miles from certain coastlines. The amounts dropped to less than 18 lb/A/yr 100 miles inland. Midcontinental areas such as the Great Plains and the Canadian Prairies receive less than 1 lb/A/yr.

CHLORIDE IN SUPPRESSING DISEASE

Observations made over several decades have clearly established that Cl fertilization plays a significant role in reducing infestation and delaying the onset and severity of a number of foliar and root diseases. Among those for small grains, which have been extensively studied, are leaf rust, Septoria leaf blotch, downy mildew, tan spot, stripe rust, common root rot and take-all root rot. Diseases reduced in other crops include: stalk rot of corn and sorghum; hollow heart/brown center of potatoes; Fusarium yellows of celery; and gray leafspot of coconut palm.

Researchers at Oregon State University have been studying interactions related to take-all disease of wheat for the past two decades in the Willamette Valley and recommend the following practices when successive wheat crops are planted for less than 5 years (*Combating take-all of winter wheat in western Oregon*, Jan. 1993, EC 1423, OSU Extension Service) These recommendation are specific for the Willamette Valley which is a high rainfall-high yield area, but exemplify a set of best management practices to achieve optimum benefit from fertilizer in reducing disease pressure.

Pre-plant management

Liming -- A soil pH of 5.5 is desirable for combating take-all. Apply lime only if the soil pH is 5.2 or less.

Stubble -- Chop stubble and plow deeply to bury inoculum.

Planting

Planting date -- On well-drained valley-floor soils, delay planting until late October if possible. Do not delay planting beyond mid-October on hill soils or valley-floor soils with reduced drainage.

Fertilization -- Band 20-30 lb N/A in ammonium form, 30-50 lb P_2O_5/A, and 10-15 lb S/A. Apply 25-30 lb K_2O/A if a soil test indicates the need for K.

Growing season

Fertilization -- Apply 140-180 lb N/A as ammonium sulfate plus 100 lb Cl/A as KCl before Feekes growth stage 5. Alternatively, apply 40 lb N/A and 100 lb Cl/A at late tillering (Feekes 4; mid-Feb.) and the remaining N within 3-4 weeks, but before jointing (Feekes 6).

It is important to recognize that Cl does not have a direct effect on disease organisms and does not act as a fungicide or pesticide. Its effect is due to altering soil conditions to a point less conducive for pathogen growth or to altering plant metabolism or morphology to enhance resistance. Many other examples of reducing disease with Cl fertilization and associated management practices in addition to take-all could be detailed. See **References** for further information.

CHLORIDE IN REDUCING PHYSIOLOGICAL LEAF SPOT

A wheat leaf spot complex, previously of unknown origin, that produces necrotic spots on tissue is frequently observed in the Pacific Northwest and High Plains. It has been termed "physiological leaf spot". Symptoms first appear on lower or oldest leaves and progress to successively younger leaves over a 2-3 week period. Symptoms are usually more severe toward the tip half of the leaf blade. The lesions coalesce in severely affected plants, leading to premature leaf death during grain ripening. Agronomists/pathologists have described the symptoms as being similar to tanspot or Septoria leaf blotch diseases but causative organisms have not been isolated. Symptoms of physiological leaf spot are also dependent on wheat variety and the environment.

Research information compiled at numerous universities has led to the conclusion that the leaf spot symptoms described above are due to a physiological disorder caused by inadequate Cl nutrition. In other words, plants are simply Cl deficient. This conclusion is based on the following observations:

- Multiple foliar applications of propiconazole fungicide had no effect on leaf spot severity.
- A pathogen could not be isolated from affected tissue.
- Cl fertilizer applications reduced or eliminated the symptoms.
- There is a highly significant relationship between plant Cl concentration and leaf spot severity.
- Soil Cl analysis is useful in predicting response to fertilizer Cl applications.

SUMMARY

It is time to give Cl its due. No longer can we think of it only as "an accompanying ion" in K fertilization programs...or a problem in certain situations. There are many situations in the Pacific Northwest and High Plains from the provinces of Canada to Texas where research over the past two decades has established the economic benefit of Cl fertilization to aid in depressing various diseases and, more recently, directly as a plant essential nutrient. The question now is... Where can Cl fertilizer be beneficially applied in California?

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Managing Nitrate in Groundwater Impacted by Human and Animal Wastes

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ABSTRACT

Management of nitrate contamination in groundwater is being regulated with increasing frequency in California and will impact agribusiness. Groundwater impacted by nitrate from human and animal wastes is investigated and remediated using a variety of techniques described from case studies. Constant-head groundwater moats (patent pending), a promising new strategy for shallow groundwater plumes is introduced. The strategy combines agricultural drain tile encircling contaminant plumes and transpiration from plants to remediate nitrate in shallow groundwater.

INTRODUCTION

This paper focuses on examples of groundwater nitrate contamination that the regulatory agencies are attributing to manure, both human and animal. Farmers have long recognized the value of turning manures back to the soil. There are references to manuring fields in the Bible. Chinese farmers have been applying "nightsoil" to their land for thousands of years. Not until the late 1970's did regulatory agencies begin to relate constituents in groundwater to these surface applications of manures. A portion of the agenda of the Clean Water Act is directed at developing "Best Management Practices" (BMPs) that will reduce nitrate pollution of groundwater. Nitrate related BMPs are being used in California on a voluntary basis currently, and will probably be mandated in the near future. The work discussed in this paper is not about BMP management of manure inputs because the pollution in these cases, has already taken place. There are several different methods of investigation to determine the extent of nitrate contamination and there are even more options for remediation.

THE REGULATORY JUGGERNAUT

Surface and ground waters of the State of California are regulated by the nine Regional Water Quality Control Boards established in the Porter-Cologne Water Quality Control Act of 1987. The Regional Boards are charged with adopting Regional Water Quality Control Plans and for establishing water quality objectives consistent with the identified beneficial uses of the water. The Regional Boards also enforce compliance with regulations from California Code of Regulations (CCR) Title 23. Chapter 15 of Title 23 deals with discharges of waste to land, including dewatered sewage and treatment sludge (Article 2), and manure from confined animal facilities (Article 6).

The water quality control plans require dischargers who may affect the quality of waters of the State to file a Report of Waste Discharge (RWD). The boards issue orders that include Waste Discharge Requirements with Monitoring And Reporting Programs. The Regional Boards may also issue clean-up and abatement orders for those who have not filed RWD. The Regional Boards are staffed by technically-trained professionals who oversee compliance with regulations. Staff may observe and/or otherwise become aware of unreported waste discharges to surface or groundwater. This may happen, for example, in response to a complaint from a domestic well user. Once a discharger has been identified and a case is opened, the Regional Board can order performance of remediation, monitoring and reporting. The staff can issue Notices of Violation and recommend to the Regional Boards the imposition of Administrative Civil Liability Fines of up to $5,000 per day of non-compliance. With regards to manure applications, the Regional Boards usually become involved in response to RWD, for example, if a conditional use permit is required by a local government entity, or if a composting permit is requested. The Regional Boards are impacting agribusiness operations with increasing frequency as point sources and non-point sources of nitrate in groundwater are identified.

Beneficial uses for groundwater cited by the Regional Boards generally include municipal and domestic supply regardless of location unless the area has been specifically excepted. Therefore, the water quality objectives are set at the maximum contaminant level (MCL) for drinking water. The California Department of Toxic Substances Control and the US EPA have established the MCL for nitrate (N) at 10 mg/l. Furthermore, the combined concentration of nitrate and nitrite (reported as N) is also 10 mg/l. There are opportunities for the responsible party to show that complete clean-up is technologically impossible, and there are new policies being initiated to define “containment zones”, where the regional board will allow suspension of remediation activities before compliance is achieved if the contaminated groundwater will not migrate outside the containment zone.

NITRATE SOURCES

Confined Animal Facilities

Livestock production facilities in the Central Valley of California operate with a greater number of animal units per acre than would be present at a farming operation. Liquid and solid manure from these operations must be disposed of in a fashion that will not pose a threat to the waters of the State. Requirements to file are regulated in part by the Federal National Pollution Discharge Elimination System (NPDES) permits. These are required for large dairies (>700 head), cattle feedlots (>1,000 head), pork production facilities (>2,500 head over 55 pounds), sheep feedlots (>10,000 head) and poultry (30,000-100,000 birds, depending on facilities). Although operations of any size can be regulated. Requirements for new operations can include nitrogen balances, lined and bermed manure storage facilities, stormwater pollution prevention plans, groundwater monitoring plans and review under the California Environmental Quality Act (CEQA). Much of the regulation is imposed to protect groundwater. Operations that have been in existence prior to a specific regulation possess a "grandfathered" status. Grandfathered operations are regulated in more of crisis management fashion, as opposed to the upfront regulatory requirements.

Land Application of Biosolids

Human manure is more heavily regulated than animal manure. Wastewater treatment plants exist near most cities. Municipal wastewater is treated to the point that solids are separated from liquids. Biosolids is the environmentally friendly term that is currently used for the treated wastewater sludges or solids. The majority of the plant nutrients, including nitrogen remain in the solid fraction. Various methods of beneficial reuse for biosolids exist and the simplest is direct land application. Biosoids that have been determined to be of high enough quality to be land applied are recommended to be applied at agronomic rates. The agronomic rate is typically based on the amount of nitrogen in the biosolids and the amount of nitrogen that the crop to be grown can utilize. The goal of the agronomic rate is not to over apply nitrogen.

Complications can arise when there is also an effluent irrigation operation taking place on the same land where ongoing land application is occurring. Irrigation water nitrogen is often not included in the calculation of the agronomic rate. Undocumented accounts of three and four times evapotranspiration have occurred. In some cases "agronomic" rate has been mistaken for "astronomic". It is estimated that up to 900 pounds of total nitrogen have been applied per acre per year on some poorly managed sites monitored by the Regional Water Quality Control Board.

GROUNDWATER INVESTIGATIONS AND PLUME CHARACTERIZATION

The objective of groundwater investigation and plume characterization is to delineate the edges and bottom of the nitrate plume using samples. An initial conceptual model of the groundwater flow system and the age of the plume is useful in guiding the location of samples. Nitrate is a soluble anionic compound with little adsorption and its migration can be readily predicted by analyzing groundwater flow. Grab samples of the groundwater are usually favored in the early stages of an investigation over monitoring wells. Grab samples do not establish permanent monitoring points that will incur ongoing sampling and analytical costs. Depending on site conditions, the samples are collected using either a truck-mounted hydraulic press to push rods with slotted sample ports into the ground, or a drilling rig that augers borings where a grab sampler is driven into virgin aquifer at the bottom of the borings. To define the vertical extent of the plume, a sampler must pass through the nitrate plume to the clean aquifer beneath. Samplers with protective rubber socks that isolate the sampler from water in the boring have been developed for ensuring no cross contamination. The number and location of the grab samples depends on the site, but an initial investigation in the Central Valley can usually be performed in two days of field work.

A minimum of three observation wells are required in order to measure the elevation of the water table and calculate its slope, which is used to predict the rate and direction of plume migration. Although the water table slope defines the direction in which the groundwater *tends* to flow, specific pathways are controlled by the geometry of the aquifer porosity. Complicated geology, particularly fractured bedrock may require numerous wells. Wells are typically monitored quarterly so that seasonal fluctuations, reversals of groundwater gradient, and changes in water quality associated with plume migration can be identified.

GROUNDWATER NITRATE REMEDIATION OPTIONS

Nitrate is a water soluble marketed commodity. Therefore, nitrate should be more practical to remediate than residuals from waste oils, pesticides, or heavy metals. Plants utilize large quantities of nitrates. Nitrates move with water so that they are not difficult to leach or extract. Nitrates can be denitrified. The nitrogen and carbon cycles are interconnected so that soluble, nonfermenting sugars can be introduced to nitrate-laden groundwater and indigenous or introduced microbes will convert nitrate into microbial tissue as they convert the sugar into carbon dioxide. However, even though nitrates are so useful and seem to be so easy to work with, remediation efforts can be costly. Methods for managing groundwater nitrate at several sites are reviewed below.

A Confined Animal Facility

Groundwater monitoring indicated that nitrate levels in groundwater were consistently above the MCL at a confined animal facility in the Central Valley. The plume was investigated and several remedial options were assessed. Some options that might work at other sites were rejected for site specific reasons as presented below.

No Action Option (rejected)

This option involved attempting to convince the Regional Board that no action should be required. Attainment of required cleanup goals was unlikely under this option. Nitrates don't normally self remediate. This option could have been pursued by seeking data to show that background nitrate is equal to or higher than nitrate beneath the site, or by demonstrating that no significant health risk was posed by the contamination. These arguments had been advanced previously and were fruitless at this site. Arguing for a variance based on low health risk runs counter to established Board policy and would require a major political effort. There is significant risk that other remedial measures would be required anyway.

In-situ Treatment or Subsurface Trench Filter (rejected)

Nitrate can be reduced in-situ through manipulations of the geochemical system by introducing chemical or biological amendments to groundwater (pH adjustment, biological mineralization or other means). Candidate chemicals would be pH adjusters, liquid carbon sources (e.g. alcohol) and specific nitrate reductase enzymes. Organisms include normal anaerobic facultative bacteria which use the oxygen available in nitrate for metabolism. This option would have included activities to distribute the additives throughout the groundwater system, including injection wells or infiltration galleries, and some form of soil gas, or groundwater monitoring.

In-situ treatment may also be accomplished by constructing subsurface groundwater filters through which aquifer water will flow. Filters consisting of a trench filled with silt-sawdust mixtures have been successful in treating groundwater by providing a carbon source for biological metabolism, and by providing low-oxygen environments for nitrate reduction. The nitrate reduction process results in gaseous forms of nitrogen, including nitric and nitrous oxide, and elemental nitrogen. These gasses should be off-gassed in order to promote complete nitrate reduction; the surface above trenches should be uncovered. A full-trench filter along the site boundary would ensure all nitrate in groundwater from the site passes through a carbonaceous-reducing zone. However, filter trenches, though simple in design, have never been tested for the projected duration of the treatment (234 years). It was considered likely that clogging would occur, necessitating the construction of one or more replacement filter system(s). The hydraulic conductivity of the filter may also diminish slowly with time, creating a barrier and gradually altering the groundwater flow path. This would require monitoring. Pumping may be required by the Regional Board to speed treatment. In addition, downgradient contamination could not be addressed without impacting the neighbor's land. Finally, a filter trench as deep as the bottom of the plume (50 feet) was not technically or financially feasible.

Pump to Infiltration Beds (rejected)

Reduction of nitrate can also be accomplished by constructing a soil profile in which the water being treated is infiltrated through an aerobic zone overlying an anaerobic layer. After flowing through these two zones the water is either (1) allowed to move down into groundwater, or (2) is caught with artificial drainage and recycled. The subsurface flow system includes engineered cells containing gravel, soil and/or sand treatment media. One system that has been studied is a compacted silt layer, ten inches thick, located at about four feet below the ground surface (Robertson and Cherry, 1995). Another system is a two-foot-thick layer of silt/sawdust, silt/compost, and silt/rye seed mixtures located at one to two feet of depth. A degradation calculation for the layers described as silt/sawdust, silt/compost and silt/rye seed predicted an effective life of 30 years or more In both cases, a sand layer (about a foot thick) was placed directly above the silt layer. Systems have not been proven to perform over long periods of time. Potential clogging could require reconstruction. This system would be mostly underground so it would require monitoring to ensure correct operation.

Phytoremediation Options, General Comments

A simple definition of phytoremediation is to remediate with plants. Groundwater containing elevated levels of nitrates can supply water to plant communities, including agronomic crops, trees and shrubs. Plants take up soluble inorganic nitrogen as nitrate-nitrogen or ammonium-nitrogen through their roots. Root systems that grow deep remove large volumes of pore water. Water uptake and nitrogen usage are directly related to the overall biomass growth: the greater the plant growth, the greater the resulting nitrogen uptake. Biomass can be in the form of woody parts, stem and leaf growth, seeds and roots.

Pump to Constructed Wetlands (rejected)

Constructed wetlands have successfully treated groundwater that is laden with nitrates. Systems include marsh - pond - meadow sequences. Wetlands may require the construction of lined cells to which the groundwater would need to be pumped. Lined cells are expensive (approximately $1.5/sq ft) and unlined cells may be mitigated by placement of an underlying sawdust layer to generate a reducing zone, along with locating the cells within the capture zone of the groundwater extraction well. Water then would flow or migrate through the cells in serpentine fashion. The wetland requires the addition of different types of media for water to flow over, and for plants to grow on. The plant community that will grow in constructed wetlands consists of cattails, reeds, bulrushes, species of arrowhead rushes, and sedge. The marsh/pond/meadow design would require a maximum depth of excavation of four feet, not including the liner thickness. A free water system would have a typical retention time of three weeks. Once the pumped water has migrated through the cell series, it could be used to irrigate landscaping. Creating a wetland provides habitat for birds, insects and animals. Any endangered species that chose to live in this new habitat might then be dependent on having a guaranteed water supply. Mosquito abatement might necessitate chemical control.

Constructed wetlands have been used quite effectively to polish nitrate from sewage treatment water and landfill leachate during warm months. An example of a constructed wetland being used to reclaim landfill leachate water in Florida showed a decrease of total TKN from 526 mg/l to 3 mg/l. To ensure year-round clean-up of nitrogen, a greenhouse facility was constructed over constructed wetlands at the Hornsby Bend, TX Wastewater Treatment Plant.

Pump to Irrigated Plants on Site (rejected)

Grasses - Phytoremediation by irrigation could be accomplished by an overland sheet flow system for grasses. This system would consist of sprinkling pumped groundwater onto a vegetated bed that gradually sloped down to a collection trough. Flow rates are set low enough, and the slope gradient gradual enough, that the water would filter through the vegetation and be polished of nitrogen by the time it enters the trough catchment. Polishing is accomplished through plant uptake and physical filtering through the plant and soil matrix. Vegetation is planted in a coarse soil material that allows lateral movement of the water. A compacted clay layer under the vegetated bed ensures that water does not percolate deeply. Production of turf grass could provide cash input.

Trees - Four to five rows of native trees and shrubs could be used to form a vegetated buffer zone between the facility and neighboring properties. The vegetated zone would also be designed to serve as a natural break in surface drainage between, onto, and off of the property. This option would create an effective wind, noise and visual screen between the site and adjacent properties. The wind screen would greatly enhance compliance with pending federal and state PM-10 control regulations. The enhanced vegetation zone would create a large root system that would help prevent off-site nitrate migration from ongoing manure storage activities.

An 8 to 12-foot-long unrooted poplar pole planted in February will grow to a 16 to 18 foot well-branched tree in seven months. Hybrid poplars are cold hardy to below zero degrees Fahrenheit and will also tolerate high summer temperatures. The life-span of the hybrid poplar is approximately 100 years. Poplar trees can be expected to utilize at least 0.5 acre-feet of water per year containing 140 pounds of nitrate.

Pump and Pipe to Offsite Irrigated Pasture (accepted)

The final solution at the confined animal facility site was found when a neighboring farmer agreed to accept the extracted groundwater. He will blend this with his own pumped groundwater for application to irrigated pasture. A cropping plan was developed and approved by the Regional Board. The farmer was named in the Monitoring and Reporting Plan by the Regional Board. The cropping plan included calculations of monthly water and nitrogen balance. In the spring and fall, virtually all the irrigated pasture needs were satisfied by nitrate-impacted groundwater from the extraction wells. In the summer this was supplemented by the farmer's groundwater production.

Biosolids Management Sites

Hay Production

High soil nitrate levels were measured at a biosolids application site that was located in a coastal range site. Groundwater was within 6 feet of the surface. Site conditions are relatively cool nighttime temperatures and high soil organic nitrogen concentrations. The site has brackish groundwater that will probably not be degraded by leached nitrate, but clay-rich surface soils are not prone to leaching. The regional board had required that biosolids applications be halted until soil nitrate levels were reduced. Red oat hay was grown on the site without irrigation in an attempt to harvest nitrogen from the site. Dairy cows fed the hay were reported to have died from nitrate toxicity. Nitrate levels from hay grown the next year were still considered toxic to cattle. This year nitrate levels in the hay are below toxic level but are still considered to be elevated. Hay will continue to be grown on the site in an attempt to rehabilitate it for future feed production and perhaps waste application. This site was also studied as a possible yard trimmings direct application site. Heavy applications of yard trimmings were estimated to contribute too much nitrogen for an application to be feasible.

Silage Production

Elevated groundwater nitrate levels were detected in monitoring wells next to a biosolids land application site. Biosolids have been applied at an agronomic rate for several years, but effluent had been applied at rates that fit the schedule of the water treatment operation rather than evapotranspiration. The site soils are sandy loams and there are no significant hard pans present at the site. A silage corn and alfalfa rotation has been grown at the site for as long as the soils have been amended with biosolids. Yield monitoring has just been implemented in order to estimate how much nitrogen is being removed by the crop. A groundwater study has begun to determine if pollution detected in monitoring wells is coming from other near-site sources. Groundwater monitoring of nitrate movement below the root zone has been required by the Regional Board.

GROUNDWATER CONTROL AND MANAGEMENT

Pumping Systems for Containment of the Nitrate Plume

Groundwater pumping is employed to extract contaminated groundwater for remediation at sites where in-situ treatment is not feasible. Pumping for shallow groundwater extraction is different from groundwater production practiced by most farmers. Wells are typically shallow, less than 50 feet deep. Consequently patterns of small wells are often required to effect extraction. Figure 1 shows a computer simulated groundwater flow net showing capture of the plume by a row of four shallow wells, each pumping at a rate of 15 gpm.

Groundwater Moats

Groundwater is within 10 feet of the surface at the biosolids application site where silage is produced. At this type of site, the use of groundwater constant-head moats (patent pending) is a promising containment strategy that, when combined with evapotranspirational pumping, provides a system capable of containing and remediating nitrate-contaminated shallow groundwater. Groundwater constant-head moats have two key elements: (1) the local groundwater flow is eliminated by encircling the site with a closed loop of perforated pipe (e.g., agricultural drainage tile); and (2) groundwater flow within the loop is directed inward by using vegetation to pump water from the perimeter drain towards the center of the site, Figure 2.

Element (1) is the physical equivalent of a subsurface moat. In a moat, the free water surface surrounding a site is at uniform potential and no gradient exists for water flow. Lack of a surface expression of free water does not affect this reality. Thus, a subsurface moat can be used to eliminate advective groundwater movement through a contaminated soil zone.

The 'gradient leveling' approach has the unusual characteristics of lacking an inlet, an outlet, or a gradient in this closed loop configuration. The perforated pipe is installed below the water table and backfilled in the saturated zone with material of high transmissivity. The presence of the buried pipe ensures that head differences between one side of the moat and the other cannot exist. Anisotropy should be considered in determining the depth of backfill. In areas with large seasonal water table fluctuations, feeder or bleeder lines may be needed to maintain a constant water table and hydraulic control of a contaminated site. Water head in the moat can be manipulated, as desired, using a simple standpipe of adjustable height that overflows into a standard subsurface drain pipe. Water flow also can be manipulated by the use of concentric moats.

Gradient leveling, where applicable, is inexpensive. Agricultural drainage tile (perforated pipe) is used widely on farms around the U.S.. Flexible perforated 4" black plastic pipe is readily available in spools of 2900 feet. The pipe can be purchased and installed for less than $1.50/ft to a depth of seven feet. Equipment is also available for deeper installation.

Element (2) of our design harnesses transpiration to provide an inward hydraulic gradient to offset outward contaminant diffusion. Absence of a local groundwater gradient greatly reduces performance requirements placed upon the vegetative cover.

The effectiveness of transpiration-driven hydraulic control is dependent upon vegetation, climate, hydraulic properties, and system scale. Riparian plants, such as cottonwood (*Populus* spp.), can transpire enormous volumes of water. Rainfall, potential evapotranspiration, and seasonal minima in transpiration will provide limits to system performance. Conductivity and storage characteristics of the aquifer will determine the groundwater gradient established within the moat, and will determine whether an adequate inward gradient can persist through seasonal fluctuations in evapotranspiration. Larger sites have a larger area to perimeter ratio. This larger ratio will result in persistence of larger gradients through seasonal variations.

Phytoremediation is also an intrinsic component of this design. However, it may or may not be important at a given location. Ideally, phytoremediation should be considered potentially important at the site selected and integrated into the study. For sites with metals contamination, the trees not only maintain the desired inward gradient but also provide long-term storage of contaminants as dissolved metals are incorporated into woody tissues. In addition, many organic compounds show increased degradation rates in the presence of plant roots.

Initial experiments could be inexpensively performed on an existing group of trees overlying a shallow aquifer. Pumping within the moat could be used initially to ensure containment prior to establishment of an adequate annual or seasonal evaporative demand.

Example design:

A 10-acre site with surface and subsurface contamination is contributing to a shallow groundwater contaminant plume. The depth to groundwater is about 8 feet. The plume must be contained and treated and surface contamination covered. The square 10 acre site has a perimeter of 2,640 feet (0.5 mile). Clean soil is excavated from the clean perimeter and used to cover surface contamination on five of the ten acres to a depth of one foot. This requires approximately 8,100 yd^3 or 218,000 ft^3 of soil. This is equivalent to removing 83 ft^3 of soil per foot of perimeter. A dry surface ditch, two feet deep by 40 feet wide can be constructed surrounding the site. Expensive hauling is minimized.

A "constant head moat" is constructed by installing a submerged perforated pipe in a perimeter trench. Due to an essentially zero perimeter gradient, groundwater flow within the moat is hydraulically disconnected from groundwater exterior to the moat.

The surface ditch provides surface water control to ensure that no run-off occurs from the site. Runoff either evaporates or infiltrates and is pulled inward. Trenching is performed along the outer edge of the ditch to the depth determined by site hydrogeology. Cottonwoods or locally favored vegetation are established on and within the ditch. The vegetation creates the negative gradient needed for inward flow.

CONCLUSIONS

Managing nitrate in groundwater is becoming increasingly important particularly in the Central Valley near confined animal facilities and biosolid application areas. Regulations are beginning to impact agribusiness operations through permitting requirements and Waste Discharge Requirements. Groundwater investigation methods including drilling and sampling of groundwater with auger drills or truck-mounted push probes are a potentially significant cash drain for agribusinesses. Phytoremediation, irrigation of tress and cropland with extracted groundwater, is the most promising cost-efficient approach to nitrate remediation. Other potential options include subsurface filter beds, wetlands and no action. Groundwater extraction systems can pump nitrate-laden groundwater at some costs for reuse, as long as TDS is acceptable or dilution with other water is permitted. A passive approach to groundwater extraction using constant head moats and deep-rooted trees is introduced in this paper.

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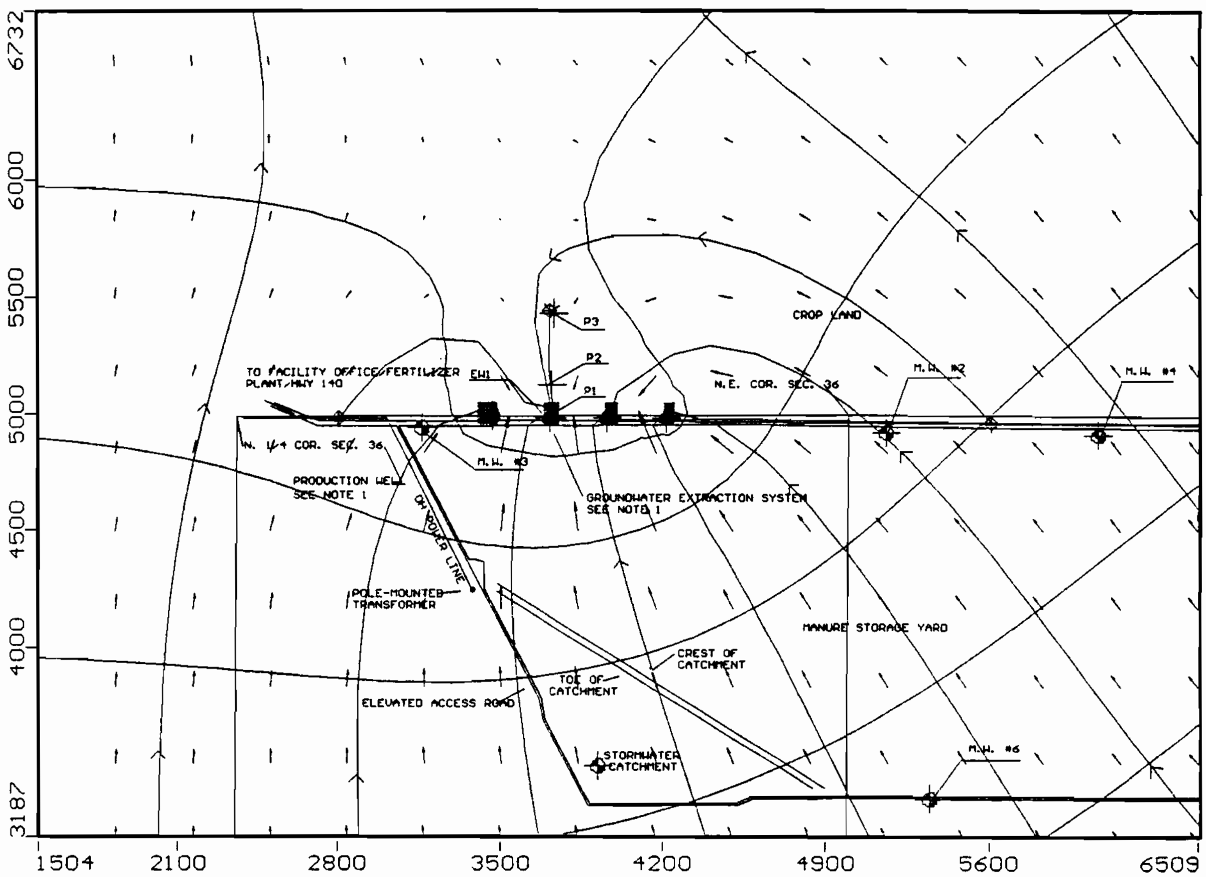
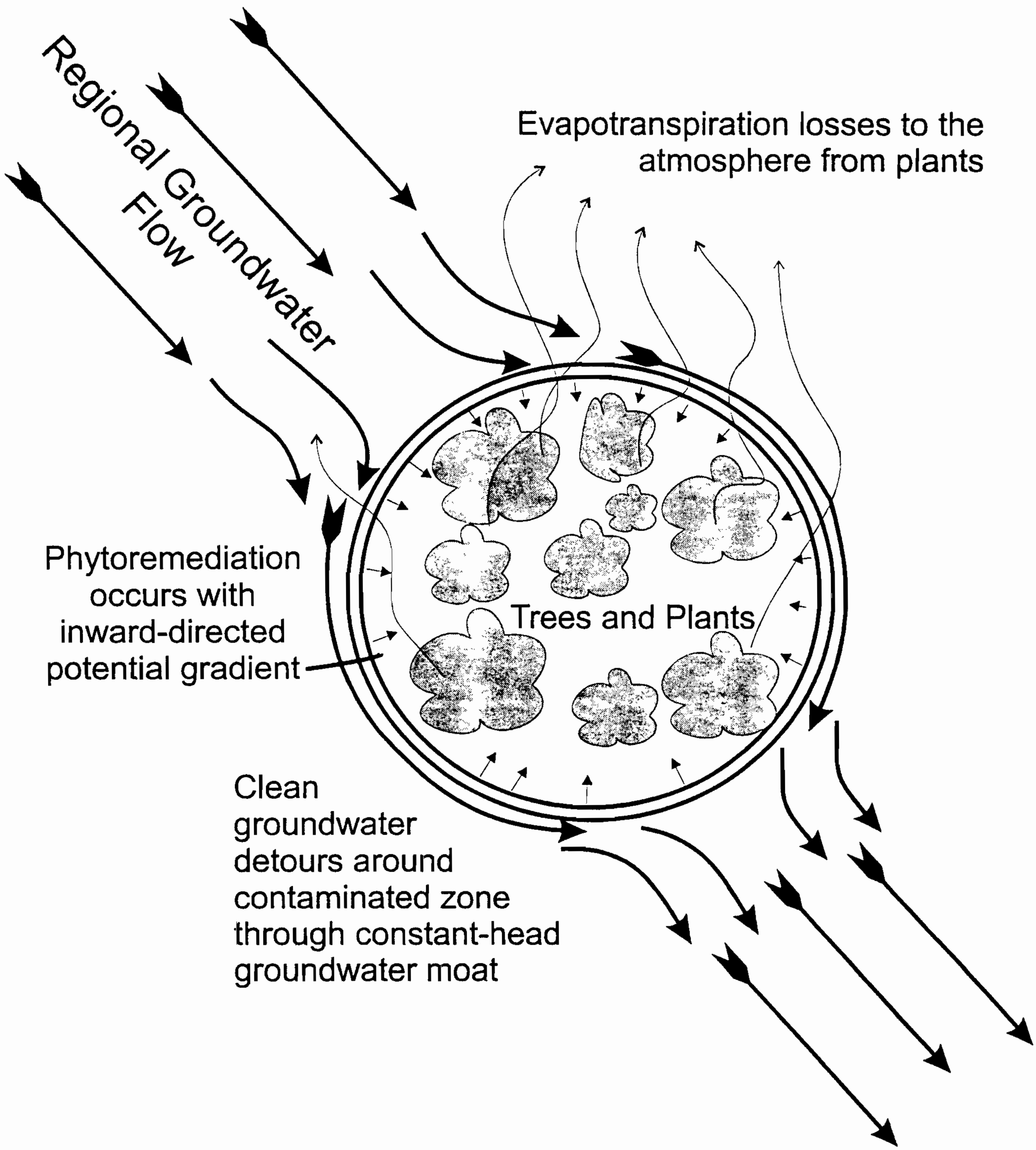


Condor Environmental – Stockton, CA Project: MANURE STORAGE FACILITY Description: EW1–4 @15 gpm w/pathline Modeller: JHK 24 Oct 96	Visual MODFLOW v.1.50, (c) 1995 Waterloo Hydrogeologic Software NC: 55 NR: 51 NL: 2 Current Layer: 1

Figure 2. Constant-Head Groundwater Moats for Plume Containment (Plan Viiew)



HOW DO I BELIEVE THAT MY CAREER IN AGRICULTURE WILL IMPACT THE SOCIAL AND ENVIRONMENTAL ISSUES FACING PRODUCTION AGRICULTURE IN CALIFORNIA

Dana Lou Ashford
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A career in teaching, either as a college professor or an extension agent, will allow me to pass on valuable information to the members of the agricultural community. I think this career should be looked at as a form of information sharing and two-way communication, rather than a one-way flow of facts and figures to the farmers and students from the researchers. I strongly believe this is the way extension agents and professors should interact with their clients, the growers and students.

I think many environmental issues facing production agriculture in California are very important today and will become even more important in the years to come. This is one reason I have chosen to take many courses which provide me with information regarding these issues, the problems, and the possible solutions. It is important that all members of the agricultural community be aware of the issues. Although some members may not be faced with the problems today on their farm, they may encounter the issues in the future or be asked to make an intelligent vote regarding the issue. Also, all of today's growers should take note of sustainable alternatives that can be implemented in their systems. These alternatives should be provided to the growers by the extension agents.

I also believe sustainable agricultural practices should be the backbone of many courses being taught in our agricultural institutions today. We should not ignore all other types of cultural practices which may not be considered sustainable, but we should also learn the reasons for their unsustainability and changes that can be made to make them more sustainable and more environmentally friendly. Learning about these alternative practices and about sustainability in general has given me a broad spectrum of knowledge that can help me relate to growers and students. I am prepared to provide information to these clients. More importantly, I am also prepared to receive their ideas on other options to help deal with the environmental issues facing production agriculture.

The social issues facing production agriculture in California have many components. They can best be addressed by looking at the whole region in a holistic way and considering all possible interactions. My ability to look at the systems holistically and my sociology and psychology background course work will help me assess these issues and suggest possible actions to be taken.

HOW DO I BELIEVE THAT MY CAREER IN AGRICULTURE WILL IMPACT THE SOCIAL AND ENVIRONMENTAL ISSUES FACING PRODUCTION AGRICULTURE IN CALIFORNIA

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My selection of a major at Cal Poly, fruit science, with a minor in ag business and plant protection, will provide me with a broad perspective of the agricultural industry. It is important to have a diverse background of production agriculture as well as a good business outlook. My education, work experience, and a career as a Pest Control Advisor will positively impact issues facing production agriculture in California.

On a social level, I believe continued education on the importance of agriculture to California's economy, its diversity, and the quality of its products, is essential. The average consumer does not realize how vital our $20 billion agriculture industry is in the production of a number of commodities. As the business of food production changes over the next 75 years, farmers will have to change as well. With less and less people involved in farming and processing, it will be even more important to educate our urban neighbors and legislators on the potential impacts affecting the quality of their food and marketability. I plan to take an active role in the education and promotion of California agriculture.

Profitability and government regulations are the biggest challenges facing production agriculture. The future of our food production depends on my generation getting involved with issues affecting our industry, such as the Endangered Species Act, the Clean Water Act and the Clean Air Act. While addressing environmental concerns is important, there needs to be some sort of reasonableness applied to legislation and decision making. A perfect example is the Environmental Protection Agency's proposed ban on methyl bromide even though there are no viable, cost-effective alternatives available to farmers. Our tools continue to be taken away, yet we must remain competitive in the international marketplace.

In summary, I will have the education, work experience, credentials and energy to promote and represent production agriculture's interest, socially and environmentally in California. It is the responsibility of my generation to further educate consumers and legislators alike.

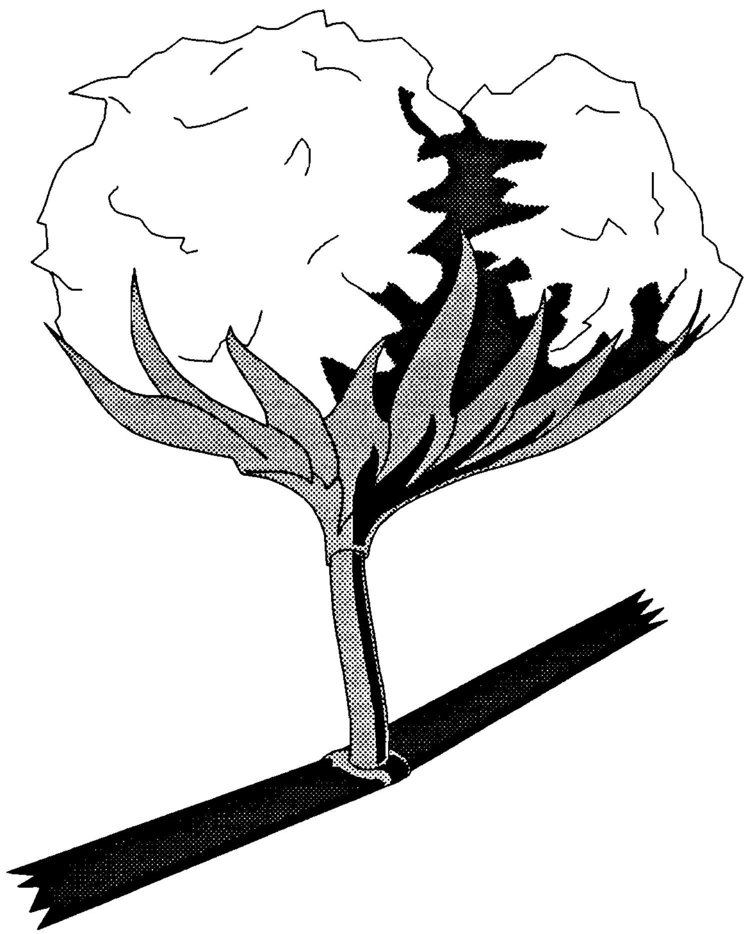
POSTER SESSION

TWENTY-FIFTH ANNIVERSARY CHAPTER ACTIVITIES—1972-1997

PRESENTED BY ASA BOARD OF DIRECTORS

In January 1972, the first annual Plant and Soil Conference was held in Sacramento, California. The credit for these twenty-five years of success belongs to the members of the California Chapter of the American Society of Agronomy and the work of many Board members. A key element has been the broad base of interest represented on the Board: agricultural industry, both University systems, and state agencies. Those who develop and provide information and services to California agriculture are the primary clientele. This is reflected in both the Chapter membership (over 200 in 1996) and the attendees at the annual conferences. The annual conferences are co-sponsored by the California Fertilizer Association which provides financial support and organizes the industry dinner program. There are also associations with the Certified Crop Advisor Program and the Fertilizer Research and Education Program. In 1994, we built 20 new poster boards and are deeply grateful to the 12 sponsors who partially offset their cost. In 1996, the Chapter initiated a scholarship program: $1000 was given to a student from U.C. Davis, and $500 was given to a Cal Poly, SLO student. As far as we know, your scholarship program is the largest of any regional Chapter in the nation.

CROP RELATED POSTERS:



Conventional and Organic Cropping System Effects on Wind Erodibility

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A long term agricultural farming systems project in Davis, California was utilized to investigate the impact of conventional and organic systems on wind erodibility. Three replicate undisturbed surface samples were obtained from each of four farming systems in the Fall after tomato harvest and before planting of the winter legume cover crop. Dry aggregate size distribution, surface roughness, total carbon, and soil flux measurements were made for each sample tray. Soil flux measurements included the total amount of material eroded, size distribution of the eroded particles, and threshold friction velocities (TFV). The undisturbed soil samples were subjected to thirteen wind speeds ranging from 4.7 ms^{-1} to 14 ms^{-1} in a stationary wind tunnel. Soil particles were eroded on to a greasy adhesive material 70cm from the edge of the tray and collected further downwind in the Big Spring No. Eight sampler. TFVs and amount eroded were determined by particle size analysis using NIH Imaging software on digitized images of the eroded particles on the adhesive. Surface roughness and dry aggregate size distribution for the two conventional systems were significantly higher than the organic and low-input systems, indicating lower erodibility. However, the soil flux measurements for the two conventional systems were also significantly higher than the organic and low-input systems, indicating higher erodibility. The higher erodibility of the conventional systems is attributable to lower total carbon content, lack of a winter legume cover crop, and increased tillage operations which contribute to less aggregation of individual particles.

Wheat Response to Interactive Effects of Boron and Salinity

C.M. Grieve, J.A. Poss, and L.E. Francois
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Excess boron salts may occur in areas where salinity is also a problem. To determine the interactive effects of these two hazards to crop production, the hard, red spring wheat cultivar, 'Yecora Rojo', was grown in greenhouse sand cultures. A completely randomized block experiment, With three replications, was conducted with treatments consisting of four salinitv levels (electrical conductivities of the irrigation waters = 1.5. 4.0, 8.0, and 12.0 dS m^{-1}) and four boron concentrations (1, 5, 10, L^{-1}). Treatments were imposed at emergence. Regardless of blades of plants irrigated with solutions containing 10 and 15 Mg L .showed severe injury symptoms within two weeks after imposition of treatments. Main-stem leaf number, plant height, biomass production, tillering capacity, and yield were significantly reduced by the interactive effects of boron toxicity and salinity stress. The interaction also altered accumulation in shoot tissue.

Optimal Water Requirements, Water Use and Root Distribution for Lettuce Cultivars

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Not Submitted in Time for Publication

A Field Method for Measuring the Potassium Content of Alfalfa

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Recently introduced to the agricultural market is a hand-held, ion-specific electrode, commonly referred to as the K^+Cardy meter. The K^+Cardy meter reportedly allows producers to measure the potassium content of plant tissue in the field. Despite the importance of K for successful alfalfa (Medicago sativa L.) production, there is little information about using the K^+Cardy meter for this forage. Our objective was to compare the K^+Cardy meter to atomic absorption as a tool to estimate the K content of alfalfa in the field. A total of 75 fields in the low deserts of California and Arizona were sampled in June, and again in December, of 1995. Seventy-five mid-stems from each field were collected and chopped into 1 cm pieces. Sap was extracted from half of the sample with a garlic press and analyzed with the K^+Cardy meter either immediately in the field (method 1) or after transport to the laboratory (method 2). The other half of the sample was oven dried at 60° C and analyzed for K content by atomic absorption. Sap K concentration by method 1 was well correlated with (r^2=0.68) with atomic absorption analysis; sap samples transported to the laboratory (method 2) were not as well correlated. We conclude that the K^+Cardy meter could be used as a quick and inexpensive tool to monitor the K content of alfalfa midstems as long as samples are extracted and read immediately in the field.

Determination of Best Nitrogen Management Practices for Broccoli Production in the San Joaquin Valley[1]

Michelle Le Strange, UC Cooperative Extension, Tulare & Kings Counties
Jeffrey P. Mitchell, UC Cooperative Extension, Kearney Agricultural Center
Louise E. Jackson, Vegetable Crops Dept., University of California, Davis

INTRODUCTION

Several areas in the San Joaquin Valley have been targeted as nitrate sensitive areas, and broccoli production in Fresno and Tulare counties overlaps several of them. Broccoli is a crop that can create a high potential for nitrate leaching losses because it requires high N inputs, tends to be irrigated frequently, has a relatively shallow root system, and is a high value crop. There is also a tendency to add excess nitrogen since it is apparently not harmed by excessive nitrogen.

OBJECTIVES

[1] *This research project is made possible by a grant from the California Department of Food and Agriculture, Fertilizer Research and Education Program (CDFA-FREP).*

1. To determine nitrogen fertilizer best management practices (BMPs) for broccoli production in the San Joaquin Valley.
2. To determine if BMPs change for fall versus spring harvested broccoli.
3. To identify nitrate movement and potential nitrate leaching losses of applied nitrogen fertilizer under furrow irrigation.
4. To evaluate the effectiveness and utility of the Cardy meter for quick test nitrate values for decision-making in broccoli nitrogen management during fall and spring growing seasons.

DESCRIPTION

Two broccoli nitrogen fertilizer field tests, one targeting a spring harvest and another targeting a fall harvest, will be planted each year. Seven nitrogen rates and three application timings (for a total of thirteen nitrogen treatments) will focus on nitrogen needs and response by the crop, and investigate nitrate leaching. Seven treatments use low nitrogen levels at preplant and first sidedress with higher rates applied as a second sidedress application.

Data measurements include sampling petioles and whole plants at key stages of broccoli production: thinning, rapid vegetative growth, button formation, preharvest, and postharvest. Samples will be subject to laboratory analysis and nitrate quick testing. Results from the lab will be correlated to the quick test. Soils sampled to a depth of 59 inches (150 cm) will be collected before planting, during rapid vegetative growth, and at harvest. They will be sent to the lab for nitrate analysis. Ion exchange resin bags will be buried at two depths 45 cm/18" and 90 cm/35") prior to seeding and removed after harvest to investigate nitrate movement through the soil profile. Yield and quality characteristics are being assessed.

Salinity Tolerance of Four Pistachio Rootstocks

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University of California, Davis
Kearney Agricultural Center

Five replications of 'Kerman' pistachios on four different pistachio rootstocks, Atlantica, Integerrima and two interspecific hybrids of these two species (both Atlantica X Integerrrima) were irrigated for three successive seasons with five levels of irrigation water ranging from 0.75 to 8.0 dS/m2. Results thus far indicate no significant effects on growth or yield suggesting, among tree crops, pistachios are tolerant of salinity. Differences in nutrient uptake, visible foliar salt damage, growth and yield among the four rootstocks suggest trees on Atlantica rootstocks tolerate salinity better than trees on Integerrima rootstocks. Thus, pistachios on Atlantica rootstocks may be good candidates for planting in areas with marginal quality water.

Site Specific Relationships Among Flag Leaf Nitrogen, SPAD Meter Values and Grain Protein in an Irrigated Wheat Field

R.O. Miller, S. Pettygrove, R. F. Dennison, L. Jackson, M. Cahn, and T. Kearney and R. Plant
University of California Davis

Relationships between flag leaf nitrogen, grain head nitrogen, SPAD meter values and grain protein were spatially evaluated across three 80 acre fields of spring wheat in the Sacramento Valley of California in 1996. Fields were grid sampled at 0.40 ha resolution at anthesis and wheat flag leaves measured using a Minolta SPAD meter and analyzed for total nitrogen. Grain head samples were analyzed for total nitrogen at anthesis and grain for protein at maturity. Grain yields and grain protein on each of the fields ranged from 2.2 to 6.3 Mg ha^{-1} and 10.1 to 14.8 %, respectively. Results will be presented on spatial correlations between soil physio-chemical measurements flag leaf nitrogen and grain head nitrogen at anthesis and relationships with Minolta SPAD meter values. Grain protein at maturity was impacted by variations in weed intensity which was mapped as a co-variable.

Participatory On-Farm Demonstration Projects Within the San Joaquin Valley's West Side

J.P. Mitchell, P.B. Goodell, R. Bader, R. Cifuentes, T. O'Neill, T.S. Prather, D.M. May, R. L. Coviello and K. Hembree
University of California Davis

Sixteen on-farm demonstration comparisons of biologically integrated soil building/pest management systems and conventionally-managed production systems have been set up and are being monitored by participating farmers and University of California researchers in the West Side row crop area of California's San Joaquin Valley. Composted organic materials and cover crops are integrated into rotations whenever appropriate in each of the biologically integrated comparison parcels, whereas mineral fertilizer applications are made in the conventionally-managed parcels. Key soil physical, biological and chemical attributes including nutrient status, water stable aggregates, organic matter, dehydrogenase enzyme levels and water infiltration rates are monitored. Participating farmers contribute to the evaluation and development of biologically and informationally intensive pest management practices by conducting on-farm trials. Information related to the objectives, structure and monitoring activities of this project during the establishment phase will be discussed.

Drip-irrigation—Crop Rotation Studies for the Western San Joaquin Valley

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Abstracted not submitted in time for publication in proceedings.

Genotypic and Agronomic Assessments of Salt Problems in California Rice Production

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Stringent requirements for water holding for California rice producers who use pesticides have resulted in the loss of stand and visible symptoms of leaf damage for some growers. A field assessment was made. Growth and stand loss and high leaf Na^+ and Cl^- were correlated with high salinity in soil mud and water. Greenhouse studies were conducted to determine the range of genetic variability for salt tolerance among ten varieties of rice that are common to Northern California rice-growing areas. Seed was planted in sand cultures and flooded with saline waters having electrical conductivities of approximately 1 (control), 3, 7, 11, 13, and 16 dS m^{-1} with 3 replications. Salinity decreased emergence rate final stand, and led to reductions in shoot and root weights. At the highest salinity, shoot weighed were 20 percent of the control after 17 days. Leaf tissues of plants grown at 16 dS m^{-1} had five times as much Na^+ and 3 times as much Cl^- as controls. Leaf concentration of K^+ was decreased by about 40 percent by salinity. There were significant differences in growth rates related to variety, but relative salt tolerance differences were nil. A third experiment showed that there were significant interactions between Salinity and ponding depth in seedling emergence and growth.

Petiole Sap Nitrate Tests for Broccoli and Cauliflower

A. Kubota, T.L. Thompson, and T.A. Doerge
University of Arizona

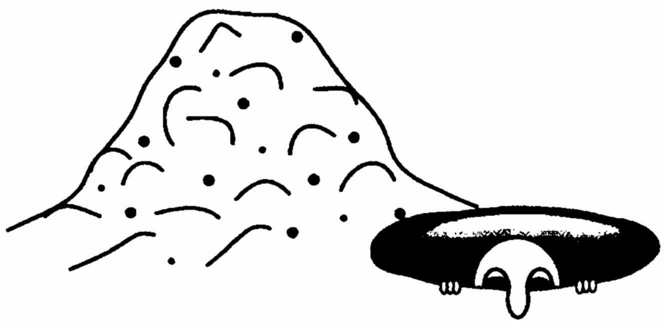
Analysis of dried plant tissues for determining nutrient status may present a limitation to growers because of the delay between sampling and analysis. These studies were conducted to evaluate a recently developed portable nitrate meter for broccoli (*Brassica oleracea L.* Italica group) and cauliflower (*Brassica oleracea* L. Botrysis group). These crops were grown with subsurface drip irrigation in two irrigation rate by N rate experiments in southern Arizona. Plant petiole samples were collected several times each season and were split for analysis of dried petiole nitrate by ion-selective electrode and for sap analysis by the portable nitrate meter. Linear correlations for the two measurements were similar between the seasons, regardless of crop water-status. Therefore, regression equations were derived: Y =0.047 X + 343 for broccoli, and Y = 0.047 X + 218 for cauliflower, where X and Y are $N0_3$-N in dried petioles (mg kg^{-1}) and in petiole sap (mg L^{-1}), respectively. The sap test can be a useful technique for monitoring nitrogen status of these crops.

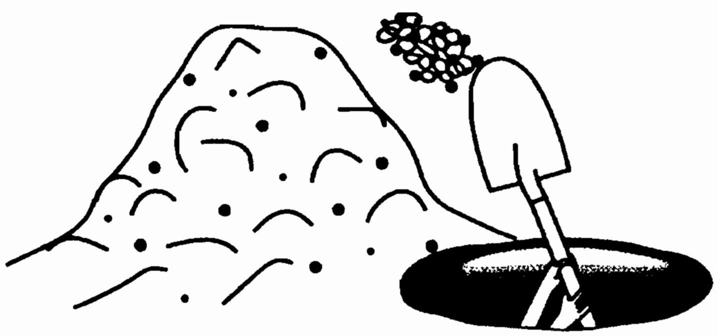
Uptake of Split N Applications to Subsurface Drip-Irrigated Broccoli

T.L. Thompson, 0. Lopez-Portillo, and T.A. Doerge
University of Arizona

Subsurface drip irrigation and fertigation offer the potential for efficient water and nutrient management. However, nutrient use efficiency will depend upon the time of nutrient application and water management. Three pulse-labeled ^{15}N microplot experiments with subsurface drip-irrigated broccoli (*Brassica oleracea* L. Italica group) were conducted in southern AZ. The objectives were to determine the effects of soil water tension (SWT) and time of N application on: 1) plant uptake and partitioning of split-applied N, and 2) soil N transformations and losses. Experiments had three target SWT's (deficient to excessive), and two times of $(^{15}NH_4)SO_4$ application (early or late). All plots received identical amounts of N fertilizer. In general, uptake of ^{15}N was more affected by soil water tension than by time of application. During three years, an average of 45% of applied ^{15}N was taken up by plants receiving excessive irrigation, compared to 59% by plants receiving deficient or optimum irrigation. Immobilization of ^{15}N in soil was usually lower for late (average of 6%) than for early-applied ^{15}N (average of 9%), probably due to a stronger crop N demand at the time of late application. Split N applications made at early growth stages may be taken up as efficiently as those made during head formation if water is efficiently managed.

SOIL RELATED POSTERS:





Soil Nitrate Distribution Patterns in Surface Irrigated Commercial Fields After Harvest

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Producers are currently attempting to comply with requirements to follow best management practices for fertilizer management. Soil samples were taken in 0.3 mm increments to a depth of 2.7 m following harvest of wheat, cotton, and spinach and after alfalfa had been plowed down in fields from two farms. One producer had no runoff and added fertilizer directly to the irrigation water and the other had runoff and side-dressed fertilizer as anhydrous ammonia. Samples were extracted with 2 M KCl and the extract analyzed colorimetrically for NO_3-N. In general, residual NO_3-N levels under both management systems were less than 5 mg kg^{-1} of soil. However, there was evidence of NO_3 leaching after each season in fields from both producers. Leaching occurred when the field length was over 400 m and in sandy intrusions in the field. Problems occurring as a result of length of run can be corrected with changes in the irrigation system design.

Speciation and Bioavailability of Selected Trace Elements Added as Biosolids to Field-Grown Apricots

H.A. Ajwa, G.S. Bañuelos, and S.K. Downey
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Application of composted municipal waste (biosolids) to agricultural lands is a common practice for waste disposal and for supplying nutrients to annual and perennial crops. We evaluated bioavailability and geochemical forms of trace elements (Cd, Co, Cr, Cu, Ni, Pb, and Zn) applied as biosolids to irrigated apricot trees grown on 1.2 ha of sandy loam soil. Multiple annual applications of biosolids (based on N content of 0.75%) consisted of 0, 7.6, 22.5, and 45.0 Mg ha^{-1}. Trace elements in soils were speciated into five fractions using sequential chemical extraction. In general, large percentages of Cd, Cr, Ni, and Zn were in the acid (residual) and EDTA (carbonates) extractable fractions, irrespective of the loading rates. However, Co and Cu contents in the EDTA and NaOH extractable fractions increased considerably with greater loading rates. Correlations between trace element concentrations in various fractions in the surface and subsurface soils and in leaves and fruit will be presented.

Defining Roles of Mycorrhizal Fungi in Sustainable Agriculture

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A goal of sustainable agriculture is to balance our need to maximize crop production while maintaining the resource base. We have examined both plant-development and soil-structure responses to mycorrhizal fungi in a number of studies, in an effort to understand the functional roles of mycorrhizal fungi within the context of sustainability.

A comparison of three mycorrhizal fungi associated with soybean in sandy loam showed that Glomus mosseae was superior to either Glomus etunicatum or Gigaspora rosea in enhancing seed pod development and stability of soil aggregates. these responses were correlated with greater soil mycelial development of G. mosseae.

In another study comparing fungicide effects on three mycorrhizal fungi inoculated alone or together as a mix associated with peas in silty-clay loam, the community of three fungi outperformed each of the single fungi in promoting soil aggregate stability, while seed yield was not different among the mycorrhizal plants. The ability of mixed inoculs to increase aggregate stability above that of single-fungus treatments, but to maintain a similar level of seed yield increase over nonmycorrhizal plants was related to a reduction in total root length in the mixed-fungus treatment.

Our results show that mycorrhizal fungi have differing abilities to enhance soil stability, which is affected by the particular plant-soil-fungus combination, and is related to soil hyphal development and resource allocation within the host plant.

Correlation of Nitrogen Availability and Vegetative Cover on Disturbed Wildlands Soils

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Revegetation of denuded granitic and volcanic soils in the high elevation Lake Tahoe Basin is difficult because of the hot, dry summers, short growing seasons and the poor nutrient content of the disturbed soil materials. Low plant nitrogen availability has been indicated as a likely cause of poor plant colonization on other granite soils in Northern California. The N availability in these soils is deficient both in intensity and in quantity, probably due to low soil organic matter levels.

Amendment with organic or slow release N forms are expected to be needed to help regenerate plant cover on these disturbed sites. In order to establish target levels for these amendments, a survey of vegetative cover and associated soils in the Basin was conducted. Survey sites included native plant communities, areas that were disturbed but revegetating and areas that were disturbed and remained barren. Vegetative cover and soil N pools were inventoried for sites in both granitic and volcanic parent material. Soil nitrogen was partitioned into several pools of decreasing plant availability.

Assessment of DOC Released from Organic Soils, Sacramento-San Joaquin Delta-California

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Agricultural drainage waters originating from peat islands in the Sacramento-San Joaquin Delta are a significant source of DOC to channel waters, contributing 20 to 52% of the total DOC. Analysis of soil water from one agricultural field in the Delta over the one-month winter flooding/leaching period showed that DOC concentrations from near surface decomposed peat soils (lysimeter samples) ranged from 50 to 70 mg L^{-1}, and were lower than DOC concentrations from deeper fibrous peat soils (piezometer samples), which ranged from 62 to 78 mg L^{-1}. Characterization of DOC (XAD-8 and XAD-4 fractionation, specific UV absorbance at 254 nm) indicates that the piezometer samples contained greater amounts of humic substances compared to the lysimeter samples, possibly reflecting longer residence times and more reduced conditions at deeper depths. Further characterization of DOC (^{13}C-NMR analysis of XAD isolates, disinfection by-product formation potentials, etc.) and preliminary data from summer irrigations also are presented.

Irrigation Water Quality and Polyacrylamide Amendment Effects on Furrow Infiltration

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Infiltration rate reductions occurring during furrow Irrigation are problematic for some soils, Irrigators are rapidly accepting a new, erosion- and infiltration-control tool that maintains higher infiltration in treated furrows. A high molecular weight, anionic polyacrylamide (PAM) is applied to irrigation inflows (10 mg L^{-1}) when water first advances along the furrow. We hypothesized that PAM's infiltration-maintenance efficacy would be influenced by inflow-source water quality. Eight treatments comprising four different water-quality sources, with and without 0.25 mg L^{-1} PAM, were included in the study. Infiltration was measured in a recirculating furrow infiltrometer. Soil was Portneuf silt loam (Durixerollic Calciorthid). Principal component analysis indicated that the infiltration rate-vs-time curves and cumulative infiltration differed between treatments. PAM treatment increased overall cumulative infiltration by 42 mm and infiltration rate by 5.7 mm hr^{1} compared to no-PAM. PAM's capacity to increase infiltration rate was reduced when source-water SAR increased from 0.7 $[mmol_c\ L^{-1}]^{0.5}$ to 9.2. The effect of increasing source-water EC from 0.6 dS m^{-1} to 1.9 dS m^{-1} varied with the water's SAR. Our results suggest that PAM's influence on furrow infiltration is altered with changes in source water quality.

Leachate N from Forested, Non-Forested, and Riparian Soils of the Sierra Nevada

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Recent investigations in the Lake Tahoe Basin have suggested that colloid nutrient transport may plan an important role in lake and tributary water quality. The magnitude and mobility of inorganic and colloid-N in the Incline Creek watershed was assessed by constant head permeameter leaching experiments using intact soil columns. We evaluated the interaction of plot condition (forested, non-forested, and riparian) and depth on magnitude and form of nutrient discharge. Riparian and non-forested areas contributed the largest total amount of N. Colloid-N was mobile and the most dominant form. Results from column leaching studies were corroborated by data obtained from in-situ tension lysimeters. The mobility and presence of significant amounts of colloid-N indicates this nutrient form to be an important component of Sierra Nevada watershed processes.

Behavior of 44 Crop Species Grown in Saline Soils with High Boron Concentrations.

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The coastal region of northern Chile is a desert, and the salinity and boron levels in the soils can be high. The irrigation water is also saline (7 - 9 dS/m), with high concentrations of sodium, chloride, and boron. Despite these conditions, irrigation of alfalfa, winter grains, and vegetables has been practiced on the alluvial soils near the rivers, since before the arrival of the Spanish in the 16th century. A field experiment was conducted in 1989 and 1990 to document the effects of irrigation on the growth and yield of 44 crops species near the city of Calama. The EC of the Loa river water used in the study was 8.2 dS/m, and the boron content was 17 mg/L. The EC level exceeds the threshold salinity of most crops, and the boron level exceeds the threshold level for all crops. The crops were planted in December of 1989 and harvested the following May. Drip irrigation was used. The plant growth and crop yields of asparagus, red and sugar beets, swiss chard, artichoke, celery, a local variety of sweet corn, potato, onion, shallot, carrot, broad bean, spinach, and prickly pear cactus were greater than expected based on published information. If separate effects of salinity and boron were additive, little or no growth would be expected for all of these crops. Interactions likely occur which affect the individual tolerance coefficients for boron and salinity when a crop is exposed to both sources of stress at the same time. Foliar levels of boron may be reduced because high soil salinity levels reduce plant water uptake. The milder climate in Chile than in Riverside California, where much of the salt and boron tolerance data has been obtained, could be partially responsible for the better crop response to salinity and boron than expected. Finally, the productivity of the local variety of sweet corn suggests it is a more salt tolerant variety, which has arisen as a consequence of seed selection practiced since the time irrigation began in the region.

Relationships Among Soil Electroconductivity, Soil Texture, Grain Protein, and Yield of Irrigated Wheat

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As part of site-specific farming research, we investigated the use of the Geonics EM 38 Ground Conductivity Unit to measure soil- and irrigation-related properties in furrow-irrigated wheat fields. We hypothesized that measurements made during early grain fill after an irrigation in which N fertilizer was applied would reflect irrigation non-uniformity and would therefore be related to grain protein and yield. Data were collected at a 61 x 61-m spacing in a 32-ha field having low salinity and a clay loam soil. EM-38 values in beds and furrows were obtained both following the irrigation and following an 8-cm rain. A significant relationship (r^2=0.51) was observed between percent silt (0-15 cm depth, silt content ranging from 23 to 47%) and EM-38 value measured after irrigation. Silt content also was correlated elated with grain N content over a range of 2.0 to 2.6% (r^2=0.41). However, no relationship was seen between grain N content and EM value. No improvement in the correlation was obtained by normalizing EM values for the values observed after a profile-filling rain. Relationships among EM-38 value, grain yield, and leaf color at anthesis (measured on flag leaves with the Minolta SPAD chlorophyll meter and in color infrared aerial photographs) will be presented.

Irrigation Efficiency and Water Movement in Surface Irrigated Fields

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Developing best management practices for irrigated agriculture requires an understanding of water and nitrate movement through the soil in order to minimize nitrate contamination of the groundwater. Application efficiency and movement of water and solutes were studied for level and sloping fields under surface irrigation. Potassium bromide was used as a tracer and applied to sample plot areas in the fields at the start of the growing season. Soil samples were taken after harvest to a depth of 2.7 m in 0.3 m intervals at 15 locations in each field. Irrigation efficiency was higher in the level basins. Runoff losses in the sloping fields was about 20%. Bromide was detected at the 2.7 m depth in both fields, indicating that deep percolation was significant.

Water and Soil Salinity Studies on California Rice

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A water and soil salinity survey was conducted (1993-95) on the westside of the Sacramento Valley to assess salinity problems on rice (Oryza sativa L.). Each year in June, July, and August, soil and/or water samples were collected from 13 water sources and the inlet, top and bottom basins of 27 rice fields. Yield samples were also collected. Another survey studied rice seedlings and salinity. The Electrical Conductivity (EC) of most water sources was below 0.7 dS/m, which does not pose a salinity problem. Some drain water sources, however, were between 0.7 and 1.7 dS/m and these may contribute to crop salinity problems. Field water and soil EC levels increased significantly from top to bottom basins. Each declined significantly from June to August. Significant differences in water flow and depth between top and bottom basins and from June to August are probable explanations for these salinity differences. Rice yields decreased with increased salinity and were significantly lower in bottom basins compared to top basins. Seedling density and biomass decreased with increased water EC.

Use of Information on Microbial Communities to Fingerprint Soils

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The characterization of microbial communities provides a rich body of information with which it may be possible to develop a unique biological fingerprint for a specific soil. Methods for characterizing microbial communities, without requiring the selection or culturing, include the analysis of microbial phospholipid fatty acids (PLFA) or DNA directly extracted from soil. It was possible to discriminate among soil types from different land uses and soil taxonomic groups in California based on PLFA patterns analyzed using multivariate statistics. It was possible to discriminate between two different farming management practices, organic and conventional, in the same soil cropped with tomato and at different times over the growing season in rice soils. Management practices influenced the soil fingerprint less than did soil type and location. Preliminary data on the molecular characterization of soil community DNA indicates that rapidly amplified polymeric DNA (RAPD) patterns are able to discriminate among different soils.

Pesticide Sorbed In Agricultural Dust

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Pesticides are widely used in the United States and around the world. According to the Pesticide Use Report front the EPA, about 200 million pounds of pesticides were applied, in California alone, during 1994. The agricultural use of pesticides is the main anthropogenic source into the atmosphere due to losses during and after application. Once they are applied, some pesticides volatilize due to their high vapor pressure, and others with low vapor pressure are sorbed by aerosols and transported in the atmosphere. Paraquat and sodium chlorate sorbed on the soil particles may be suspended and transported by wind during wind erosion events or agricultural operations. The objective of this research is to estimate the amount of paraquat and sodium chlorate sorbed onto different size fractions of soil particles with diameters less than 75μm, which are the ones that are more susceptible to become dust. The analysis of paraquat will be done by extraction of the sorbed paraquat with 6N HCl followed by reduction with alkaline sodium borohydride to the mono- and di-ene dipyridyl compounds, and detection using a nitrogen-selective gas chromatography technique. For sodium chlorate, a colorimetric technique will be used in which the chlorate is reacted with chloride under acidic conditions to form chlorine. The chlorine released forms a yellow solution with o-tolidine having a maximum absorption at 448 nm.

Mineralogy of Agricultural Dust, Central Valley, California

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Air quality standards for PM-10 (particulate matter <10 μm) are not met at some sites in California's Central Valley. Some PM-10 can be traced to industrial and automobile sources, but some is clearly derived from soils, either by wind erosion or as fugitive dust from agricultural operations. Our objectives were to identify dust mineralogy and determine if mineralogy could be used to trace dust sources. Using x-ray diffraction (XRD), particle-induced x-ray emission (PIXE), and electron probe microanalysis (EPMA), we compared dust composition to local soil mineralogy. Dust masses were too small for effective XRD analysis, and many parts were too small for elemental analysis by EPMA. Allocation of elements, determined by PIXE analysis, to mineral structural formulas, determined by EPMA of soil minerals, suggest that the dust mineral fractions consist of about 50% quartz, 20% biotite plus altered biotite, 20% montmorillonite, and 10% other minerals, including feldspars and carbonates. Dust derived from Sierran granitic alluvium contains more biotite, Fe, and Ti, whereas dust from Coast Range alluvium contains more smectite. Our results show that PM-10 mineralogy is variable, and that PIXE analysis may be the most effective method for identifying sources.

Development of a Vegetation Management Scheme for the Bioremediation of Selenium

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Abstract unavailable when proceedings printed.

Transport and Transformation of Nitric Oxide in Fertilized Soils

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Nitric oxide gas (NO), which is be produced by several processes in soils, can reduce the amount of N available for crop assimilation and also may have significant impact on local ozone levels. High ozone levels in proximity to crops are estimated to be responsible for over $150 million in crop losses annually in the San Joaquin Valley. The impact of several soil properties on the generation and transport of NO was examined in laboratory experiments. Subsurface fertilizer placement was found to reduce gaseous NO-N losses by over 80% in a silt loam. Net NO production was directly related to levels of available NH_4-N, and increased with time after wetting, while oxidative consumption rate coefficients were relatively constant. NO-N + N_2O-N losses of 70 kg N ha-1 (14% of available NH_4-N) occurred in 30 days in a loam, while 0.13 kg NO-N ha-1 (0.3%) occurred in 4 days in a silt loam. Transport equations may require multiple source and sink terms, each of which may be functions of time and space. Several regulating processes may need to be simulated: N mineralization, immobilization, nitrification and enzymatic and non-enzymatic denitrification, biomass growth, gaseous diffusion and gas-liquid phase partitioning. Before improvements in existing models of NO flux can be made, further experiments are required to correlate changes in NO flux with changes in these chemical concentrations and physical properties.

Facilitated Transport of Devronol© by Dissolved Organic Matter Through Soil Columns

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Degradation of the environment due to the use of agriculturally applied chemicals is of great concern. The movement of these chemicals into groundwater has been reported in numerous cases and is usually attributed to preferential flow. However, it is proposed that a water soluble facilitator such as dissolved organic matter is capable of increasing the movement of devronol© through soil. Devronol© was applied to repacked soil columns where steps were taken to remove preferential flow. Columns were irrigated with a constant hydraulic head of 3.0 cm. Devronol© was detected in the initial effluent from the columns. The devronol© concentration then decreased to below detectable limits within 3.3 cm of cumulative effluent with > 95% of the applied chemical remaining in the top 6 cm of the soil. Similarly dissolved organic matter in the effluent was also highest in the initial effluent and decreased with cumulative effluent. A linear relationship was found between the devronol© concentration and the dissolved organic matter concentration. Use of the convection-dispersion equation would predict that the all of the devronol© should be within the top 6 cm. Devronol© was also applied to biosolid amended soil. The addition of biosolids had increased the organic matter content of the soil which should retard the mobility of devronol©. It was found that the devronol© center of mass was retarded but that more devronol© was found in the leachate of biosolid amended soil as opposed to the untreated soil. An association between devronol© and dissolved organic matter appears responsible for increased movement of devronol© through soil.

Pulses of Inorganic Nitrogen and Microbial Activity After Tillage

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A consistent trend in short-term dynamics immediately after tillage has been observed in several soil types under intensive vegetable production in the Salinas Valley of California. During the 7 to 14 days after tillage, there was a surge then decline ('surge-crash') in NO_3^--N and microbial biomass N (MBN). The decline in NO_3^--N occurred even when soil moisture was dry, enough to preclude leaching, The size of the surge and decline appeared to depend upon soil type, moisture status, and our sampling frequency. More detailed measurements at some sites showed that microbial biomass C stayed more constant than did MBN during the post-tillage period, possibly due to changes in C/N ratios of soil biota. We hypothesize that tillage may temporarily increase C and N availability by exposing new microsites, increasing microbial growth and activity, then leading to subsequent 0, limitation, so that denitrification in these microsites could explain the decline in NO_3^--N. The decline in MBN could be explained by decreased C and/or O_2 availability. 'Surge-crash' dynamics immediately after tillage may be especially pronounced in these highly tilled, degraded soils, and could be an important factor for C and N loss.

Modeling Methyl Bromide Diffusion in a Field Soil

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Methyl Bromide (MeBr) was injected into a non-covered Greenfield sandy loam field using a tractor with two shanks spaced 1.68 m apart. The depth of injection was 0.68 m and the rate of injection was 325 kg MeBr ha^{-1}. MeBr concentrations in the soil air were measured over a two month period after the injection. The data set provided calibration points in the optimization of diffusion model parameters. comparisons between measured and modeled MeBr concentrations in the soil profile are presented. Also included are exposure data in the form of concentration-time (CT) with position relative to the point of injection.

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