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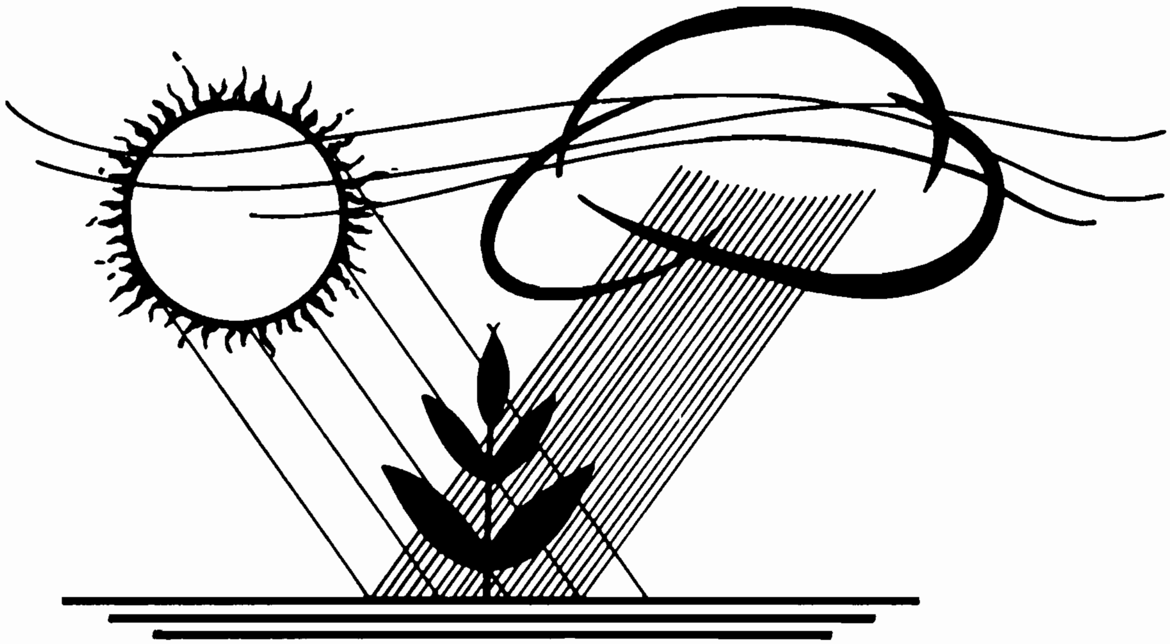

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TURF AND ORNAMENTALS

MANAGING PLANT STRESS I

MANAGING PLANT STRESS II

GETTING YOUR MESSAGE ACROSS

(Tips on how to ensure understanding and positive reaction when presenting technical information)

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It is important to communicate well especially when it entails technical information. Basic communications methods apply even in the technical sciences. Since the dawn of man word of mouth has been the communication mainstay, much to the consternation and confusion of generations. Now we know better what makes for successful communication and why. Some practical presentation rules-of-thumb that should help in the process, are reviewed. The use and appropriateness of various presentation methods for workshops, demonstrations and visual presentations, will be discussed. Specifically addressed are ways to start or introduce a presentation; how to use visual aids; helping the audience remember; consideration of attitudes and the feedback process; handling questions; summing up; using handouts and evaluation of the presentation.

USING ONLINE INFORMATION SYSTEMS:

DATABASES FOR AGRICULTURE

Mary Aversa, Marketing

DIALOG Information Services, Inc.

Abstract

Information sources and resources for agriculture have grown astronomically in the last ten years. The need to quickly locate relevant data and publications for research and for the business of agriculture has increased. Computer-based systems have evolved to effectively handle the storage and retrieval tasks that are time-consuming as manual jobs. Online systems are the most powerful available in the technological developments because of their interactive nature, i.e., the ability of the user to define exactly the information required. The tremendous processing speed capabilities of computers enable an online system to go through literally millions of records in seconds.

Examples of online searches for information illustrate the ability to locate as much information or as little as required. Broadening, limiting, and eliminating are all easily accomplished within seconds in an online search.

A database is a group of records (e.g., references to literature, statistical time series) with similar characteristics. In general, each record will have a number of fields of information. A database, in most cases, contains information on one general or broad subject area. Types of databases for agriculture fall into three major categories:

1. Bibliographic

These databases contain all the information necessary to locate the source material. Often, as well as title, author, publication reference, date, and organizational source, the records will contain detailed abstracts of the cited document or research in progress. Important bibliographic databases for agriculture are AGRICOLA (U.S. Department of Agriculture), CRIS (U.S.D.A.'s Current Research Information Service), CAB (Commonwealth Agricultural Bureau), and agLine (Doane-Western).

2. Statistical Data

Another type of online database is statistical — that is, the records contain numerical series of data. For agriculture, statistical databases include Crop Reporting Board releases through Martin-Marietta, weather data through World Weather Watch and others, and economic data through Chase Econometrics and Data Resources.

3. Full-text Information

Some databases are composed of records containing the full information necessary for decisionmaking. These databases have become especially useful and popular for farm-oriented systems. "How to" management information is featured in Control Data Corporation's AgTech database and in AgriData Resources Inc.'s AgriStar system. Newsletters, newspapers, and encyclopedic databases are going online as important sources of information for agricultural operations.

Online systems are accessed by computer equipment which can communicate with the computer housing databanks of information. Basic types of equipment used are computer terminals, microcomputers, and communicating word processors. Users of online systems learn command protocols which range from simple (i.e., user-friendly, often employing a "help" message) to complex. Training methods range from short self-instructional guides to week-long seminars. Often, an individual or department is identified within an organization to effectively utilize the various systems available.

Even as "end users," those who have the need for and request information without using online hands-on, agronomic researchers should be aware of applications of online systems. It's essentially the only way to sift through massive quantities of data and to prepare as comprehensive a report as is possible on a subject, product, or company. Examples illustrate actual cases and a problem-solving approach to the use of online systems in the academic and business environment for agriculture.

Costs vary from system to system and from database to database. Some online systems take their name quite literally and charge only for online connect time. DIALOG is one of these systems. Costs for telecommunications, training, documentation, and equipment must be considered in budgeting. In addition, some systems require a monthly or annual subscription fee — either in addition to or applied toward online use. Some statistical data systems charge for CPU as well as online connect time. Additionally, some information suppliers charge for each piece of data retrieved. A sample budget for DIALOG use will give a basic understanding of cost considerations.

Cost-savings are accomplished in time saved and in the value of information retrieved. Moreover, through the use of online systems, the impossible becomes possible.

COMPUTERS IN AGRICULTURE--A LOOK AT TODAY AND A PEEK AT TOMORROW IN SUMMARY

by

Harlan Hughes[1]

INTRODUCTION

Farm and ranch managers are in for a change. While production has been the key to success in the past, management will become the key to success in the eighties. Financial success in the 80's will require a sophisticated "on-the-farm" management information system serving as the scientific foundation for management decisions. The complexity and quantity of agricultural production, marketing, and financial information in this management system will necessitate an "on-the-farm" computer. Innovative farmers and ranchers already recognize the need for a comprehensive management information system and are already attempting to learn about farm and ranch computers. The purpose of this paper is to share with the conference participants what is currently going on in Computers in Agriculture and how we see farmers and ranchers using microcomputers.

Each of you, as agricultural professionals, will need to be familiar with and understand where farm computers fit into your professional contacts with farmers. Production information will need to be integrated into the on-the-farm management information systems. The challenge to each of you is to make sure that your expertise is part of the on-the-farm management information systems in the 80's. Those professions that will have the major impact on agricultural production may well be those

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[1]Harlan Hughes is Associate Professor and AGNET Coordinator, University of Wyoming. Paper presented at Plant & Soil Conference, Riverside, California, January 27, 1983.

professions that integrate their information into producers' management information systems. How we will accomplish this electronically is only just now starting to unfold. I am willing, however, to predict that computers will play a major role in agricultural information dissemination in the 80's.

AGRICULTURAL COMPUTER SYSTEMS -- NOT A NEW CONCEPT

Selected agricultural scientists have long recognized the potential for computers in agriculture and have devoted their professional careers to developing computerized agricultural applications. As early as 1967, the Kellogg Foundation funded the development of an agricultural computer system and Michigan State University developed the TELPLAN System. The TELPLAN System was designed so county extension offices could provide farmers with their first contact with agricultural computer programs. Michigan took the system into the field in 1969 and several neighboring states joined the TELPLAN System in 1971 to form the first multi-state agricultural computer network. The TELPLAN System today provides computer services to agriculture. Extension specialists, extension agents, agri-businesses and farmers are subscribing to the system.

The Computerized Management Network (CMN) was the second major multi-state computer system to be formed. It has been operating out of Virginia Polytechnic Institute since the early 1970's. CMN primarily serves the Southeastern part of the United States; however, they have subscribers from all over the nation.

AGNET, the newest regional agricultural computer system to come on the scene, was developed at Nebraska in the mid-70's. In 1977, the governors of Nebraska, South Dakota, North Dakota, Montana and Wyoming approved funding to install a cooperative AGNET System in the five states. Since that time, the state of Washington has joined to make this a six state partnership.

Selected Extension specialists and researchers from the six states are designing agricultural and home economics computer programs that are in AGNET's computer library. There are currently over eight full time programmers working on agricultural programs and they are adding two to three new programs per month to the library. This cooperative development effort substantially reduces an individual state's development costs by sharing the developed models across state lines. All AGNET users have access to the total AGNET computer program library.

Wyoming does not have the resources nor modeling expertise to build all of its needs in computerized biological and economic models.

CATEGORIES OF PROGRAMS

The three major categories of programs being written for the AGNET system are:

1. Agricultural production and simulation models designed for management problem solving and "what if" questions in forward planning.

2. Information Networking where time-critical agricultural and consumer information is made available on a real-time basis.

3. Electronic mail and electronic conferencing.

The first two categories--production simulation and information networking--should be of considerable interest to agricultural professionals.

Production Simulations

Agricultural professionals have a unique opportunity to integrate their subject matter material into computer models used by agricultural professionals, farmers and ranchers. A professional's expertise can be inserted into computer programs in two ways:

1. Through the subject matter equations built into the biological models. Environmental variables could be inputted by the users so that the biological models have a wide geographical application.

2. Through the data bases driving the biological models. These data bases are very geographic specific and permit the model users to tailor the input to his specific environmental conditions.

Not all models have a data base driving them; however, users tend to prefer the models driven by comprehensive data bases. It appears that users are accessing the models as much or even more for the information retrieval ability as for their problem solving ability. A professional designing a model utilized by a thousand farmers can have quite an impact on agriculture. Building your subject matter expertise into biological computer models may well prove to be a key dissemination system of the 80's.

Information Networking

Information Networking is a new concept where data banks are stored in a central location and users access the data banks with computer terminals and microcomputers. AGNET was a pioneer in information networking and currently has eight agricultural data bases available to its subscribers. The eight data bases are:

1. Agricultural commodity prices
2. News releases from USDA and participating states
3. Outlook and situation reports
4. Hay for sale
5. Sheep for sale
6. Certified pesticide applicators in Wyoming
7. Microcomputer programs available
8. Foreign Agricultural trade leads and commodity reports.

Nebraska also has real-time weather data bases collected daily that farmers can use in their irrigation scheduling. Depending on the time of the year, we have had drought reports, growing season reports, pest reports, canning tips, and horticultural tips. As more agricultural professionals become aware of the potential for rapid disseminating information directly to producers that own computers, more and more subject matter materials will be put into computer data bases. Commercial data base networks are starting to come on-line. We fully expect several of these commercial systems to be around in the next year or so.

FARMER OWNED MICROCOMPUTERS -- WHERE THE ACTION IS

In the late fall of 1977, Radio Shack put on a massive advertising campaign to introduce the public to home computers. The potential of these home computers has now grown into small business computers with considerable potential for farmers and ranchers. A farmer's and rancher's management information system can now be computerized right on the farm or ranch. On-the-farm computer systems can now be purchased for $4,000 on up, depending on the size of the management information system.

As I visit with farmers and ranchers, I hear them expressing interest in microcomputers for three application areas. These areas are:

1. Financial record keeping, often including enterprise accounting.
2. Production records such as herd performance, crop and field records.
3. Financial planning as required by the credit agencies.

Financial accounting tends to be the most popular expressed interest. In Wyoming our ranchers are expressing interest in keeping their livestock herd performance data on a computer. They know that their current 3x5 card system is slow and does not allow the flexibility that they need.

As financial pressures grow in today's operations, interest in computerized financial planning is increasing. More and more bankers are encouraging computerized financial planning. The microcomputer certainly makes financial planning easier by doing the repetitive calculations.

Telecommunications

Hardware and software now exists so that the producer-owned microcomputers can now be used as a terminal into central data bases and networks like AGNET. A microcomputer used as a "smart terminal" can now be used to "upload" and "download" data to a mainframe computer. What this all means to agricultural professionals, farmers and ranchers is a significant cost reduction in accessing centralized data bases. For example, AGNET Wyoming has software to allow an Apple user to generate his data off-line with the microcomputer and when the data input is completed, edited and corrected, he can have the microcomputer automatically send the data to the AGNET computer and automatically receive the answer back. Uploading and downloading makes the cost of accessing central data bases relatively cheap. On certain types of programs, it may always be cheaper to access a mainframe program when that program is needed than to keep an up-to-date program on a producer's own microcomputer. Buyland is a good example--a producer may only do this once or twice in a lifetime. Frequently used programs, on the other hand, belong on the producer's own computer. Record keeping programs fall into this frequently used category and belong on the producer's own microcomputer.

Private industry is doing a reasonably good job of providing record keeping software for microcomputers. Comprehensive simulation models, however, require considerably more expertise and are more costly to develop. It looks like the private sector may end up concentrating on the record keeping type programs and the public sector may end up concentrating on the more costly simulation programs. The net outcome of the public and private sectors' efforts is that farmers and ranchers will have a much larger program library to select from. Our challenge, as ag professionals, is to ensure that the subject matter integrated into the computer programs is correct.

MACADAMIA CULTURE IN CALIFORNIA

ALVA V. SNIDER, PRESIDENT

CALIFORNIA MACADAMIA SOCIETY

The Macadamia, a member of the Proteaceae family native to Australia, is believed to have been introduced into California about 1880, by Professor C. H. Dwinelle, of the University of California at Berkeley, who had obtained seeds from Australia. One of the original trees still exists on the campus. Since that time, only a few scattered trees were grown, primarily in the Southern California area, until the end of World War II, when, as a result of many Servicemen's contact with the nut in Hawaii, a considerable interest in growing this delicious nut developed.

Of the two main species, M. Tetraphylla and M. Integrifolia, initially the first commercial plantings were Tetraphylla seedlings. Subsequently, because of the success of the Integrifolia varieties in Hawaii, scion wood from there was brought to the Mainland and many seedling groves were grafted over to the named Hawaiian varieties, i.e. "Keauhou", "Ikaika", "Kakea", and "Keauu". Since the early 1970's, interest has swung to the Tetraphylla variety, "Cate ", and most of the commercial groves are now planted to this variety.

CULTURAL ASPECTS:

The Macadamia has about the same frost tolerance as the "Fuerte" avocado (i. e.: about 30°F.), which, of course, limits the areas of California in which it can be successfully grown.

The Macadamia tree, however, has a very wide tolerance for a variety of soils, and, most importantly, will grow in heavy soils in which an avocado will not survive. Macadamias, except for an occasional trunk lesion, are not affected by the Phytophthora Cinnamomi fungus. Because of this, Macadamias have become a replacement crop in areas where the soil is not suitable for avocados.

Macadamias can be propagated by rooting cuttings, but greatest success has been achieved by grafting scions of preferred varieties onto Tetraphylla seedlings.

Macadamia trees have a moisture requirement similar to that of an avocado, with many of the newer plantings doing very well on either drip or mini-sprinkler irrigation. The trees in many cases are planted with the same spacing as avocados, but can be planted as close as 10' x 20', without suffering from loss of production until the trees are over 15 years of age.

Some early pruning is desirable to produce a sturdy structure with wide-angled branches to avoid wind damage, as the wood is quite brittle.

At the present time, there are no significant diseases or pests, and spraying is not required. However, rodents are a problem and should be controlled to avoid a considerable loss of the crop.

Most Macadamia growers fertilize with mixtures commonly used for citrus. It is recommended that leaf analysis be determined each year. Preliminary standards have been established, based on Hawaiian and Australian results. Considerably more work needs to be done in this area in relation to California soils and growing conditions.

In California, the nuts are harvested by collecting them from the ground periodically as they fall. It is recommended that they be collected every two to three weeks to avoid losses due to mold or rodent attack. There are mechanical harvesters available, and as larger plantings come to maturity, purchase of such machines can be justified. Once the nuts are collected, they should promptly be husked and placed on drying racks to lower the moisture level from approximately 25% to the 8% to 10% level. This requires ten days to two weeks. Current recommendations are that the nuts not be dried in the sun.

Commercially, the nuts are further dried in warm air ovens at 100° to 120°F to a moisture level of 1.5 to 2%, which is recommended by researchers at the University of Hawaii. At this moisture level, the nuts crack more easily and can be stored in-shell for a year or more without becoming rancid.

In California, the industry is not large enough as yet to justify a cracking and processing operation, for once the nuts are cracked, it is necessary that they be refrigerated, vacuum packed, or nitrogen packed to prevent the nut meats from becoming rancid.

Current acreage figures are only estimates, which range from 300 to 1000 acres. The California Macadamia Society is currently conducting a tree census in an effort to better establish the actual acreage. Indications from nurseries specializing in propagating Macadamia trees are that the number of plantings has accelerated as there is approximately a one year wait for young grafted trees.

The Hawaiian industry has done such an outstanding job of merchandising the Macadamia nut that it has maintained its acceptance as a gourmet item, and consequently a relatively high price and corresponding high value to the grower.

Cultural Practices in Turfgrass Sod Production

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The turfgrass sod industry had its beginnings in the East and upper Midwest in the 1920's. At that time, farmers would mow native Kentucky bluegrass pasture down to lawn turf height, strip the sod, and sell it. Pasture sod predominated well into the 1940's when the elite turf type Kentucky bluegrasses began to get popular. Pasture sod slowly gave way to cultivated sod.

In California, commercial sod production did not actually begin until 1958. Since that time industry growth has been steady and rapid, until the current recession. Currently it is estimated that there are 5300 acres of sod production in California for an annual sales volume of $30 million. The breakdown of grasses sold are as follows: Ky. bluegrass/perennial ryegrass mixture 40%, Ky. bluegrass 30%, Hybrid bermuda 20%, Dichondra 5%, St. Augustine 2%, improved tall fescue 1%, and other grasses 2%. Customer breakdown is as follows: Landscape contractors 65%, retail nurseries 20%, governments and institutions 10%, golf courses 1%, direct retail 1%, and others 3%. The sod goes into the following sites: Single family dwellings 65%, multiple family dwellings 20%, government installations 5%, industrial parks 5%, golf courses 1%, and other 4%.

Production of turfgrass sod is an intense cash crop culture and bears little resemblance to turf management. The cool season grasses—Ky. bluegrass, perennial ryegrass, and tall fescue—are generally reseeded after each crop is harvested. Land preparation includes plowing, disking, rototilling, landplaning or levelling, and rolling with a cultipacker or flat roller or both. Often the soil is fumigated to control *Poa annua*, nutgrass, bindweed, and common bermuda.

Nitrogen use is relatively high through the crop cycle. Commonly 320# of N per acre is used during the eight month period. Water use varies with soil, location, and species, but 40 inches per eight month period per acre would not be unusual.

Weed control is quite important for the California market. Poa annua and crabgrass are probably the only weeds that a sod farmer deals with that a turf manager would also have. For the most part we must control "farm" weeds such as pigweed, Shepherd's purse, groundsel, Malva parvafolia, watergrass, foxtail barley, etc. Herbicides that are commonly used include: 2,4-D, MCPP, dicamba, bromoxynil, Devrinal, Kerb, MSMA, DSMA, Paraquat, Roundup, Tupersan, and AAtrex. Due to the practice of fumigation the phenoxys are the only weed killers used in any volume.

Diseases can be devastating just as with most other crops. SOB disease (Fusarium roseum) is a highly significant problem in Southern California, much less so in Northern California. This is a warm weather pest of Ky. bluegrass. So far no effective control has been found that could economically be used on a sod farm. Mixing perennial ryegrass with Ky. bluegrass has nearly eliminated the disease, with very little quality loss in the turf. Rust is another disease of Ky. bluegrass which also affects perennial ryegrass. This is usually an indicator that the plant growth has slowed. Normally an application of nitrogen fertilizer gets the turf growing so the rust can be mowed off. Other than the dichondra diseases, these are the most bothersome.

Insect problems don't occur often on sod farms. When they do, obviously, they are of concern. Cutworm, white grubs, and sod webworm (lawn moth) are perhaps the most common.

The maintenance cultural operations are essentially mowing, sweeping, fertilizing, and irrigating. Labor is higher for sod production than for many other crops because of the daily maintenance requirements.

Sod is harvested to order. An order will be cut during the day and delivered the following morning. The installer has from 12 to 24 hours to lay it, depending on weather, after he receives it. Sod has been held for much longer periods, but it does lose its color.

The production of turfgrass sod has become an important segment of the overall landscape industry in California. The future is somewhat cloudy due to the housing industry and, perhaps, more significantly, due to the statewide water situation.

UNUSUAL CULTURAL METHODS FOR DESERT GROWN VEGETABLES

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The winter climate of the low desert of the Imperial, Coachella, Palo Verde and Yuma Valleys is characterized by relatively high day temperatures, low humidities, and occasional nighttime radiation frosts. Variations of temperature within the area are due to wind exposure, elevation above the surrounding country, the effects of bodies of water (i.e. the Salton Sea and Colorado River), and crop cover.

The low desert areas are well known for their production of cold sensitive vegetables including summer squash, eggplant, tomatoes, and bell peppers.

The area is also noted for "off-season" production of cantaloupes, mixed melons, sweet corn, asparagus, and watermelons. The desert often produces vegetables when the West Coast of Mexico is past its prime and before the San Joaquin Valley has started to ship. During this time, vegetables often command high prices. In order to produce crops sown during December, January, and February, growers devised specialized techniques to increase heat energy to the plant and protect it from frost.

Slant Beds

One technique used by local growers is to grow tomatoes, melons, and squash, on raised beds. About a month before planting, soil is mounded into 2½ foot, raised beds using a border disc. The furrows are seven feet apart.

Several passes are necessary to fluff up the soil to this height. All beds run east-west in direction. Special home-built planters are used to shave off the soil on the southern side of the beds to provide maximum sun exposure . The seedlines are placed on the southern slopes about 14-16 inches above the bottom of the furrow. In 1-2 months, the growers flatten off the beds until the ground is virtually level. New furrows are dug with the plant lines centered between furrows. The reconstruction of the bed top allows the melons to spread runners equally in all directions, whereas those left on slant beds produce vines that tend to grow down into the water furrows. Fruit formed in the furrow will often decay and become unmarketable.

Petroleum Mulches

Black petroleum asphalt mulch is sometimes sprayed in 6-inch bands over the seedlines on melons or tomatoes grown on slant beds. The purpose of the mulch is to increase heat absorption in the seeded area. Researchers have shown that petroleum mulch increases stand uniformity and seedling emergence, but there are no major advantages for earlier production. Petroleum mulch does, however, prevent rodents from consuming seeds and the mulch reduces moisture loss in the seedline. The mulch is applied at a rate of 60 gallons per acre.

Brushing

One technique that has been highly successful in increasing early crop growth in cold weather is called "brushing." The original method involved driving 2x2" posts at the end of each row. Three strands of wire were stretched from post to post. A roll of brown kraft paper was rolled out post to post. Arrowweed, a type of local ditchbank weed, was pruned of its foliage except for the top 6-10 inches. The 3-4 long, slender stems were used to support the paper to the wires. The sturdy arrowweeds were woven into the wire, being careful not to tear the paper. The paper barrier was angled about 30° from verticle. Seeds of cold, sensitive vegetables, such as tomatoes, squash, peppers, and eggplant, were sown close to the south side of the paper. The kraft paper served several purposes including reducing heat loss due to winds , increasing the soil temperature on the south side of the paper by reflecting solar radiation back at the plants and trapping nightly radiated heat.
Today the arrowweeds have largely been replaced by lath, but the principle is the same. The high cost of brushing has reduced its use in the Imperial Valley.

Hotcaps

Early watermelons are still hotcapped as the crop is grown on 100 inch beds with plants spaced 3 feet apart in row. The plant population is 1045 watermelon plants (hotcaps) per acre versus 6222 hotcaps required for cantaloupes that are spaced 12 inches apart in row on 84 inch beds. Hotcaps consisting of glassine or wax paper are formed over a wire or bamboo splint frame. The plants receive additional heat that amounts to 2-6°F above the minimal temperature of the ambient air. At the end of February, the caps are removed by first poking a hole in the downwind end of the cap. After 2-3 days, the whole cap is removed.

Excelsior

Finely curled wood shavings called excelsior are used to cover fall grown muskmelons during November and December. Melons are susceptible to both sunburn and frost injury which can easily occur during these months. The excelsior protects the fruits and allows the grower to keep the fruit "stored" in the field until it is fully mature. Late fall fruit often command high market prices.

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Control of Fusarium Yellows of Celery

with a Modified Fertility Program

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There is a voluminous literature concerning the effects of various plant nutrients on disease severity. Much of this work has focused on the relationships between form of N, i.e., ammonium or nitrate, and disease development. With few exceptions these studies have been conducted in the greenhouse under highly artificial conditions. There have been very few published accounts of field applications, and essentially no hypotheses have been advanced to explain the mechanisms of disease suppression. The purpose of this communication is to describe greenhouse and field experiments on the effects of form of N and potassium and chloride on Fusarium yellows of celery, a disease which has become a major threat to the celery industry in California.

Results from initial greenhouse experiments indicated that the use of KNO_3 as a source of N gave almost complete control of the disease. However, field experiments did not confirm greenhouse findings. In fact, disease was more severe in treatments receiving KNO_3 compared to $Ca(NO_3)_2$ and NH_4NO_3. When the greenhouse experiments wre repeated with a different soil, the KNO_3 effect was not confirmed. After numerous experiments it was learned that disease suppression could be obtained only when tissue concentrations of K and Cl were nearly equivalent. In retrospect, the former soil had a high Cl content which provided the plant with a balanced supply of Cl when KNO_3 was used. In addition, the "K-effect" was nullified in the presence of excess Ca or as little as 20% added NH_4-N. These cations affected both K and Cl uptake. Thus, greenhouse experiments indicated that substantial disease control could be achieved with KCl under a NO_3-N regime (Table 1).

Field experiments were conducted at the South Coast Field Station to determine if these findings could be applied in commercial practice. In 1981 the experimental materials were applied and uniformly incorporated into the soil before transplanting because the fungus penetrates the host at the root tip. Also, theory suggested that the infection court must be continuously protected. Thus, because K is immobile in the soil, it was concluded that sidedress applications would not be effective. This posed several agronomic problems inasmuch as celery is a heavy nitrogen consumer late in the season. However, excellent disease control was obtained. Furthermore, petiole analyses showed that there were no significant differences in K concentration between plants receiving 224 and 672 kg K/ha. Thus, there was ample K available to meet the needs of the plant for disease control.

Because K availability was not a limiting factor and Cl is highly mobile in the soil, the field experiment was repeated in 1982 except that KCl and $Ca(NO_3)_2$ were applied by sidedressing at 2-week intervals. Results presented in Table 2 clearly indicate the high level of disease control obtained with $Ca(N)_3)_2$ and KCl.

TABLE 1. Effect of various potassium salts on Fusarium yellows of celery.

Treatment	Disease severity	Dry weight (g)	
KCl	2.6	7.21	
KNO_3	4.1	4.34	
K_2SO_4	3.7	5.93	
L.S.D. (*P* = 0.05)	0.6	0.6	1.86

1 All treatments received $Ca(N)_3)_2$ at 1.57 g/kg soil and cations at 45.2 meq/kg soil.
2 1 = healthy; 5 = wilted.

TABLE 2. Influence of mineral nutrition on incidence of Fusarium yellows of celery at the South Coast Field Station.

Treatment	Disease incidence[1]	Plant weight[2]
$(NH_4)_2SO_4$	80.0	7.9
KNO_3	42.5	9.8
KNO_3 + KCl	56.2	8.5
$Ca(NO_3)_2$	52.5	11.4
$Ca(NO_3)_2$ + KCl	16.2	12.8
16-16-16 + $Ca(NO_3)_2$	40.0	12.4
L.S.D. (P = 0.05)	20.4	4.0

1 Percent of plants with vascular discoloration in crown.
2 Weight of 20 plants (pounds) at 90 days after transplant.

UNIQUE PLASTIC ROW COVERS
FOR
VEGETABLE CROPS

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HISTORY

Plastic row wooden frame covers had its beginning in 1958 with an early cucumber planting in San Diego County. An obtuse-shaped row cover was first used to force the early crop. This early planting matured a month ahead of double paper cap planting. By 1960, practically all of the early spring cucumbers were started under plastic row covers due to early maturity and favorable markets.

Staked tomato row cover trials started in 1960, and commercial plantings were made in 1962. By 1964, practically all the early crop was started with plastic row covers either as an oval or as an inverted V-shape. Also, by this time growers had shifted to wire hoops in forming the shape. The standard hoop was 70 inches long, and made out of nine-gauge galvanized wire. Growers started with one five foot, clear plastic sheet, with 1½ mil thickness, then changed to two 36-inch wide sheets to simplify and reduce the cultural operations. Special strong clothespins were used to secure the two plastic sheets at the top wire, which was stapled to the stakes at the apex of the covers. By 1965, practically all of the early spring crops of cucumbers, tomatoes and squash were started under polyethylene plastic row covers.

PURPOSE

The purpose of row covers is to capture the sun's rays, warm a greater soil surface and heat the soil covered by the plastic. Air temperature usually increases from six to twenty degrees Fahrenheit inside the enclosed row cover area at mid-day. Also, soil temperatures were raised four to eight degrees Fahrenheit in the day-time to a depth of three inches. This extra soil heat collected in the day-time is released at night to maintain more rapid plant growth. In the San Diego County area of California, the crops matured three to five weeks earlier than with paper covers. This early crop maturity has favored market conditions.

CONSTRUCTION

Staked tomatoes - The normal staking method is to place two plants between each stake. Six foot, by one inch, by one inch, stakes are spaced three to four feet apart. A sixteen-gauge wire is stapled to the stakes at a 20 to 22-inch height. Nine-gauge wire hoops, 70 inches long, are spaced at alternate stakes. These hoops are forced into the ground covering an area of 26 to 28 inches wide and usually placed over the apex wire. The hoops are placed close to the stake. Two 36-inch plastic sheets with a haze of 12 to 20 percent factor are generally used to form the row covers. Six inches of plastic at the base of each side of the row cover are covered by soil in securing the base of the row cover. At the top of the row cover, the two sheets overlap three or four inches and are pinned to the apical wire with the special strong clothespins. Three to four pins are used between two stakes.

The two sheet construction allows ease of cultural operations from one side of the row cover. The clothespins are released and the plastic is dropped on one side, which is adequate space for weeding, pesticide application, as well as other cultural operations. Venting is simplified by pinning the top edge of the row cover to the hoops. One or two inches may be the first venting and this top space can be widened as the plant grows, or as the seasonal spring temperatures increase. Both sides of the plastic may continue to recede on the wire hoops until the entire row cover is open at the top. The plastic is then used as a windbreak for two to four weeks or until the early harvest begins. The early tomato crop is transplanted in January and the venting starts in February. The plastic is usually removed at the start of harvest or in May. Four to eight separate ventings are made in the process of opening the row covers. If temperatures are slightly unfavorable for natural fruit setting, chemicals applied as cluster sprays or cluster vibration are used in securing fruit set.

VINE CROPS

Cucumber and Squash Construction - The construction of vine crop row covers is very similar to staked tomatoes. These crops are grown as bush plantings and do not need the tall stakes. Most growers use stakes one inch, by one inch, by 26 inches long, and drive these into the ground, giving a row cover height of 16 to 18 inches. These are spaced 10 to 15 feet apart in the rows. The apical, sixteen-gauge wire is stapled to the top of the stakes. The same width and type of plastic is used to form the row cover. The two soil edges of the plastic are covered with four to six inches of soil. The soil under the row covered area is the same as for tomatoes. The two sheets are also secured at the top wire with clothespins. Hoops are spaced four to eight feet apart down the rows in forming the shape which also keeps the plastic taut.

Planting crops in windy areas can be managed with extra hoops. These can be placed on top of the plastic and above the hoop under the plastic. In severe winds, twistems are used to secure the bottom hoop to the top one and also tied to the apical longitudinal wire. This construction has given good securement in fairly severe storms. Cucumbers and squash are more tender than tomatoes. They require slower venting or opening in conditioning the plants. They may be injured readily if they are opened too rapidly. Most growers use the plastic as windbreaks during harvest. This assists in fruit setting and also fruit quality.

IRRIGATION AND FROST PROTECTION

Tomato covers have a furrow next to the stakes under the row cover. This furrow was used for irrigating and fertilizer application. Cucumber and squash also had the furrow next to the stakes and to the edge of the area covered. It was also used for both irrigation and fertilizer application. Tomato plants were set in the center of soil covered areas. Two transplants were set between each stake.

When temperatures slightly below freezing occurred, the furrow or drip water is applied to the soil enclosed by the covers late in the afternoon during these abnormal periods. Water temperatures between 50 to 60 degrees Fahrenheit warms the soil covered with the plastic row covers. This also causes a condensation of moisture on the underside of the plastic. This moisture film holds most of the soil heat released at night and protects the plants for a short frost duration.

During the early growth under the row covers, it is very important to keep the soil moisture fairly high as the moisture condensed on the underside of the plastic film also retains the heat collected in soil during the daytime and released at night.

A furrow inside the row covers has been used with drip or furrow irrigation. This original furrow is used throughout the tomato crop while the cucumber and squash vines have a tendency to block the furrow water as they develop and cover the soil. As the vines of these two crops develop inside the cover, furrows on the outside and adjacent to the row cover can be irrigated to supply the water needs of the plants.

During the last twelve years, most of the row crops started under plastic row covers have been watered with drip irrigation throughout the crops. This has reduced water needs and generally improved the crops. For the winter or early spring crops using row covers, a preplant fertilizer is applied. Liquid fertilizers can be injected into the drip lines. These liquid fertilizers can be used to control plant growth and fruit set. Low dosages of chemicals are more readily taken up by the plants.

Frost protection has been quite successful by irrigating when the inclement temperatures have occurred. The water used is generally 20 to 30 degrees Fahrenheit above freezing, and the heat released in dropping

IRRIGATION AND FROST PROTECTION
Continued

the water temperature releases considerable heat in cold periods. This is usually adequate to protect the plants in limited low temperatures.

SUMMARY

Row covers have stabilized since the beginning in 1958, and are used mainly on four crops: tomatoes, cucumbers, squash and strawberries. A limited acreage to early peppers has been used. Many growers have reduced their application costs in installation with tractors. Twenty to thirty percent of the installation costs can be reduced with tractor plastic layers. Another variation that has been helpful in cultural operation is the use of perforated film. Perforations ¼ inch in size on 3 inch spacing is standard for San Diego's climate. Whether one or two separate sheets are used, the perforated plastic produces a firmer plant growth.

Row covers used in vine crops and especially cucumbers are used as windbreaks at harvest. When light winds or normal breezes occur, these windbreaks intercept the air movement. In cucumber and soft squash plantings, this reduces the fruit scarring from the foliage spines, resulting in higher quality fruit.

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MANAGING IRRIGATION BY COMPUTERS

Richard L. Snyder

There are many factors that influence when a crop should be irrigated and there are several ways to determine how much water to apply. One set of techniques for irrigation scheduling that has proven effective on some crops is to measure plant-water status with a leaf pressure chamber, a stomatal diffusion porometer, or an infrared thermometer. Another set of techniques is to evaluate soil-water availability with a gravimetric probe, neutron probe, tensiometer, or by the "feel method." Both of these approaches, however, are labor intensive and have limitations that discourage their use in some instances.

Neither plant-water status measurements nor soil-water evaluations can tell you both when and how much to irrigate without making some subjective management decisions. Computerized water budget calculations also require subjective management decisions, but water budget calculations with a computer are not labor intensive. Additionally, soil water content and/or plant water status are often not the factors that determine when or how much a grower irrigates and a computer can aid in differentiating the ultimate determining factors.

A grower's irrigation schedule is frequently determined by labor or personnel convenience, availability of water, soil infiltration rate, and/or avoidance of disease problems resulting from prolonged standing water. These limiting factors can be easily entered into a computerized water budget program to determine the optimum schedule for a grower's site-specific situation. Neither plant- nor soil-based measurements can account for these management limitations and thus they are of limited utility in determining practical site-specific schedules unless the grower has complete flexibility in when and how much to irrigate.

The water budget method of irrigation scheduling is a bookkeeping technique where daily totals of evapotranspiration (ET) are summed from the last date of irrigation until a predetermined quantity of water has been depleted from the soil. This quantity of water, which is called the "allowable depletion," is normally expressed as a percentage of plant-available water (the volume of water stored in a soil between 15 bars soil-water tension and "field capacity"). Field capacity is the soil water content after gravitational water has drained from the soil.

Accurate ET estimates and the proper choice of allowable depletion are necessary to determine an optimum irrigation schedule using the water budget technique. The California Irrigation Management System (CIMIS) research project* is intended to both develop a system of obtaining and disseminating accurate ET estimates by the entire State and to writing computer programs that schedule irrigations by using the proper allowable depletion for a grower's site-specific situation.

Limiting factors to irrigation scheduling can be determined for a grower by first developing a normal irrigation schedule. The determining factors can then be stored on a computer disk for later use in real-time (current) ET scheduling. The first step in developing a normal irrigation schedule is to make selections of potential limiting factors from a computerized menu.

An example of a computerized menu to select limiting factors might appears on a computer terminal as follows:

1. Flexible operation time and frequency.
2. Specified operation time.
3. Specified irrigation frequency.
4. Specified in minimum frequency.

Select ___

The desired limitation is selected and the number entered into the computer. If there were no restrictions, item 1 would be chosen and the schedule would be determined by an allowable depletion that depends on the crop and soil textural class. If item 2 was chosen, a specified operation time, e.g., 24 hours, and the application rate would be entered and the schedule would be based on those

* Funded by the State Department of Water Resources.

limitations and/or the crop- and soil-based allowable depletion, whichever is more limiting. If the grower is restricted to a regular calendar schedule, item 3 would be selected and the number of days between irrigations would be entered into the computer. The schedule would be based on accumulated ET between regular calendar dates. Frequently, a grower needs a minimum number of days between irrigations to irrigate all of his fields and item 4 would be selected if that was the case. The minimum number of days between irrigations would be entered into the computer and the schedule would be based on accumulated ET and/or crop- and soil-based allowable depletions, whichever is more limiting.

In all selections, an estimate of application efficiency must be made to determine how much water to apply. This is necessary because accumulated ET provides only the required net application to replace depleted water. The gross application is calculated as:

$$\text{gross application} = (\text{net application}) \div (\text{application efficiency})$$

Clearly, application efficiency is an important factor in irrigation scheduling. This is especially true when there is a restrictive time limit that determines a maximum or minimum gross application for an irrigation.

Computers provide the means to easily compare various restrictions to irrigation scheduling and they allow application efficiency to be integrated into the determination of an optimum schedule. They are fast, efficient, and provide the accuracy needed for an optimum irrigation schedule if the input evapotranspiration, soil, and crop data are accurate.

PRECISION IRRIGATION SCHEDULING TO MAXIMIZE POTATO YIELDS

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In three different trials during 1982, irrigating with just 15% more water increased US #1 potato yields by an average of 28 sacks per acre. At $10 per sack this is $280 per acre more gross income.

Potato irrigation scheduling is very difficult for a number of reasons. Normal potato evapotranspiration (ET) varies greatly depending on planting date. Normal potato ET's for a January, February and March first planting date are 12.5, 16.7, and 18.6 inches, respectively. Since the normal values are 25 year averages, they hide how much potato ET varies from year to year. The ET of a particular planting date may be 50% less than average ET one year and 50% more than average ET the next year. There is also tremendous variability in potato ET during any one year. In the spring we can have hot sunny days for a few days and then cold rainy days. Variable weather conditions cause great fluctuations in daily ET.

In addition to variable crop ET, two other factors make potato irrigation scheduling difficult. The amount and timing of rainfall varies greatly from year to year and soil moisture is very hard to judge by feel or sight in sandy potato soils.

Trial Results

Three different potato irrigation trials were conducted on three different farms in 1982. Some plots received the same amount of water as the rest of the field, others received 15 percent less water, and still others received 15 percent more water. On the average, 15 percent more water yielded 28 more sacks of US #1 potatoes per acre.

A 15 percent increase is only an increase of 25 minutes on a three hour set and an increase of 35 minutes on a four hour set. Three and four hour irrigations are very common lengths for potato irrigation sets. It's very hard to determine if a half-hour more is needed for a particular set.

The individual trial results for each of the three farms are given in Tables 1, 2, and 3. Means not followed by the same letter are significantly different at the 95 percent confidence level. The variety of potatoes in the fields on farms A and B were White Rose and the variety in the field at farm C was Centennial.

Why did yields increase with more applied water? The wetter treatments kept soil moisture at a higher, more optimum level. This high moisture was probably needed for the whole season, but it is possible the wetter treatments had their effect only during some particularly sensitive stage. It isn't known if potato yields would have increased even further with more applied water.

Two fairly new tools are available. The necessary background information to use them in potato irrigation scheduling is being developed by the California Irrigation Management Information System (CIMIS.) These tools are a modified Penman ET estimate and neutron probe soil moisture measurements. Potato crop coefficients used in a Penman ET estimate are being refined to get accurate daily potato ET estimates from a modified Penman equation. Both ET estimates and neutron probe soil moisture measurements can be used to better schedule potato irrigations. The mechanics of their use in potatoes are subjects for another article.

The results of this trial have confirmed, under field conditions in Kern County, the sensitivity of spring potato yields to slightly more or less water. Grower experience and other experiments over the years in different areas of the country, have also shown the extreme sensitivity of potato yields to varying irrigation schedules.

Computer Scheduling

A computer program has been written to schedule irrigation of potatoes using current ET data and some basic inputs related to a grower's irrigation system and soils. Basic inputs into the program are:

1. Initial soil moisture on a given date and date of first irrigation.
2. Optimum average soil moisture to be maintained.
3. Irrigation application efficiency, or the fraction of applied water that is stored in the soil where it can be used by the crop.
4. Rate of water output per sprinkler head.
5. The distance between laterals and the distance between sprinkler heads on the lateral.

ET is input into the computer program after obtaining it from the news media or an information service. Reference evapotranspiration (ETO) will be the standard method of reporting water use starting in January 1983. To obtain the water use of potatoes, a crop coefficient, which depends on stage of crop development, is multiplied by ETO to get ET.

After the basic data is input initially, a simple process of entering the previous day's ETO, any rainfall, and date of last irrigation will provide a grower with an estimate of ET and sprinkler operation time required to replace water depleted since the last irrigation and for several days in the future. The developed computer program provides a means to greatly simplify and improve a potato grower's irrigation management and to maximize production per unit of water and energy used.

Unquestionably, some years in some fields growers maintain an optimum soil moisture for maximum yields relying solely on their experience and judgment. However, growers should be able to obtain an optimum irrigation schedule more consistently by using some objective measurements of ET and soil moisture. It is very clear that a little additional effort at potato irrigation scheduling will put more money in hand considering the yield responses seen in Table 1, 2, and 3.

Table 1.
1982 WHITE ROSE POTATO IRRIGATION YIELD TRIAL
FARM A (cwt./acre)

Applied Water (inches)	US #1's	Small	Culls	Total
9.7	391 A*	34 A	11 A	436 A
11.3	403 A	34 A	10 A	447 A
13.0	454 B	24 B	24 B	502 B

Table 2.
1982 WHITE ROSE POTATO IRRIGATION YIELD TRIAL
FARM B (cwt./acre)

Applied Water (inches)	US #1's	Small	Culls	Total
7.4	386 A*	21 A	11 A	418 A
8.8	433 B	26 A	7 AB	471 B
10.1	439 B	23 A	15 B	471 B

Table 3.
1982 CENTENNIAL POTATO IRRIGATION YIELD TRIAL
FARM C (cwt./acre)

Applied Water (inches)	US #1's	Small	Culls	Total
10.6	293 A*	46 C	1 A	342 A
12.3	320 A	39 B	4 B	360 A
14.4	327 A	29 A	2 A	359 A
16.8	371 B	33 AB	1 A	405 B

* Yields which are not followed by the same letter are significantly different by Duncan's multiple range test at the 95% confidence level.

IRRIGATION SCHEDULING USING INFRARED THERMOMETERS

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Irrigation scheduling is an important farming decision in the semi-arid, arid Western United States. Irrigation scheduling in the more humid Great Plains and Eastern United States requires even more critical evaluation due to the erratic nature of rainfall. Irrigation scheduling has two primary components: timing and amount. Generally, the timing component has been demonstrated to be more directly related to crop stress and yield while the amount component has been related to the irrigation system and the soil physical properties. Of course, there is a strong interaction between the two components. Also many other cultural and managerial decisions alter the "optimum" irrigation scheduling decisions based on crop performance, water use, salinity, climate and stage of growth. This paper provides a brief summary of research on the use of infrared thermometers to detect plant stress of cotton in the San Joaquin Valley. The use of plant stress measurements can be illustrated to be applicable to decision-making for irrigation scheduling.

Infrared Thermometry

Infrared thermometry is a non-contact procedure for determining the surface temperature of an object. This temperature measuring procedure does not interfere with the surface and yields an integrated value over the field of view of the instrument. According to the Stephen-Boltzman black-body radiation law, the surface temperature is related to the emitted radiation of a body as follows:

$$T_s = \left[\frac{R}{\varepsilon\ \sigma}\right]^{1/4}$$

where T_s is the surface temperature in °K (°C + 273.16), R is emitted radiation in W/m^2, ε is emissivity (ratio of emitted radiation to that from a "perfect" emitter), and σ is a constant (5.674×10^{-8} W/m^2 per K^4). Most infrared thermometers (IRT) use "filters" to limit the energy measurement to the 8-14 μm waveband. This measurement "window" is used because (1) the emissivity (ε) of most natural surfaces is near 1.0 within this waveband and (2) radiation absorption by water vapor is relatively low in this waveband. However, part of the radiation detected by an IRT may be radiation reflected or emitted by surrounding surfaces. Normally, if the emissivity is greater than 0.98 (which is the case for most soils and crops) this error causes an IRT underestimate of T_s less than 1 °C.

The IRT can be reliably used (with due caution for calibration, particularly sensitivity to ambient temperature effects) to measure the surface temperature of crops. Of course, the measurement must be made in a manner to minimize extraneous radiation sources, particularly soil temperature interactions for incomplete crop cover. IRT measurements averaged over several view angles with about a 30 degree angle from the horizontal have been found the most practical to minimize soil thermal effects for cotton.

Canopy Temperature and Crop Water Stress

Extensive research on the use of canopy temperature to infer crop water status has been summarized by Jackson (1982). In addition, Hatfield and Howell (1983) (in this proceedings) and Idso, et al. (1982) have summarized many of the stress relationships between cotton water stress and canopy temperature. Three methods have been found useful in quantifying crop water stress using canopy temperature measurements. The methods are:

1. Crop Water Stress Index
2. Canopy Temperature Variation
3. Comparison to "Control"

The crop water stress index method has theoretical and empirical validity (Jackson, et al., 1981; and Idso, et al., 1981; respectively). The crop water stress index is sensitive to both soil water deficit (matric) stress and salinity (osmotic) stress (Howell, et al., 1982). The crop water stress index (CWSI) method requires the simultaneous measurement of vapor pressure deficit (VPD) and the difference in canopy and air temperature. The VPD is a good normalizing variable for both diurnal and seasonal evaporative demand. Grimes (personal communication) has found that the VPD also normalizes day-to-day variations in crop water stress measurements with the pressure bomb. The CWSI concept as illustrated in Figure 1 uses an "unstressed" lower baseline and a "complete stress" upper baseline. Both lines can be determined from either theoretical calculations or experimental measurements. The CWSI is simply the ratio of the increase in canopy-air temperature (T_c-T_a) at a specific VPD to the difference in T_c-T_a for the "unstressed" and "complete stress" cases. The CWSI has a value of "0" for no stress and "1" for total stress. Since the VPD calculation can be time consuming, a nomograph has been developed to quickly convert dry-bulb and wet-bulb measurements from a psychometer to VPD in units of kPa (Figure 2). Nomographs like Figures 1 and 2 (or programs on portable, pocket calculators) can estimate the CWSI in the field quickly following the data collection.

The canopy temperature variation method proposed by Aston and Van Bavel (1972) uses the "nonhomogeneous" nature of most soils. At both wet and dry soil conditions the canopy temperature variations should be small; however, as the soil dries from the wet state, the canopy temperature variation may show an increase due to the nonhomogeneous nature of the soil properties (Figure 3). Clawson and Blad (1982) used this method to schedule corn irrigations in Nebraska based on a 0.7 to 1.0 °C variation in the crop surface temperature.

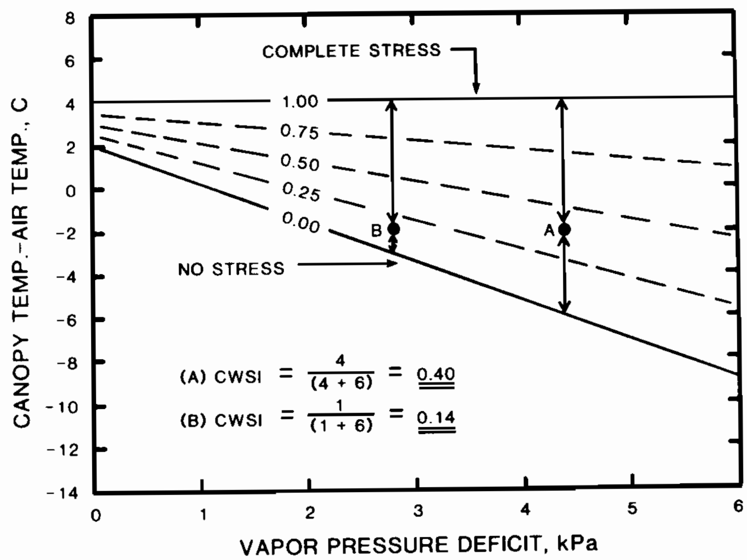

Figure 1. Example cotton crop water stress index relationship.

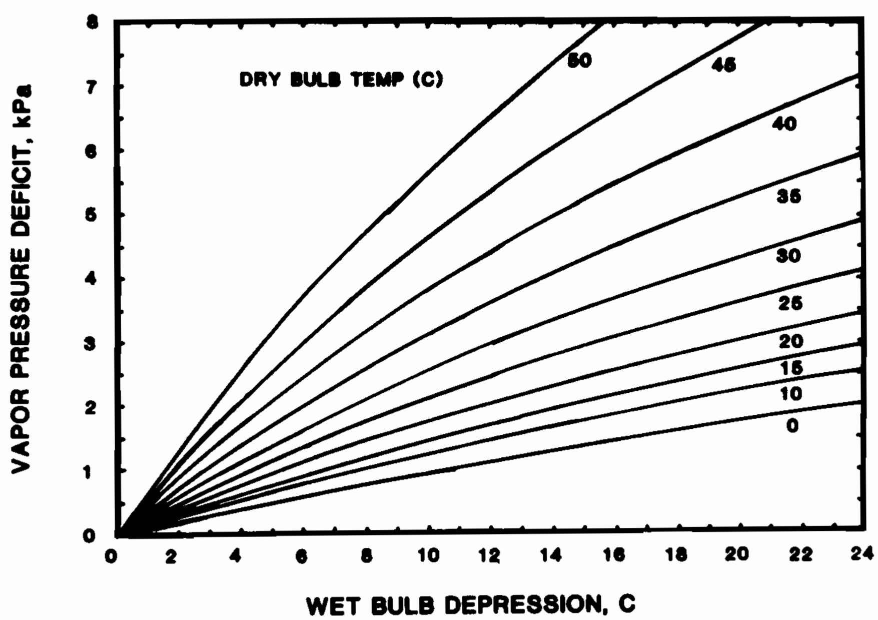

Figure 2. Nomograph for estimating vapor pressure deficit from dry- and wet-bulb temperature measurements.

This method appears more applicable to sprinkler and drip irrigation methods than surface irrigation because the irrigation nonuniformity is more random and less systematic.

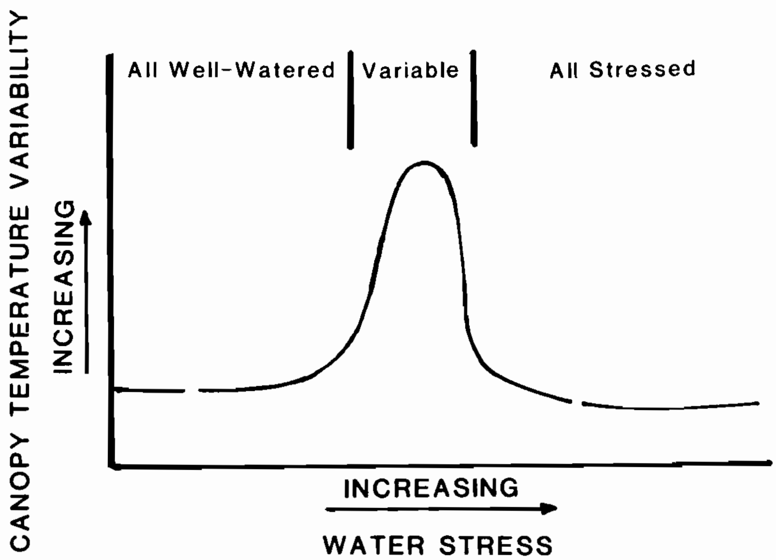

Figure 3. Schematic illustration of canopy temperature variability and soil moisture relationship.

The "control" comparison uses a simultaneous measurement of an "unknown" field and an "unstressed" field. The approach is similar to using the CWSI "unstressed" baseline. Irrigations may be initiated at a temperature difference of 2 to 3 °C. As the CWSI demonstrated, this difference would be less on more humid days and larger on drier days. The control field might be a field previously irrigated or even a neighbor's field.

The IRT has been clearly demonstrated to be sensitive to crop water stress. The IRT should detect stresses resulting from poor water penetration, salinity, poor irrigation distribution, soil water deficits and stress resulting from diseases and insects. Unfortunately (and in some cases fortunately), the IRT cannot distinguish between the source of the stress.

Irrigation Scheduling with Infrared Thermometers

As indicated in the introduction, infrared thermometers can help characterize the irrigation decision. However, other information about the irrigation system and soil water depletion would be necessary to complete the irrigation scheduling decision. The previous discussion has pointed out our biases favoring the CWSI method. The remaining discussion will illustrate methods to use the CWSI to "time" irrigations.

Daily afternoon observations of the CWSI can be used to follow the stress trend of a particular field. Due to the "uncertainty" in our current level of understanding of the dynamics of the CWSI and to "imperfect" data, a three-day running-average has been found to "filter" the data with enough precision to reliably determine the need to irrigate cotton on heavy clay loam soils. However, the baseline estimations are best characterized by intensive data measurement over a few days (diurnal measurements from 0900 to 1700 hours PST so that a large VPD range can be measured) when the crop is not under stress. The lower baseline for some crops (corn after tasseling, sorghum, wheat and barley after heading) may change due to crop phenology Hatfield, et al. (1982). The seasonal trend in the CWSI for a particular cotton irrigation treatment at the UC-West Side Field Station (Figure 4) illustrates that the daily CWSI follows the stress trends between irrigations. In addition the CWSI when averaged over the season is negatively correlated to lint yield of cotton as shown in Figure 5 for both 1.0 m and 0.5 m spaced rows.

An appropriate timing guide using the CWSI would be to irrigate cotton when the CWSI approaches 0.3. At this stress level, the cotton yield should approach good commercial yields (1400 to 1600 kg/ha). Irrigation scheduling at about this point has produced cotton yields near to 1600 kg/ha (3 bales/ac) at the UC-West Side Field Station and at Westlake Farms (Reginato, 1982). The

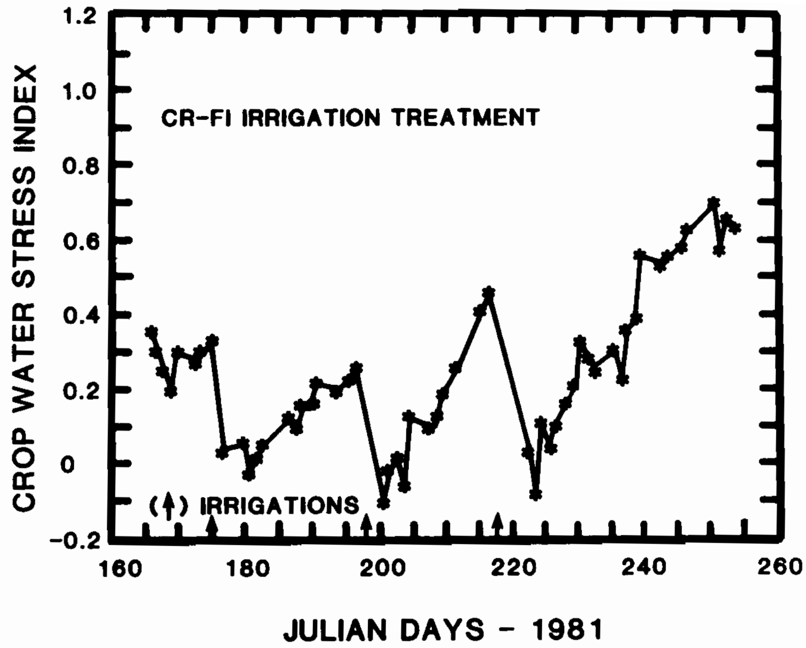

Figure 4. Seasonal trend of crop water stress index for an irrigation treatment at UC-West Side Field Station during 1981.

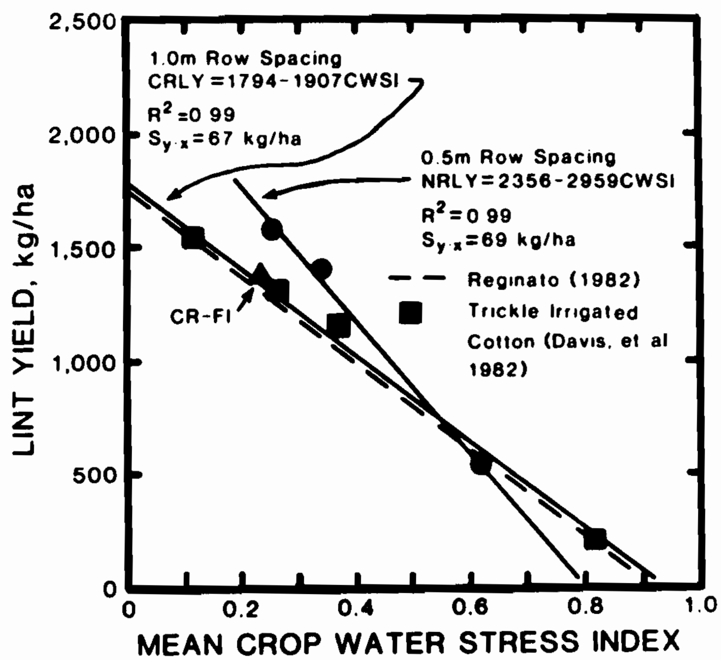

Figure 5. Relationship between lint yield for narrow row and conventional row cotton to mean crop water stress index at UC-West Side Field Station.

irrigation regimes required to produce these yields were three postplant irrigations of 374 mm total and a 274 mm preplant on the Panoche clay loam soil at the UC-WSFS and five postplant irrigations of 610 mm total and a 200 mm preplant on the Lethent clay at Westlake Farms, respectively.

Irrigation scheduling for many systems, particularly trickle and sprinkler systems, which are rate or frequency controlled can use infrared thermometers to detect the "adequacy" of irrigation. The fields can be monitored to inspect the degree of crop water stress. Since for many of these systems the irrigation schedule is practically "fixed", minor adjustments in either the irrigation amount or irrigation frequency can control the desired crop stress level. In addition, infrared thermometers can detect crop stress resulting from poor water distribution (in fact this check alone may be as cost effective as irrigation scheduling). Plugged emitters, stuck sprinklers, and poor infiltration all result in crop water stress symptoms which show poor irrigation distribution. In many cases the infrared thermometer can detect the poor irrigation distribution before visible symptoms are present.

Our conclusions are that the use of the IRT and the crop water stress index may not increase the precision of crop water stress detection (we feel that it probably does); however, it does allow stress measurements over a much larger area and in a time period which is practical. To some extent the measurements can be made anytime from 1000 to 1700 hours (PST) if the associated VPD measurements are made. A large field (100 ha or 40 ac) can be surveyed in about 20 minutes (the time to take about 10 individual plant water potential readings, to take about 2 neutron tube readings or to take about 5 soil probings). Many other irrigation scheduling methods also perform satisfactorily when the practitioner is knowledgeable and experienced. We feel that the IRT is <u>one</u> of several instruments and/or methods (not <u>the</u> one) which should be used to detect and diagnose crop water stress. Clearly, the infrared thermometer has opened new horizons of irrigation scheduling applications.

ACKNOWLEDGEMENTS

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EVAPOTRANSPIRATION AND YIELD OF PROCESSING TOMATOES UNDER FURROW AND DRIP IRRIGATION

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INTRODUCTION

The need for more precise evaluation of evaporation losses under different methods of irrigation comes from the increased interest in possible savings in overall water requirements in agriculture. With the increasing awareness that improvement of farm irrigation application efficiency may seldom lead to overall basin or district water savings, the one loss (evaporation) which for the most part, does not enhance growth of plants, has become a subject of considerable interest and controversy. Proposals for conversion of much of California's surface irrigated farmland to drip irrigation, have received serious attention. Thus, there is a vital need for developing reliable information on the magnitude of possible savings and/or the increase of production per unit of evapotranspiration (ET).

Water loss from a cropped area to the atmosphere is the result of evaporation from the soil (E) and transpiration (T) from plant surfaces. The combination of both processes, called evapotranspiration (ET), is equivalent to the crop water requirements.

When annual row crop plants are in an early growth stage and have little ground cover from the canopy, the evapotranspiration rate from the field is dominated by the soil evaporation rate. As the crop canopy increases, the evapotranspiration rate becomes more dependent on the leaf area.

Many studies have been conducted to predict the ET requirement of various crops, and models of calculating E and T separately have been studied for conventional irrigation methods which essentially wet the entire soil surface. However, because of the smaller area of wet soil surface under drip irrigation and strong thermal gradient between dry and wet zones with microscale advection from the former to the later area, the above measurements and models are not applicable to drip-irrigated crops.

Although many comparative studies of drip against other methods of irrigation have been conducted, very few involved an accurate determination of actual ET loss for short periods (i.e., hourly) or the detailed micro-climate measurements needed for separation of the E and T components of ET.

A major objective of this study was to investigate possible savings in evapotranspiration by drip-irrigated as compared to furrow-irrigated row crops and to develop the models for predicting expected evaporation losses, hopefully extrapolating to plant and row spacings not represented by the present study.

INSTRUMENTATION AND PROCEDURES

Field data were collected in the 1979 and 1980 growing seasons comparing drip and furrow-irrigation of canning tomatoes planted at a 152-cm row spacing with approximately one plant every 22.8 cm. The study involved three treatments replicated four times (10-day frequency of furrow-irrigation and two drip-irrigated treatments, one with a plastic mulch and the other without). In 1980 very detailed micrometeorological data were collected within and above the soil of two 6.1-meter diameter lysimeters, one drip irrigated daily most of the season and the other furrow irrigated at approximate 10-day intervals. Involved were some 80 soil and air temperature sensors and 12 net radiometers with data collected at 3-minute intervals during many of the summer days. Wind speed was recorded continuously for many days at both under-canopy and between-row locations at a 1-cm height above the soil surface.

RESULTS

Except for the first four to five days following furrow irrigations, very high soil surface temperatures (around 60°C) were noted in mid-row positions for both methods of irrigation. With the application of water to the broad-base flat-bottom furrows, three nearly instantaneous to longer-lasting effects were noted: 1) soil surface temperatures (-½ cm) dropped some 20-30°C; 2) net radiation (over exposed soil surfaces) increased some 0.2 to 0.3 cal cm^{-2} min^{-1}; and 3) very dramatic increases in evapotranspiration resulted, although with increasing plant cover the effect became moderated. In spite of much higher ET losses under furrow irrigation than under drip irrigation for the first two to three days following each furrow irrigation, this advantage for the drip method was cancelled out by a reversal in trend thereafter, apparently due to a continuously rather high daily loss by evaporation from the narrow (20-30 cm) wet strip under the tomato rows. During stages of plant cover of<50%, it is subject to high levels of sensible heat transfer from hot, mid-row zones of soil and air.

Yield and Water Use Efficiency

Table 1 gives yield, ET and water use efficiency data for the 1979 and 1980 seasons. Marketable yield of fruit from the drip lysimeter was 9% and 16% higher than from the furrow lysimeter from 1979 and 1980, respectively. For the field plots the drip out yielded the furrow by 19% and 13% for 1979 and 1980, respectively. Interestingly both lysimeters had somewhat higher yields in 1980 than in 1979 while the reverse was true for the field plots where 1979 yields were some 145 to 155 percent greater than in 1980. The percent ground cover of field plots in 1979 exceeded considerably that achieved in the lysimeters, with furrow plots reaching 75% cover, and both sets of drip plots approaching 90% cover. In 1980, however, the percent cover of field plots was similar to that in the lysimeters with values of 45%, 46% and 55% for furrow, drip and drip with plastic, respectively. The 1980 season with a much cooler than normal May and early June was not a good season for tomatoes in the Sacramento Valley. In relation to this study, however, it did provide a chance for extensive micromet work under limited amounts of plant cover, a condition under which evaporation savings with drip irrigation is most likely.

The water use efficiency data in Table 1 do show some advantage for drip irrigation treatments where, for example, in the field plots (replicated four times) WUE for drip plots was 20% and 9% higher than for furrow plots in 1979 and 1980, respectively. The larger difference in 1979 may have been the result of a breakage in the furrow delivery system which delayed the first furrow irrigation of field plots until July 23, whereas the drip plots were irrigated on July 12, 13, 14, 16 and 17, with a delay then until July 23. (All plots in 1979 were sprinkler irrigated until early in July.)

ACKNOWLEDGMENTS

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Table 1. Total ET in cm from planting to harvest and yield of processing tomatoes under furrow and drip irrigation. Davis, California, 1979 and 1980.

Irrigation method	ET cm	Yield Ton/ha Ripe	Green	Rotten	Total	WUE $Tha^{-1}cm^{-1}$ (ripe fruit)
			1979			
Furrow-irrigated lysimeter	61.5	75.1	2.3	2.2	79.6	1.22
Furrow field plots	65.9	86.0	7.2	0.7	93.9	1.31
Drip-irrigated lysimeter	60.8	82.1	1.9	4.5	88.5	1.35
Drip field plots	64.9	102.4	2.7	1.8	106.9	1.58
Drip & plastic plots	60.9	98.8	5.8	1.1	105.7	1.62
			1980			
Furrow-irrigated[1/] lysimeter	55.9	77.2	3.5	0.0	80.7	1.38
Furrow field plots[2/]	59.6	58.6	2.1	-	60.7	0.98
Drip-irrigated[3/] lysimeter	56.6	89.4	5.5	4.5	94.9	1.58
Drip field plots[2/]	61.6	66.2	1.0	-	67.2	1.07
Drip & plastic plots[2/]	61.2	83.8	1.5	-	85.8	1.37

1/ Furrow lysimeter plants were cut at ground level on September 6 and left on lysimeter for a special test to determine a wind functional relationship. Fresh weight of fruit as measured on September 17 was corrected back to September 6 based on changes in percent moisture of a subsample of two vines with their fruit allowed to dry in the field.

2/ Harvest date of September 10.

3/ As harvested on September 17 seven days after field plots were harvested. Since at this stage of maturity tomato fruits tend to show little if any further assimilation the affect on yield due to the different harvest dates can be ignored.

UNIFORMITY CONSIDERATIONS UNDER SURGE IRRIGATION

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The overdraft of groundwater in California can be circumvented by development of more water supply or greater conservation. New technology in surface irrigation methodology has the potential for conserving water and energy at the on-farm level. Surge flow is an example of a new concept in surface irrigation.

Surge irrigation is the practice of applying intermittent pulses of water to a field surface. Water from each surge or pulse is distributed across the soil surface by gravity. Independently applied volumes sum to replace the moisture depleted by evapotranspiration.

Initial studies (Bishop et al., 1981; Coolidge et al., 1981; Podmore et al., 1982) show that advance over the field is modified by surge irrigation. In some cases less than half the volume of water was needed to move the advancing front across the field when a stream of the same flow rate was pulsed rather than continuously applied to the furrows. Change in advance was linked to the reduction in infiltration rate under intermittent wetting (Walker et al., 1982). Although the exact mechanism is not known at this time, preliminary field tests would support consolidated and surface sealing as important factors in reducing intake rate.

The purpose of this paper is to describe the distribution of applied water under surge and continuous flow surface irrigation within and between furrows.

Method and Field Trials

Water application depth with distance was estimated for two blocks of 28 consecutive furrows during the summer of 1982. The adjacent blocks were planted to milo to remove water from the soil before installing the furrows spaced every 76.2 cm. Advance and recession trajectories were measured for each continuous flow furrow included in block one and similarly in block two the time-distance trajectories were measured for the four surges introduced in each furrow. Observation stations were spaced 20 m apart. Instantaneous flow rate of 1 lps was maintained eight hours in the continuous flow furrows while in the surged furrows water was cycled 60 min on, then 60 min off such that the total volume applied to the surged furrows was approximately one-half the continuous flow furrows.

Continuous and surge infiltration was measured in an adjacent block with a flowing furrow infiltrometer as described by Walker et al. (1982). Rates were measured for a one-meter furrow section where the flow was maintained at 0.5 lps. One-half the test furrow inflow rate (0.5 lps) was selected as a representative flow condition. Curves of volume infiltrated with time were fitted using least squares regression.

Distribution uniformity (DU) was estimated as the average infiltration volume per meter of the low quarter length divided by the average over the entire length (Merriam and Keller, 1978). Volume of water infiltrated per meter along the furrow was calculated from opportunity time determined via the advance-recession curves. Total advance distance and uniformity within and between each of the two blocks of 28 furrows were compared using statistical analysis.

Results and Discussion

Advance distance and DU for surge and continuous flow furrows was not significantly different at the 5% level of confidence as shown in Table 1. Similar coefficients of variation for surge and continuous advance and DU are in conflict with the observations of Coolidge et al. (1982) who found less variability between advance times for surged furrows. Infiltration and furrow hydraulic differences are possible sources of error which would explain the results obtained by the researchers.

Table 1. Statistical comparison of surge and continuous irrigation.

Statistic	Advance		Distribution uniformity	
	continuous	surge	continuous	surge
Mean* (meters)	264.3a	258.1a	60.4b	60.8b
Coefficient var.	9.4	6.8	10.5	10.9

* Values followed by same letter are not significantly different at the 5% level.

DU and advance distance were not spatially dependent on furrow location according to semivariance analysis. This finding in conjunction with the assumption of a normal distribution of error provide the foundation for further use of traditional statistics. Water infiltrated along the furrow is presented in Fig. 1 for a continuous flow furrow and four surges of a surged furrow. Though the distributions are similar for continuous and surge furrows, the depth or volume of water applied under surging is much less than with continuous flow especially at the upstream end of the furrow. Calculated volumes, represented by areas enscribed by the curves, were less than the actual volumes applied but this should not preclude comparison. Low test flow rate (0.5 lps) is most likely the cause of underprediction in both cases.

Conclusions

Distribution uniformity was the same for surge and continuous flow furrows and the variability between furrows was independent of furrow location within the blocks tested. Though uniformity is the same for both application strategies, surging enables the irrigator to apply a smaller depth of water per irrigation.

Implications for energy and water conservation at the on-farm level are of importance if the surge effect is general. This is especially true of those annual crops where the targeted application depth is small early in the season. Efficiency is often low in those cases where surface irrigation is used to moisten the seed bed for germination. Greater flexibility is built into the irrigation schedule because a wider range of application depths can be uniformly and thus efficiently applied. The increase in efficiency translates into reduced water and pumping costs.

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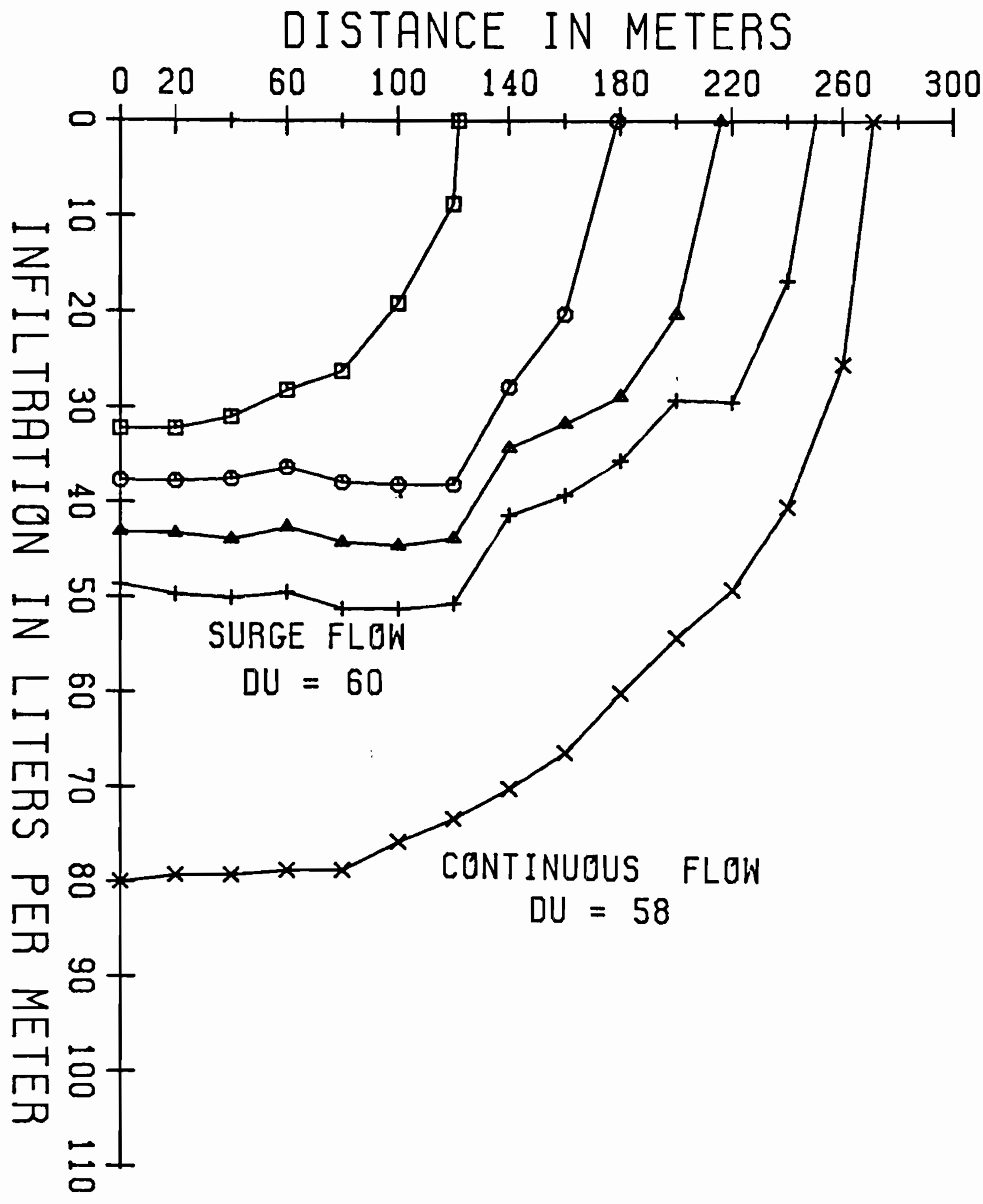

Figure 1. Water distribution profile for surge and continuous flow furrows.

CALIFORNIA IRRIGATION MANAGEMENT INFORMATION SYSTEM

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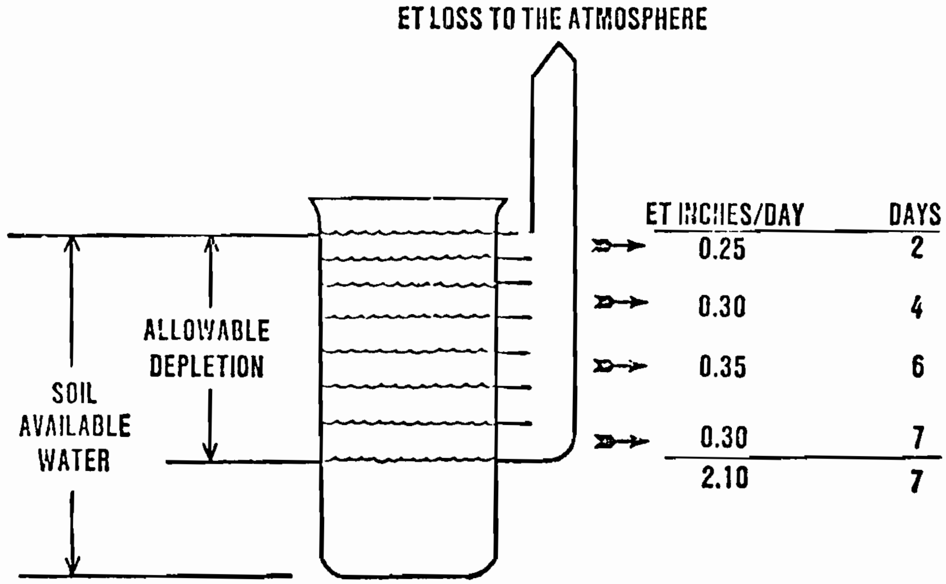
For years the effective application of water was an art rather than a science, even though it had been reasoned that irrigations could be effective if the amount of water applied during each irrigation was commensurate with that taken from the soil profile since the last irrigation. As illustrated, the irrigations were equivalent to the allowable depletion that was lost through evapotransporation.

WATER BUDGET METHOD OF IRRIGATION



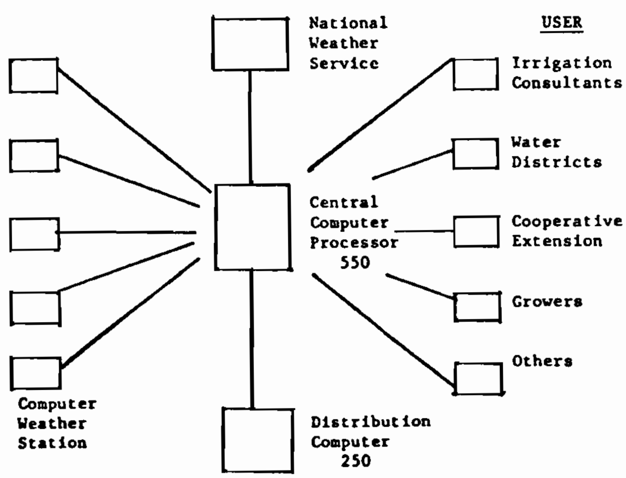
Simple and straight-forward in reasoning, the water budget method of irrigation nevertheless remained elusive in its application.

That is until now when high technology wedded computer know-how with climatological data and the California Irrigation Management Information System (CIMIS) was born.

Over the years, continuous study has established the evapotranspiration (ET) of many of the major crops grown in California. In addition, much has been learned of the water retention properties of major soils. It was inevitable that in time this scheduled irrigation approach would be assisted by advancements in engineering technologies to evolve into an effective water managment program. Added impact came to bear with mounting fuel costs, urban encroachment, increasing public demands for water conservation and with legislatures and growers increasingly being concerned over maintaining California's high level of agricultural output. Further impetus came with the knowledge that shortly in 1984-85, California would lose approximately 550,000 acre-feet of its Colorado River water supply. That followed by the defeat of the Peripheral Canal proposal made the need to effectively and efficiently use water a real actuality. It all culminated in the establishment of the California Irrigation Management Information System (CIMIS).

CIMIS is a three year research feasibility study proposed to develop a statewide irrigation information system. It will continually use updated weather data along with crop and field data to improve irrigation scheduling based on actual crop water requirements. Funded by the Energy and Resource Fund, it also is being researched and developed for the Department of Water Resources by the University of California Cooperative Extension and Agricultural Experiment station. Using real time weather data, CIMIS is a basis for large scale scheduling of irrigations. It gives both the time as well as the amount of water to be applied to answer a water user's three most pressing questions: (1) when to irrigate, (2) how much water to deplete from the soil, and (3) how to effectively replace that amount that has been depleted.

The project encompasses a network of forty automated weather stations. These will be erected throughout the state in five prime agricultural regions: Imperial-Coachella, Kern County, western Fresno and King counties, Salinas and Pajaro Valleys, and Sacramento Valley. Each of the CIMIS weather stations is equipped with nine weather-related sensors: wind direction and speed, solar and net radiation, air and soil temperature, humidity, dew and rain. Each sensor is connected to the station's "mini-computer," a micrologger developed by Campbell-Scientific, Inc., the engineering firm for the weather stations. The nine sensoring devices are collectively the very pulse of each station. They constantly take measurements throughout each hour of each day. The data obtained is stored by the micrologger and then conveyed to a central receiving station through a phone modem. Consequently, each station location must have access to a phone line. The accumulated data can also be easily retrieved manually by depressing the proper sequence of numbers on the computer's keyboard along with the weather station's identification number. Current readouts are then attainable as well as the data previously accumulated and stored. The readings are visibly displayed in digital metric measurements. The system, therefore, consists basically of: (1) its nine sensoring devices, (2) a battery powered micro processor that samples all weather factors constantly throughout each hour, averages automatically, stores the data continually and releases it automatically as well as on demand, and (3) a phone modem to retrieve the data and convey it to a control computer. Cooperating with the program are localized national weather stations that will incorporate their forecasts to make and achieve even greater accuracy of the data accumulated. The entire project is schematically shown as follows:



As illustrated, the project will establish a state network of climatic data acquisition plus a computer processing service. In doing so, it will establish a level of technology currently too expensive for the average manager only. It will also provide a ultimate level of reliability and specificity not available from a large single unit and do so with greater assurance against failure while providing a strong statewide research and extension education program. While CIMIS was primarily intended to completely automate agricultural irrigation systems to eliminate over-irrigation, the system and data it develops can do the same for turf and landscape irrigation schedules. The capabilities of the already sophisticated landscape control systems, now being produced, can then be fully maximized. Also achieved would be the ultimate in the water conservation potential of each system through effective scheduling. In keeping with the CIMIS goal of effective use of water, its other goals include: yield improvement, energy conservation, labor conservation, improved fertilization and salinity management would also be achieved.

As for the final outlook for CIMIS, the entire program will be evaluated at the end of the three-year period. Recommendations will then be made of its feasibility, its possible continuance, and need for modification and/or expansion. The final determination of its future, however, will ultimately rest on a cost-benefit analysis and the acceptance or rejection by its users.

TURFGRASS WATER CONSERVATION

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Importance of Turf in California

Turf has a direct effect on the way most Californians live. Many recreational facilities depend on a uniform, vigorous, well-maintained turf sward as the medium of play. Common examples include golf courses, bowling greens, picnic areas and parks, soccer, lacrosse, polo, baseball, and football fields, and school grounds. Turf also affects people's lives when used in ornamental settings to create a desired aesthetic appearance.

Turfs and other plant material reduce discomforting glare, especially in urban areas with buildings, metals, and concrete. Likewise, turf, along with properly placed trees and shrubs, can reduce traffic noise considerably. Soil erosion is reduced or controlled by turf, and chemical and particulate air pollution is decreased at the turfgrass surface. Because of transpirational cooling, turf modifies high temperatures by heat dissipation.

Turf influences the state's economy, however the costs associated with California turf maintenance are not well documented. Many facilities are an obvious source of economic activity, such as golf courses, parks, cemeteries, highways, airports, industrial and municipal lawns, and home lawns. A second category of economic involvement is manufacturing--production of equipment, fertilizer, chemicals, seed, sod, and other supplies used by the facilities. A service category includes individuals, groups, or firms such as distributors, architects, contractors, and consultants who provide services for the facility and manufacturing categories. Last, an institutional category involves those who conduct research on industry problems, such as University of California or USDA personnel, and educational programs directly serving the industry, such as colleges and universities, including Cooperative Extension.

In summary, as population, discretionary time, and discretionary income have increased, so too has the importance of turfgrass to the urban Californian. This increased importance can be measured or described in many ways, including the value to our life style, environment, and economy.

Project Objectives

The research is directed toward water conservation, increased water use efficiency, and water use management during drought periods for the commonly used California turfgrass species including the cool season species Kentucky bluegrass, perennial ryegrass and tall fescue, and the warm season grasses seashore Paspalum, hybrid bermudagrass and zoysiagrass.

Minimum water requirements of turfgrass species are being determined and new turfgrass irrigation technology developed. This is the basis for selection of water efficient turfgrass species, for the development of irrigation strategies for water conservation and for turfgrass survival during drought when irrigation water is severely limited.

Specifically, the objectives are:

1) To investigate the effects of applying reduced amounts of irrigation water in terms of percent of calculated evapotranspiration (ET) on cool-season and warm-season turfgrasses. These results serve as a basis for establishing minimum water requirements for turf maintenance or turf survival rather than production of highest quality turf.
2) To evaluate a subterranean irrigation system as a potentially more efficient method of turf irrigation, as compared to standard sprinkler application.
3) To compare evaporation rates under turf conditions from real time weather data. The data are intended to provide a basis for arriving at calculated evapotranspiration rates for turf.

Grass Selection and Water Savings

Kentucky bluegrass, perennial ryegrass and tall fescue showed no significant difference between turf quality ratings at 100% and 80% ET under sprinkler irrigation. From these results it appears that a 20% water savings can be realized without significantly affecting turf quality. Cool season grasses maintained at 60% ET was shown to be very good the following season despite a longer recovery period and a lower quality rating following recovery.

Seashore Palpalum, hybrid bermuda and zoysia exhibited no significant difference between turf quality ratings at 100%, 80% and 60% ET under sprinkler irrigation. From these short-term results it appears that a 40% water savings can be realized without significantly affecting turf quality.

When comparing water use of cool and warm season grasses, figures point to a rough estimate of 50% water savings with warm season grasses. Lower transpiration rates, deeper root systems and specific climatic adaptation are the primary reasons for this major water savings.

Method of Irrigation

From first hand observation and turf quality ratings throughout the year, it appears that subterranean irrigation with the 'Water Saver'® product at the depth (8") and spacing (23") specified by the manufacturer is not feasible for cool season grasses under sandy loam soil conditions. Depth and spacing problems have resulted in poor upward water movement, poor lateral water movement, and excessive gravitational losses. Kentucky bluegrass and perennial ryegrass, both shallow rooted grasses, were totally devastated during the hot summer months. Tall fescue, a deeper rooted cool season grass, showed better response, but still produced a turf of marginal quality. Efficiency of water application was so poor with the subterranean system that turf quality ratings for the 60% ET sprinkler treatments were equal to or greater than turf quality ratings for the 100% ET subterranean treatments.

Warm season grasses exhibited a much more favorable response to subterranean irrigation due, most likely, to (a) deeper and more extensive rooting, (b) lower transpiration rates, (c) lower water requirements, and (d) specific climatic adaptation. Hybrid bermuda has the deepest root system of the three warm season grasses and exhibited the highest turf quality ratings. Zoysia has the shallowest root system and showed the lowest turf quality ratings with subterranean irrigation. As with the sprinkler method, there was no difference in response to different ET rates within grass type.

Despite the poor performance in this study of the 'Water Saver' subterranean irrigation system, the concepts behind sub-surface irrigation still show great potential. Practical advantages such as (a) limited evaporation losses, (b) direct root zone water application, (c) limited run-off problems and, (d) low vandalism potential are valuable considerations in a water management program. However, disadvantages such as (a) improper placement specifications, (b) clogged and missing injectors, (c) untested fertilizer injection systems, and (d) improper irrigation scheduling and application rates must be corrected in order for this material to make real contributions in water conservation programs.

The results at this time indicate at least a 50% water savings with warm season grasses is possible using real time weather data in comparison to cool season grasses.

This study, cofunded by the turfgrass industry and Metropolitan Water District, is projected to continue until 1984.

Turfgrass quality characteristics, actual water use quantification, and crop coefficients will be determined at the conclusion of this research.

COMPUTERIZED TURF IRRIGATION MANAGEMENT

Hugh G. McKay

For many years the United States and other countries have been warned of the imminent shortage of our natural resources and the need for more efficient and effective resource management: labor, water, power, equipment and materials.

In the 80's, we have just began to heed the warnings because of the high costs of turf, landscape and golf operations.

Everyone involved in grounds maintenance--- landscape designers, turf managers, irrigation consultants and contractors, equipment designers and manufacturers, seed and sod producers, fertilizer producers and countless others who make up this industry---must accept the fact that changes are needed. And the changes must embrace all aspects of the environmental spectrum---soil, water, climate and plant genetics.

Our industry must consider water shortage as the primary resource management problem of the 1980's.

Scientists have told us that the quality and quantity of our fresh-water resources are in jeopardy.

The usual response has been similar to the response to warnings of imminent energy crisis in the 1950's and 1960's. Despite convincing evidence of widespread acceptance, we continue to consume without regard to waste.

Turf managers are just now beginning to heed warnings of a water crisis: however, there is little evidence of widespread acceptance of a need to change the way we use water. Even in areas experiencing prolonged drought, users waste water once the drought is "over".

The water shortage is a result of a growing world population that comsumes and pollutes water at a rate that exceeds nature's ability to replenish or recycle it. The hydroloc cycle, which is powered by solar energy, is no longer adequate and there is no other natural phenomenon we can turn to.

Less than 1 percent of the world's water is fresh--in drinkable form---and it is that 1 percent that has been subjected to enormous increase in use by the green industry, individuals, agriculture and other industries. It is the same 1 percent that has been diminished by pollution and misuse, which, despite dramatic improvements in the United States and California in recent years, have not abated.

We are now facing a water crisis---as illustrated by the high cost and availability of water---that forces us to act "now".

Hugh G. McKay Associates
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What measures can we take?

The green industry has the ability to lead the way toward more efficient water use. It has the technology, experience and training to conserve water through proven techniques such as controlling water application to match plant needs, altering cultural practises, using drought resistant plants and using effluent and wastewater for irrigation.

Far too many intensively maintained, high quality turfs are now overwatered. Studies indicate that as much as 50% savings in water use can be achieved by simply applying the cultural practices now known. Overwatering not only wastes water, but also leads to disease, soil compaction, weed and nutrient leaching problems, drainage problems and excessive equipment usuage, repair and replacement.

To what extent overwatering requires additional manpower, equipment usuage, repair and replacement, not to mention turf damage repair or replacement has yet to be determined---perhaps future studies will indicate as much as 20 - 30 percent of operating budgets.

Recent studies by researchers at the Hebrew University of Jerusalem recently indicate that turfgrass selection may be the single most important factor in determining water consumption---cool-season grasses showed a 45 percent higher water consumption than the warm season grasses. If the criterion is water consuption in relation to availability and cost, then cool season grasses shouldn't be chosen for warm semi-arid zones.

Perhaps other water conserving measures related to turf maintenance practices will require reducing areas being irrigated which receive minimal use. On golf courses this may include narrowing the fairway width being irrigated, not irrigating primary rough zone betweeen tee and landing area and non-use areas. In parks, cemeteries and other areas irrigation can be reduced to prime viewing and activity areas.

How do we effect these measures?

Fortunately, we are in a transformational process from the industrial era to the communications era and the marriage of computers and the irrigation system controller, coupled with space-age technology has resulted in Computerized Turf Irrigation Control Systems.

By applying the technology, experience and training, we can now program our water requirements through Computerized Control Centers that control and communicate with multible field units to form a complete control system capable of handling hundreds of stations and valves, randomly accessible and programmable.

Even though computerized controllers have enormous capabilities, it is not necessary for the operator to be a computer programmer.

Irrigation scheduling is established by the operator and entered into the computer. To simplify programming, valves are numbered accordingly. Scheduled in groups, the operator merely types in valve numbers and orders the computer to apply from zero percent to two hundred percent of the standard amount allotted to the group. All programs can be updated daily by use of cassette tapes based on the time of year and evapotranspiration.

One of the great differences between computerized irrigation control systems and the conventional controller/field or satellite units is the function of the field units. In the electro-mechanical system, the valve wires are connected to the field unit that actually controls them; the central control basically serves to start the operation of each field unit at a pre-set time.

In the computerized systems, the field unit has active communication that links the stations to the computer itself. By means of field sensors such as moisture sensing, evapo-transpiration, rainfall, wind speed and direction, pressure and flow rates and temperature (for frost protection) the field unit monitors everything that takes place and sends this information back to the computer, which compares it with the information placed in the program by the operator. The computer then makes the operational decisions based on that information and stores a record of all events for monitoring or play-back by the operator so he can see exactly what has taken place.

Although all of these capabilities are presently available, they are not necessarily incorporated in "all" models. Specifications should be checked carefully if specific capabilities are required.

Events that happen in the field such as line breakage (sprinkler or communication) valve, field unit and/or station failure, pump problems can be recorded with the use of an optional printer and the permanent record of events printed on paper for ready reference to simplify maintenance and repair.

It is also possible to schedule a program for operation of a fertilizer injection system according to flow to meet plant needs and provide uniform plant growth.

The control system will automatically differentiate areas and on golf courses separate greens, tees, roughs and fairways, matching plant needs to be watered accordingly.

All of the above mentionaed capabilities and more are available now to include maintaining cumulative records by week, month or year as a management tool for comparison purposes and budgeting.

Computerized Turf Irrigation Systems used as a management tool can allow for more efficient and effective resource management. the focus however, is on management and more specifically, the turf manager.

Through these efforts, the turf manager can excercise cost controls that will provide a functional, adequate quality turf for the user at the most economical cost and investment.

The green industry has the ability to lead the way toward more efficient water use. It has the technology, experience and training to conserve water through proven techniques such as controlling water application to meet plant needs, altering cultural practises, using drought resistant plants, using effluent and other wastewater for irrigation.

Coupled with the use of Computerized Turf Irrigation Control Systems, our industry has a precious opportunity and an obligation to move responsibly and assertively to help find the solutions to what will be the most complex and perplexing problem of the next decade - the problem of water shortage.

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SCREENING ORNAMENTAL PLANT MATERIALS for WATER CONSERVATION

Submitted to 1983 California Plant and Soil Conference--Turf and Ornamentals Section

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The impending water crisis in Southern California has caused substantial interest in plants that will grow in dry landscapes.

Before one embarks on revamping the landscape with water conserving plants, one should evaluate the landscape project to learn what the problem really is. Perhaps the problem is not with the plant materials, but lies with other factors. Is your present irrigation system well designed? Does it operate efficiently? Are you scheduling your irrigations by evapotranspiration instead of by a clock? Can the plants in your landscape be hardened off to the use of less water? Last, but not least, does your landscape layout lend itself to efficient irrigation?

Many irrigation systems are not well designed nor properly maintained. In such cases, they are costly to operate even when there is plenty of low cost water. A thorough study of the irrigation system may reveal serious defects, and a correction of these may eliminate the need for low-water-use plants.

Scheduling irrigation by evapotranspiration--or the plant's need--is a good management tool because the irrigation will be replacing the water lost by the plant. An occasional extra irrigation may be required to leach salts out of the root zone.

Many of the plants now in use in landscapes are drought-hardy and are receiving more water than they need. By gradually lengthening the duration of time between irrigations, the plants can be hardened to use less water.

Landscape layout is a critical factor in water management. Narrow strips or small spaces do not lend themselves to efficient irrigation; sprinklers frequently apply more water to pathways and streets than on the landscaped areas.

A portion of my horticultural program is the screening of plant materials to learn their value as ornamental plants in a water conservation program. This study has been exciting and interesting because most of these plants are attractive and functional and would augment any landscape.

We need to change our conventional concept of landscaping when using low-water-use plants. The landscape can be elegant and satisfying without every inch of space covered with lush vegetation. Although green swards are an intricate part of our urban environment and should provide open space for passive and active recreation, there is no need for postage-stamp-sized turf areas interlaced with trees and shrubs. Water is becoming a more expensive and scarcer commodity and we cannot afford to use it on the landscape as we have in the past. Low-water-use plants will require less water while enhancing our environment as well as the customary landscape plants.

In conventional thinking, a dry landscape consists of cacti, aloes, agave and gravel; however, a dry landscape can also include trees, shrubs and ground covers that have attractive foliage and colorful flowers. One of my goals in this study is to promote plants with low water demands that will nullify an arid appearance.

These are the criteria I use in screening:

(1) Attractive foliage

First and foremost, the plant must have attractive foliage for most of the year. I rate this aspect above flower color because the plant is seen with its foliage 12 months a year, whereas the flowers are seen for a few weeks.

(2) Plants with some tolerance to poorly-drained soil

Much of our soil in urban areas of Southern California drains poorly. It would appear that land developers take delight in compacting and mutilating the soil structure so that even a good soil would be unsatisfactory. Plants must be able to tolerate wet conditions that exist during winter rains.

(3) Require little training or pruning

Some plants do not have a good natural form and require some training and pruning to make satisfactory landscape plants. This maintenance activity should not become a major task in the landscape because of cost and shortage of trained personnel to do this work.

(4) Low nutrient requirement

The cost of fertilizer and its application are more expensive and will continue to rise; therefore, selection of plants that have low nutrient requirements is an advantage. Plants are also observed for susceptibility to minor element deficiency: iron chlorosis, for example. . . .in high calcareous soils.

(5) Small- to medium-sized trees and shrubs

Space around dwellings and industrial structure sites is very limited. Large trees soon tower over homes and apartments and their invasive roots damage sidewalks and foundations.

(6) Pest free, or nearly so

A multitude of our landscape plants are susceptible to pests and an attempt shall be made to screen out plants that are prone to numerous pests. Pest control is expensive, and the public is suspicious of the use of pesticides.

(7) Climate zone is very important

San Diego County has several climates. This constituent is very important in screening plant materials for water conservation. Hopefully, I will be able to find some plants that will grow well in all climate zones; but most likely, few plants will qualify.

Most San Diego residents live in the maritime and coastal climates. Plants are selected for use in these climates rather than the mountain and desert areas. The maritime climate is characterized by summer fog and there is a narrow diurnal and seasonal temperature change.

The coastal climate is characterized by an increased fluctuation in both diurnal and seasonal temperatures with increased distance from the ocean. Summer fog decreases, or is absent. Winter frost occurs in valleys and can be severe, especially in the interior regions.

It would be desirable to have an experimental trial (randomized and replicated blocks) of plants to be examined; but, because of wide range of both temperatures and soil, it would not be possible to have one location that would satisfy all these demands.

I do have observation trials located in all climate zones of San Diego County, i.e. maritime, coastal plains and valleys, central uplands and desert. Even though these trials are rather new, I have learned plants thrive in one climate zone on a certain soil type, but will do rather poorly in another zone. This observation has been made with cultivars of Grevillea spp. and Melaleuca spp. Other plants will do fairly well in several locations.

In this study, I am evaluating over 150 species of plants that include trees, shrubs and ground covers. By the spring of 1983, I will have between 25-30 more plants in the programs. The vast majority of these plants never make good landscape plant material for the southern California urban dweller.

Cooperators are very important in Cooperative Extension programs; without them, I would not be able to have observation trials. My cooperators are: Cal Trans, San Diego Gas and Electric Company, San Diego County Parks and Recreation Department, Otay Municipal Water District, Costa Real Municipal Water District, San Diego Public Works, San Diego County Buildings and Grounds Department, San Diego Wild Animal Park, Quail Gardens and University of California's South Coast Field Station.

One difficult task will be the removal of a beautiful plant from the program because: it would not perform well with the kind of care the average homeowner will provide, or is highly susceptible to pests. These plants would please a horticulturalist--but, they will not survive the kind of care given by many homeowners.

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RESPONSES AND ADAPTATIONS OF PLANTS TO ENVIRONMENTAL STRESSES

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Environmental stresses to which plants are commonly subjected are either due to stressful soil or unfavorable atmospheric conditions. The most important soil constraints are related to water stress (drought, flooding) and various mineral stresses, both in terms of deficiencies and excesses. Salinity is a prominent mineral stress. The most common atmospheric constraint is temperature stress ranging all the way from freezing and chilling to heat. In addition to temperature extremes, air pollution can be harmful to plants and thus has to be included among the unfavorable atmospheric conditions. I am mostly interested in the responses and adaptations of plants to salinity, mineral deficiencies (particularly low phosphorus availability), and the gaseous air pollutants SO_2 and ozone. Of particular concern to me are plant responses to these environmental constraints that are related to processes at the level of cell membranes.

Are environmental stresses limiting crop production? Boyer (1982), in a recent article on plant productivity and environment, emphasized that there is a large but unrealized potential for yield, the yield losses being primarily caused by unfavorable physicochemical environments. Boyer furthermore stated there are opportunities for improving crop production in stressful environments by genetic research and development. A better understanding of the mechanisms of environmental stresses in plants will significantly aid in the development of crop genotypes better adapted to unfavorable environments. I shall discuss some physiological features of plant responses to chilling temperatures, air pollution caused by SO_2 and salinity, with emphasis on membrane-related processes.

Chilling stress

Cell membranes are considered to be the primary sites of plant response to chilling temperatures. One of the leading hypotheses is that cell membranes which are normally in a 'fluid mosaic' state undergo a phase transition upon exposure to chilling (Lyons and Breidenbach, 1979). The consequence of this phase transition is solidification of the lipids to form patches of membrane regions in a solid gel state and lateral and vertical displacement of the proteins in clusters near the membrane surfaces, leading to disruption of the functions of cell membranes. Other observed physiological effects of chilling on plants such as water loss, ion leakage, imbalance of metabolism and eventually injury are considered secondary effects caused by the primary phase transition of cell membranes (Wilson and McCurdo, 1981).

Air pollution due to SO_2

Stomatal conductance is proposed to be useful as a physiological method for assessing air pollution stress caused by pollutant gases. This proposal was tested with three corn cultivars differing in sensitivity to SO_2. The experiments were conducted in fumigation chambers contained in an environment-controlled growth chamber. Exposure to 1.5 $\mu \ell \cdot \ell^{-1}$ SO_2 for 6 hours caused severe visual injury on the third and fourth leaves of the cultivars Bonanza (sweet corn) and NC 59 (field corn), but the sweet corn cultivar NK 51, 036 did not develop leaf injury following this SO_2 treatment. There were some slight differences in stomatal density among the three cultivars; stomatal densities, however, were not correlated with differences in SO_2 sensitivity. Measurements of stomatal conductance showed that the SO_2 resistance of the NK cultivar can possibly be explained by a low stomatal conductance in the absence of SO_2 and a further reduction in stomatal conductance (about 50%) after SO_2 fumigation, thus reducing SO_2 uptake. Stomatal conductance after SO_2 fumigation in the other two, sensitive cultivars exceeded that of NK, allowing higher SO_2 uptake. Hence, in these corn cultivars sensitivity to SO_2 appears correlated with SO_2 uptake by the leaves which is regulated by the stomata. A preliminary account of this work has been presented earlier (Mock and Läuchli, 1982).

Salinity stress

In our project on growth and other physiological responses of cotton to salinity stress it was found that germination and seedling growth were very sensitive to a salinity level of 200 mM NaCl in a 1/10 diluted Johnson nutrient solution containing 0.4 mM Ca^{2+}. Addition of 10 mM Ca^{2+} (as chloride or sulfate) did not overcome the salinity-induced inhibition of germination, but seedling growth, particularly of the root, was much ameliorated by this high calcium treatment. The Ca effect was cation specific; Mg or K did not mimic the Ca effect (Läuchli et al, 1982). It is proposed that the ameliorating effect of calcium on salinity response of cotton root growth is mediated by a membrane-related process. A potential practical application of this beneficial Ca effect is the addition of gypsum or some other calcium salt to a salinity affected soil that is not dominated by calcium, and examine whether seedling growth of cotton may also be improved in the field.

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Responses and Adaptation of Plants to Biological Stresses

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In the healthy plant, the capture of light energy by photosynthesis initiates the flow of energy into the plant; light energy is captured in photoassimilates which may be temporarily stored as starch in the chloroplast, transported to other parts of the plant (e.g., roots) for utilization as energy sources and conversion to cellular constituents, or converted to storage forms in "metabolic sinks" such as seeds. The machinery for dark respiration serves as a back-up system to the photosynthetic machinery for energy generation in leaves, and also provides energy in roots and other non-chlorophyllous tissues. Energy production by oxidative phosphorylation and photophosphorylation is coupled to biosynthetic reactions by ATP/ADP and reducing power (NADPH/NADP) interconversions. Thus for crop productivity, biosynthetic products determine the yield and represent the net amount of light energy captured and stored by the plants. In the healthy plant, a relatively small proportion of biosynthetic products are used for cellular maintenance and replacement of cellular structures undergoing normal turnover; the remainder is used for synthesis of materials that contribute to growth and yield.

Stresses caused by biologic agents tend to interfere with the flow of energy in the plant by disrupting one or more metabolic and developmental processes. Such affects not only can interfere with plant development but also weaken the capacity of plant cells to respond to ingress by pathogens. Hence in susceptible reactions, deleterious reactions are dominant and plant development suffers; photosynthesis may be reduced, cells may die in response to the action of toxins produced by the pathogen, and plant tissue may be destroyed by action of enzymes produced by the pathogen.

Plants may respond positively to biological stresses and produce compounds toxic to the organisms which stimulate their production. Such responses may confer resistance to biologic agents such as insects and microorganisms. Since synthesis of the toxic compounds is rapid, it appears the plants are designed to respond quickly to potentially harmful biological stresses.

Examples will be discussed that illustrate fundamental concepts on effects of biological stresses on plants.

MANAGING PLANT WATER STRESS IN INDETERMINATE CROPS--WITH EMPHASIS ON DRY BEANS

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Indeterminate crops such as blackeye beans, lima beans, cotton, and tomatoes have the ability to produce both leaves and reproductive structures after the commencement of flowering. In contrast, with determinate crops, such as wheat, stems which have begun to produce heads do not produce any more leaves. In some indeterminate crops, management of plant water stress and nitrogen nutrition can influence the relative proportions of reproductive and vegetative growth as well as their water use--factors which can influence economic yield, responses to diseases and insects, ease of harvesting, and profits.

We will describe a research project of the University of California, conducted at Riverside and the West Side Field Station, which has been developing optimal irrigation and fertilizer management methods for blackeye beans and lima beans. Some of these methods, with modification, may also be appropriate for other indeterminate crops.

Present commercial irrigation and fertilization practices used with blackeye beans in California result in large differences in the appearance of the crop, with some fields having extremely viny plants and others having stunted, compact plants. We have demonstrated that differences in the frequency of irrigation and plant water stress are probably mainly responsible for these differences in morphology of blackeyes, whereas differences in nitrogen fertilization may have only small effects on plant growth with this crop (Ziska and Hall, 1982a). Blackeye beans have substantial potential for fixing atmospheric nitrogen due to the symbiotic association with the rhizobia in the nodules on their roots; consequently, they exhibit a certain degree of independence from variations in nitrogen fertilization practices. However, as will be discussed later, in some circumstances nitrogen fertilization can increase dry bean yields of blackeyes.

The irrigation treatments which caused large differences in the extent of vining in blackeyes (variety, California Blackeye No. 5) and mild to moderate plant stress did not significantly influence the yields of dry beans, even though water stress caused a small reduction in shoot biomass production (Table 1).

TABLE 1. Dry Bean Yields and Biomass Production of Blackeyes Which Were Irrigated from Emergence to Maturation

	Riverside 1981			West Side 1982		
Percent depletion of available water	15	30	44	25	50	75
Days between irrigation	4	8	12	5	10	15
	100 lbs./acre					
Dry bean yield (at 10% moisture)	27.5	28.3	26.3	20.5	19.7	19.9
Shoot biomass production (dry matter)	63.9	59.7	57.3	43.4	42.7	39.2

Earlier studies with blackeyes at Riverside by Turk et al. (1980) and Shouse et al. (1981) had indicated that substantial water stress during the vegetative stage (up to the first occurrence of macroscopic floral buds) may have little or no influence on dry bean yields while reducing crop water use. This suggested that, for blackeyes, planned-water-deficit management of irrigation might decrease water requirements and increase profits.

The effects of withholding irrigation during the vegetative stage were tested in rain-free environments in combination with different irrigation intervals during flowering and podfilling. Additional treatments were included at Riverside to test the influence of presowing nitrogen fertilization, and at West Side Field Station to test the influence of different row widths. Vegetative-stage drought had little influence on dry bean yield of blackeyes irrespective of the presowing nitrogen level or row width (Table 2), providing the irrigation intervals were no longer than those described in Table 1. In addition, the different row widths and levels of presowing nitrogen fertilization did not significantly affect dry bean yields of blackeyes.

TABLE 2. Dry Bean Yields of Blackeyes

Duration of irrigation		Full season	Floral buds to maturation	Full season	Floral buds to maturation
Row width inches	N application lbs./acre	100 lbs./acre (at 10% moisture)			
30 single	29	25.9	28.1		
30 single	150	28.8	28.2		
30 single	50			18.3	17.9
40 single	50			21.1	20.3
40 double	50			20.7	19.7

Withholding irrigation during the vegetative stage and extending the irrigation frequency during flowering and podfilling substantially reduced the water use of blackeyes, compared with the most frequent full-season irrigation treatment which was designed to maximize shoot biomass production (Table 3).

TABLE 3. Water Use of Blackeyes

	Riverside 1981		West Side 1982	
Duration of irrigation	Full season	Floral buds to maturation	Full season	Floral buds to maturation
Irrigation frequency	Crop water use in inches			
Most frequent irrigation	29.2	21.7	23.1	17.5
Intermediate frequency	24.8	20.6	19.7	15.3
Least frequent irrigation	22.2	20.2	19.2	13.8

Dry bean yields of blackeyes can be maintained at high levels while saving water by the following irrigation management methods. Preirrigation should be used where winter rainfall is limited to bring the soil profile to field capacity down to at least 3 feet and/or provide at least 4 inches of available soil moisture. Seed should be sown into moisture, and the first irrigation should be applied when macroscopic floral buds first appear. These floral buds first appear from 30 to 50 days after sowing and appear sooner if the weather is hot. Subsequent irrigations should be applied at intervals which provide a consistent mild to moderate stress until chlorosis and senescence of the foliage indicate that the crop is maturing. The studies of Ziska and Hall (1982b) indicated that nominal depletion of available soil water may be the most practical method for determining the appropriate irrigation interval during flowering and podfilling. In this method, values of reference crop evapotranspiration (e.g., estimated using the Penman equation) are used to predict, assuming a crop coefficient of 1.0, when a critical percentage of available soil moisture has been depleted from the root zone. Unfortunately, the critical level of depletion is not constant. For the high bulk density soil used at Riverside, maintenance of dry bean yields required irrigation before 44% nominal depletion of the available water from the top 3 feet. In contrast, for the more favorable soil conditions at the West Side Field Station, irrigating at 75% nominal depletion from the top 3 feet maintained dry bean yields at levels comparable to those of more frequently irrigated plants.

Some preliminary observations are presented that may also contribute to more efficient management of irrigation and nitrogen fertilization with blackeyes. In one experiment, we compared overhead sprinkler irrigation during the day or night with furrow irrigation. Blackeyes produced 16% more dry beans under sprinkler irrigation than furrow irrigation but with no differences in yields between daytime and nighttime sprinkler irrigation. In studies of effects of nitrogen fertilization with blackeyes at Riverside, we have observed no yield responses from presowing applications of up to 176 lbs. of nitrogen per acre, in comparison with control plants which received little or no fertilizer but which were nodulated. In contrast, soil or foliar applications of 54 lbs. nitrogen per acre at first bloom have increased dry bean yields of blackeyes from 15 to 20% with no response from presowing applications of nitrogen in the same experiments (unpublished observations of R. B. Beverly, H. A. Elowad, W. M. Jarrell, and A. E. Hall). The responses of blackeyes to applications of nitrogen fertilizer at bloom and presowing should be tested under a range of soil and management conditions to establish the most profitable fertilization practices.

We have initiated studies to determine the extent to which the irrigation methods developed for blackeyes also apply to another class of dry beans, baby limas. Preliminary studies at West Side Field Station with an indeterminate, viny variety of baby limas, Mezcla, indicated some similarities and some differences in responses compared with blackeyes. Vegetative-stage drought did not influence dry bean yields of baby limas, whereas, in contrast with the responses of blackeyes, an irrigation interval giving a nominal depletion of 75% of available soil water significantly decreased the yields of baby limas by 18% (Table 4). A result of considerable practical importance was the large increase in yields of baby limas on double-row 40-inch beds compared with single rows of either 40-inch or 30-inch beds (Table 4).

The reasons for the superior performance of the baby limas on double-row beds have not been established, although they did produce substantially more shoot biomass than the plants on single-row beds (Table 5). Baby limas also produced considerably more shoot biomass than blackeyes (compare Tables 5 and 1). The lower dry bean yields with the longest irrigation interval (Table 4) were also associated with lower levels of biomass production compared with the more frequently irrigated plants (Table 5).

The remarkable responses of lima beans to row widths must be considered provisional information at this time because we have not had the time to repeat this experiment.

TABLE 4. Dry Bean Yields of Baby Limas at West Side Field Station (1982)

Duration of irrigation	Row width inches	Percent depletion of available soil water 25 / Days between irrigations 5	50 / 10	75 / 15
		100 lbs./acre (at 10% moisture)		
Full season	30 single	20.5	20.7	17.8
	40 single	24.3	26.4	22.7
	40 double	32.2	30.0	25.1
35 days after sowing to maturation	30 single	20.4	22.2	17.0
	40 single	26.1	24.9	22.8
	40 double	31.8	31.6	22.8

Row width effects were significant at the 5% level.

Irrigation interval effects were significant at the 0.1% level.

TABLE 5. Shoot Biomass Production of Baby Limas at West Side Field Station (1982)

Duration of irrigation	Row width inches	Percent depletion of available soil water 25 / Days between irrigations 5	50 / 10	75 / 15
		100 lbs./acre (dry matter)		
Full season	30 single	85.2	82.1	75.8
	40 single	91.9	95.5	76.7
	40 double	122.3	122.3	98.2
35 days after sowing to maturation	30 single	87.7	80.8	73.6
	40 single	105.3	85.9	74.8
	40 double	109.8	106.2	99.1

Row width effects were significant at the 1% level.

Irrigation interval effects were significant at the 0.1% level.

Apparently, opportunities exist for increasing the yields of dry beans by changing row widths and nitrogen fertilization practices, and for decreasing water requirements through planned-water-deficit management of irrigation.

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ENERGETICS OF SALT STRESSED PLANTS

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All plants require some salts for growth, but for most crop plants the optimum concentration in the soil solution, or nutrient solution, is rather low, on the order of 10 mM or less. At concentrations above the optimum range, even essential salts reduce growth and yield (1, 2). Large portions of the world's land and water available for agriculture are saline enough to prevent economic crop production. Desalination of water for agriculture is impractical because of energy costs. Therefore, if these saline lands and waters are to be used for agriculture, crops considerably more salt tolerant than those now available will have to be obtained by breeding, genetic engineering, chemical or physical manipulation, or whatever. For bioenergetic reasons it is probably impractical to try to produce land crops with sea water but it would be of great benefit if a satisfactory crop yield could be produced with brackish water one-fifth the concentration of sea water.

The development of more salt-tolerant crops has been severely hampered by insufficient knowledge of the mechanisms of salt injury to plants and of plant structures and processes that resist or prevent that injury. Breeders have not known how to select for salt tolerance and biochemists have not known which plant structures or processes to modify.

With the evidence now on hand it is possible to formulate hypotheses to explain salt-induced growth reduction and to predict some plant characteristics expected to increase salt tolerance. The objectives of this paper are: 1) to present one hypothesis that fits the available data, 2) indicate some plant characteristics likely to be associated with salt tolerances.

The growth reduction caused by sublethal concentrations of the salts commonly present in saline soils seems to be primarily an osmotic effect rather than an ionic one, brought about by the reduction of the osmotic potential (ψo) of the soil solution (1,2). Within limits, plants adjust to saline soils by reducing their ψo below the soil ψo (1,2). This adjustment allows plants to maintain water uptake and turgor but it does not prevent reduction of their growth. Generally, this reduction is proportional to the amount of osmotic adjustment that is necessary. The plant adjustment processes include: solute pumping across cell membranes, exclusion of harmful ions from the cell cytoplasm, and synthesis of cell-compatible osmoticum. All of these processes expend energy in the form of ATP; the amount expended is proportional to the amount of osmotic adjustment necessary. Because the plant's supply of ATP is limited by its photosynthetic capacity, increased expenditure for osmoregulation decreases the amount available for growth. This is the hypothesized cause of reduced growth under salt stress. One measure of the increased energy expenditure of salt stressed plants is their increased respiration (3). Data for mature source leaves, which show especially large increases, are shown in Table 1. These plants had grown for several weeks on saline cultures so the increased respiration is not a transient response to osmotic shock. Furthermore, the increase was greater in the salt sensitive radish than in the more tolerant mustard and turnip.

Table 1

Influence of Salt Stress on Respiration of Mature Source Leaves.

	Salt Stress (bar)				
Plant	0	-1	-2	-3	-4
	Respiration (nmole/sq cm/hr)				
Radish	379	424	504	656	727
Mustard	232	241	294	312	397
Turnip	379	361	388	433	495

Data from ref 3.

The energy charge of the adenylate system ($AEC = \frac{ATP + 1/2\ ADP}{ATP + ADP + AMP}$) provides a measure of the energy status of cells (4). Cells that generate ATP faster than they expend it have an AEC approaching one whereas those that expend it faster than they generate it have a lower AEC, approaching zero in extreme cases. Table 2 shows the effects of salt stress on the adenosine phosphate concentrations and on the AEC of mature source leaves and shoot meristems of pepper and safflower. The total adenosine phosphate of a tissue is a measure of the amount of cytoplasm; it was highest in the meristems. The latter also had the highest AEC and here it was not reduced by salt stress. The AEC was lower in source leaves and here it was significantly reduced by a salt stress. The data suggest that transpiration causes the lower AEC in source leaves -- the meristems transpire very little -- and that salt stress adds to or intensifies the effect of transpiration. Transpiration was shown (5) earlier to reduce mature leaf water potential (ψ), especially in combination with salt stress. Because of this reduction, osmoregulation and ATP expenditure are increased.

The AEC data indicate that mature transpiring source leaves are the primary sites of salt injury rather than meristems. This concurs with the earlier conclusion (5) that growth is controlled by mature leaf ψ. It also agrees with the observation that high atmospheric humidity, which would increase source leaf ψ, decreases the growth-suppressive effect of a saline root medium (5,6).

One other factor that probably contributes to a greater energy expenditure for osmoregulation in source leaves is their large cells which have a large osmotic volume to regulate.

Table 2

Influence of Salt Stress on Adenine Nucleotides and Adenylate Energy Charge of Source Leaves and Shoot Meristems of Pepper and Safflower.

Tissue Treatment	AMP	ADP	ATP	AEC
	---------nmole·g^{-1}·Fr wt^{-1} --			
		Pepper		
Source leaf				
Control	11.7	35.5	29.7	0.62
Saline	14.5	35.1	22.2	0.56
Meristem				
Control	17.2	68.5	158.4	0.79
Saline	18.4	72.2	135.7	0.76
		Safflower		
Source leaf				
Control	2.7	15.4	11.7	0.65
Saline	7.3	12.1	3.3	0.42
Meristem				
Control	3.6	30.5	42.4	0.75
Saline	7.7	28.0	50.2	0.75

Saline treatments = 51 mM NaCl plus 25.5 mM $CaCl_2$ in base nutrient solution.

Meristems have small cells and small osmotic volumes. For them, matric potential may be even more important than ψo for water uptake.

Based on the evidence described above, salt tolerant plants would be expected to have leaf structures that would reduce transpiration, low salt-stimulated respiration -- indicating energy-efficient osmoregulation, and high source leaf AEC even under stress.

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Assessing Plant Stress

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Plant stress has long been recognized as being a detriment to the harvestable yield; however, there has never been a perfect method of assessing plant stress. There are several methods which have been utilized by the research community to develop criteria for when a plant is under stress. However, we must first decide what "stress" we are trying to detect, i.e., the method for the detection of water stress will be different from that due to air pollution, and what level of sensitivity we desire in the method. One of the problems is that it may not be entirely possible to separate all stress components into their individual fractions except as the integral total of stress detracts from the potential yield to give the harvestable yield. In California, our largest concern is water and salinity stress because these can be extreme variables in our production network. Because of this we will limit our remarks to the methods which can assess plant stress resulting from inadequate soil water or excessive soil salinity.

The traditional methods of assessing plant stress resulting from water stress have focused on the plant water status or changes in plant properties. Relative leaf water content, stomatal resistance, or leaf water potential or leaf expansion rate represent methods which have been employed to quantify crop stress. Turner (1981) in reviewing these methods stated that the number of observations which could be made per hour would be about 30 and require two individuals. Although these methods have been regarded as the standard methods, they are not very quick and are labor intensive. They also require a physical attachment to the plant or destructive sampling procedure. In the recent years we have been investigating the use of infrared thermometry to detect plant stress. The research to date has applied to soil water, crop yield, disease, and salinity as typified by Hatfield (1982, 1983), Jackson et al. (1977, 1981), Pinter et al. (1979) and Howell et al. (1982). The basis of this technique is founded in the energy balance given as

$$R_n = \rho C_p \frac{(T_c - T_a)}{r_a} + \frac{\rho C_p}{\gamma} \frac{(e_s(T_c) - e_a)}{r_a + r_c} \quad (1)$$

where R_n is the net radiation, ρC_p the volumetric leaf capacity of air, T_c the canopy temperature, T_a the air temperature, r_a the aerodynamic resistance, γ the psychometric constant, $e_s(T_c)$ the saturation vapor pressure at T_c, e_a the vapor pressure of air and r_c the canopy resistance. If an individual leaf is viewed the canopy terms are replaced by leaf terms. Thus, this equation depicts the dynamic balance which a plant makes in its temperature in response to any changes in internal status, particularly those stresses which affect the water flow through the plant on the internal osmotic adjustment such as those caused by salinity stress. Recent research by Idso et al. (1981) and Jackson et al. (1981) have evaluated $(T_c - T_a)$ responses to other environmental factors. Hatfield et al. (1982a) applied this technique to the estimation of actual evapotranspiration. Thus, the canopy air temperature difference $(T_c - T_a)$ has a strong base in the energy regime of plant and allows for a reliable, accurate, nondestructive method of assessing plant stress. The recent research has shown that the inclusion of net radiation and vapor pressure deficit improve the responsiveness of these methods to environmental changes. The utilization of canopy temperatures in this framework has given rise to the development of crop water stress indices.

Research results to date indicate that changes in $T_c - T_a$ are responsive to soil water changes and that the crop water stress indices which mathematically vary from 0 (no stress) to 1 (no transpiration) can be related to the availability of soil water content. Hatfield (1982) has found that the summation of the stress index is exponentially related to soil water availability and the stress index begins to increase very rapidly beyond 60% extraction of the available water in the soil profile for grain sorghum. This would indicate that this method could be used to assess irrigation requirements and that the data would be relatively easy to collect. Further research is needed to refine these techniques for other crops. Howell et al. (1982) have found that the stress index calculation for cotton was the same over a cultivar and locations and would thus be applicable to irrigation management on over 200,000 ha of cotton.

Canopy temperatures are responsive to salinity stress which should be expected because of the effect on the osmotic component of leaf water potential. Howell et al. (1982) found that in the absence of matric potential differences this method was very responsive to changes in the salinity levels in the soil. This would suggest that this method could be deployed to assess the stress impact on yield in fields affected by increasing soil salinity.

There have been several comparisons of the $T_c - T_a$ method of assessing stress to the other methods, e.g., stomatal resistance or leaf water potential. The results from these experiments have been very encouraging and show there is a linear relationship between leaf resistance and the crop water stress index; a linear relationship was also found for leaf water potential. These results have been found for cotton, grain sorghum and wheat. Although there has been considerable scatter in these relationships, this is due to the sampling problems of the leaf measurements which are time-consuming methods compared to the remote measurement. The canopy temperature method provides a good method which provides the same answers as the more traditional and accepted methods of assessing plant stress. In evaluating the relationships between the crop water stress index and leaf water potential the values of 1 have been found to relate to complete cessation of growth and at values of about 0.3 are related to those leaf water potentials which are currently accepted for irrigation management in cotton, grain sorghum or wheat.

In an effort to determine the number of samples needed to quantify the stress level in a field, Hatfield et al. (1982b) evaluated the variability within irrigated fields of grain sorghum of various soil moisture contents. They found that the samples could be analyzed as a randomly collected set of measurements with only 10 samples needed to characterize a field with a soil water content above a 60% extraction limit. With this small number of samples, a large amount of samples can be collected in a relatively short period of time. In small plots it would not be unreasonable to collect in excess of 300 samples per hour and with an electronic data recording unit this could be extended to almost 1,000 samples per hour. Thus, this method provides a rapid method of assessing plant stress without a sacrifice of sensitivity due to sampling constraints.

The canopy temperature is in its infancy but is rapidly becoming a very useful tool for the quantitative assessment of plant stress. Research will continue to refine these techniques for application to agricultural management decisions. The responsiveness of this technique provides a method which may be used to assess plant stress which are not within the current sensitivities of the more traditional methods.

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HOST-PATHOGEN INTERACTIONS IN RELATION TO MOISTURE STRESS AND DISEASE DEVELOPMENT

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Soil-borne fungal pathogens such as *Verticillium dahliae* and *Fusarium oxypsorum* often invade the vascular systems of host plants and cause a series of reactions including vascular browning and the formation of vascular occluding gels that result in moisture stress and disease development. Systemic infections of cotton plants by *V. dahliae* extending to petioles and leaf blades result in enhanced production of ethylene by infected plants. In some instances the production of ethylene by infected cotton plants is at high enough levels to cause defoliation (8); strains of *V. dahliae* have been broadly categorized as defoliating or nondefoliating pathotypes based on plant reactions (5). Regardless of pathotype, however, the appearance of foliar symptoms is closely related to the retardation of plant growth and the reduction of lint yield. The earlier in the plant growth cycle that foliar symptoms appear, the greater will be the effect on plant growth and lint yields. Foliar symptoms, other than defoliation, are characterized by the wilting of limited sections of affected leaves and a resulting chlorosis and necrosis of the wilted sections. Wilting can be attributed to the occlusion of leaf veins (1, 3).

In field studies on Acala SJ-2 cotton plants, the minimum leaf water potential (ψ_1) of plants at first showing of foliar symptoms ranged from -15.7 to -24.6 bars with an average of -19.4 bars while those of healthy plants ranged from -11.2 to -19.3 bars with an average of -14.7 bars. Differences between healthy and diseased plants were greater prior to boll set than after boll set. However, ψ_1 of plants with foliar symptoms which appeared before boll set usually returned to values similar to healthy plants about 2 to 3 weeks after symptom development. In contrast, the minimum ψ_1 of plants with foliar symptoms which first appeared after boll set remained consistently lower than that of comparable healthy plants for the remainder of the growing season (7). Plant growth analyses have shown that approximately 2 weeks (250 degree days) before foliar symptoms are evident, growth of diseased plants is sharply inhibited. The main reason for the inhibition of growth is apparently water stress induced in leaves of diseased plants during early stages of disease development. Grimes and Yamada (2) have found that the growth rate of cotton plants follows a linear function of the minimum ψ_1.

Field grown plants infected with T9, a defoliating pathotype of V. dahliae, had a higher ψ_1 than plants infected with SS4, a nondefoliating pathotype, or healthy plants for 4 days after inoculation; however, by the eighth day, the ψ_1 of T9-inoculated plants was -20.9 bars, that of SS4-inoculated plants, -19.3 bars and that of the control plants, -16.8 bars. A marked increase in stomatal resistance (R_1) of T9-inoculated plants was associated with the rapid drop of ψ_1 by the eighth day. However, by day 16 for both upper and lower leaves, R_1 values of T9-inoculated plants had dropped to values slightly higher than those of the SS4-inoculated plants and the controls.

Another indicator of water stress in diseased plants was proline accumulation. The patterns of proline accumulation in T9- and SS4-inoculated plants and in control plants resembled those for stomatal resistance. By the eighth day, T9-inocuated plants showed sharp increases in free proline concentrations while lower increases were characteristic of SS4-inoculated plants compared with controls. However, by day 16, proline levels of T9- and SS4-inoculated plants, although higher than controls, had dropped (6).

Results with several host-pathogen systems indicate that ethylene is the key intermediate in causing vascular gelation in plants infected by Verticillium and Fusarium species (4, 9). Vascular occlusion, resulting from the formation of gel plugs, induced the main phenological and plant water stresses that are associated with moisture stress and the symptoms that are characteristic of the different vascular diseases.

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MANAGING FOR PLANT STRESS: AIR POLLUTION

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Ozone is now considered to be the number one plant damaging air pollutant in the United States. Laboratory experiments, unrelated to air pollution problems, early in the century demonstrated that ozone would injure plants, but until about 1960 it was thought that it was so chemically reactive it could not exist in the ambient atmosphere. Specific tests and/or monitoring instrumentation, capable of ozone detection in the polluted atmosphere, was not available for field use. Chemists had established that ozone was a product of photochemical reactions between nitrogen oxides and hydrocarbons, and hypothesized that an oxidation product or intermediate was responsible for the observed foliage injury. Experimentation with ozone and many plant species established that ozone is a major phytotoxicant in "smog."

Classical ozone injury symptoms on foliage are quite variable. Characteristics of the symptoms are influenced by the concentrations of ozone present in the environment, duration of the exposure, type of plant, and environmental conditions. Injury symptoms range from bifacial collapse and necrosis of large irregular leaf areas, small "stipple"-like necrotic or pigmented lesions on the upper leaf surface, and various patterns of chlorosis, some of which may be indistinguishable from natural senescence. Indogenous production of ethylene is stimulated by exposure of plant materials to ozone. Similarly, ozone enhances development of the abscission tissues, thus increasing premature drop of leaves and reproductive organs.

Long duration exposures to relatively low ozone concentrations (chronic exposure) will suppress growth and yield by many sensitive species without the development of visible injury symptoms. The loss of crop may be further exacerbated by the development of visible leaf injury symptoms. However, the extent of reduced productivity (fruit, seed and tubers) is not directly proportional to the amount of leaf injury.

Yield response of cotton to 6 levels of (O_3) was measured at Shafter, California, in 1981. The cotton growing in an activated charcoal-filtered atmosphere with a mean 7 hr/day concentration of 0.021 ppm O_3 produced 20% more cotton than comparable plants exposed to a mean concentration of 0.072 ppm O_3

in a nonfiltered chamber. Yield reductions inducted by other O_3 treatments were proportional to the mean 7 hr/day concentration. Similarly, significant yield losses of soybean, lemons, navel orange, grape, wheat and other crops have been recorded. The loss of yield is partially attributed to interference of O_3 with photosynthesis and respiration, but it is also apparent that long-term exposure to O_3 stimulates development of abscission zones resulting in excessive drop of leaves and reproductive organs.

Peroxyacetyl nitrate (PAN), a second oxidant in smoggy air, will produce visible foliar injury symptoms on susceptible species when concentrations exceeding about 10 ppb occur for 2 or more hours. The undesirable aesthetic effect of such symptoms have frequently resulted in complete loss of marketability of leafy vegetables and ornamentals grown in the southcoastal region of California. Plant growth and yield may be seriously impaired when severe foliar injury develops, but there is no evidence of significant yield loss occurring in the absence of the foliar symptoms.

Air pollutants may cause economic loss by reducing the aesthetic attractiveness of a crop, but serious losses to agriculture productivity throughout the United States result when elevated O_3 concentrations occur for extended periods of time and these losses are not necessarily correlated with the extent of visible leaf injury. Some estimates of air pollutant (O_3, PAN, SO_2 and HF)-induced losses of agricultural crop production in the United States have been as high as $2 to $3 billion. Such estimates are based on data obtained from dose-response experiments conducted with five of the leading crops exposed to realistic air pollutant dosages under field conditions. Further studies with season-long pollutant exposures may substantiate even higher losses.

Tetranychid Mites on Foliage: Effects on Almond Tree Physiology, Growth, and Productivity

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Spider mites, family Tetranychidae, are important pests in almond agroecosystems in the southern San Joaquin Valley. Previous research by Barnes and Andrews (1978) has shown that severe spider mite infestations were responsible for reductions in almond tree growth and productivity. However, the relationships between spider mite feeding damage and the subsequent reductions in growth or yield were not determined. Therefore, investigations were initiated in 1978 to quantify these relationships, as well as to provide information concerning the underlying mechanisms of these reductions. The research efforts consisted of three phases: 1) the impact of spider mite feeding upon almond tree growth or yield, 2) the relationships between spider mite feeding damage and almond tree photosynthetic and transpiration rates and 3) the impact of spider mite feeding upon the cellular integrity of the almond leaf.

Spider mite feeding damage was calculated in terms of "mite-days", one mite feeding for one day. The spider mites used in all experiments consisted of either the twospotted mite, *Tetranychus urticae* Koch, and/or the Pacific mite, *Tetranychus pacificus* McGregor.

Almond Tree Growth and Yield

Almond tree growth and yield were not significantly affected during the same year as the infestation. However, one season after spider mite feeding damage occurred, significant reductions were observed in terminal shoot extension, mean leaf size, and yield. A statistically significant 23 percent reduction in terminal shoot extension was observed by 300 mite-days, while 424 mite-days were required to demonstrate significant reductions in yield. Similarly, a 6.4 percent reduction in mean leaf size was observed by 517 mite-days.

Photosynthesis and Transpiration

Photosynthetic and transpiration rates were measured with a dual isotope porometer developed at U. C. Riverside (Johnson et al., 1979). Both photosynthesis and transpiration were reduced by spider mite feeding damage. Significant negative correlations were obtained between mite-days and leaf conductance values. The reduction in transpiration was shown to be the result of reduced stomatal opening as indicated by a reduction in stomatal conductance to tritiated water vapor. Reductions in photosynthesis appear to result from a combination of reduced stomatal and mesophyll conductance.

Almond Leaf Morphology

Spider mites, which insert stylet-like mouthparts into the leaf tissue, were shown to remove cell contents from both the spongy mesophyll and pallisade layers of the almond leaf. The evacuation of cell contents resulted in either misshapened or collapsed cells, as well as a significant 15.2 percent reduction in chlorophyll content/cm^2 at 53 mite-days/cm^2.

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SELECTION FOR STRESS TOLERANCE USING TISSUE CULTURE TECHNIQUES

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One of the soundest strategies for managing plant stress is clearly the use of stress-tolerant crop varieties. Where available varieties are insufficiently tolerant, there are a number of genetic tools that can be used to develop more tolerant varieties. Several of these tools involve the use of cultured plant cells. Plant tissue culture is a broad term encompassing a variety of techniques, most of which can in some way be used in the development of stress tolerant crop genotypes. These techniques fall into the following categories:

1) in vitro screening -- using in vitro culture techniques to identify desirable genotypes as part of a conventional breeding program (in those cases where identification is either slow or difficult with whole plants)
2) microspore culture -- culturing anthers or microspores to obtain haploid plants as a means of achieving rapid homozygosity and increasing the detection of desirable recombinant genotypes
3) protoplast fusion -- combining sexually incompatible genotypes by fusing protoplasts and regenerating somatic hybrid plants
4) somaclonal variation -- exploiting a poorly understood phenomenon in which plants regenerated from cultured cells sometimes exhibit a variety of novel, stable characteristics, including stress tolerance. This process is uncontrolled.
5) mutant selection -- application of concepts of microbial mutant selection to plant cells. Deliberate imposition of carefully conceived selection strategy to permit the preferential growth and isolation of rare mutant cells of a defined phenotype in a large cell population
6) gene transfer -- introduction of a foreign gene into a plant. Most gene transfer strategies now being developed for plants involve the use of cultured plants cells, usually protoplasts, as the recipients of the foreign genes.

Further discussion will be limited to only two of these techniques, in vitro screening and mutant selection, because they have particular promise as useful tools right now and because our laboratory is currently active in these two areas.

Plant tissue culture techniques can be used for improving tolerance to both environmental and biological stresses, as the examples will illustrate. However, these techniques are not generally applicable to all biological and environmental stresses. There are important limitations that must be recognized (and which will be discussed further below). But in those cases where a cell culture approach is appropriate, it can be a very efficient and powerful strategy for obtaining valuable genotypes.

In vitro screening

The most difficult aspect of a breeding program is often evaluating each progeny population to identify individuals with the desired trait(s). This is particularly difficult in the case of stress tolerance, as it may be hard to apply the stress uniformly to the seedlings or stress symptoms may be difficult to identify. An *in vitro* screen may overcome these problems and permit seedlings to be characterized reliably and quickly.

An example in our laboratory is nematode tolerance in grapes. Such tolerance is one of the major objectives in the grapevine rootstock breeding program at Davis. The seedlings that result from each cross must be screened for nematode tolerance in order to identify promising individuals. The conventional practice has been to grow each seedling up, pot it individually, allow it to establish a good root system, inoculate it with a defined number of nematodes, wait about eight months, and then evaluate each one for injury. This process requires about a year and delays the progress of the breeding program by a full growing season.

We are currently involved in developing a rapid screen for nematode tolerance that we hope will greatly reduce this screening time to the extent that a growing season would not be lost. This screening approach is based on 1)the establishment of dual cultures of grapevine tissue and nematodes and 2)the expression of tolerance or susceptibility in such cultures.

There are several important nematodes on grapes, but we are looking at only one to begin with, *Pratylenchus vulnus*, the lesion nematode. We have now successfully established nematodes on three types of grape cultures--rooted shoot cultures, excised root cultures, and callus cultures--and have maintained these cultures for periods of several months. We have seen juvenile nematodes, suggesting that reproduction is occurring in these cultures. In the excised root cultures and the rooted shoot cultures, we have observed the development of the root lesions typical of this nematode. We are now beginning to look for manifestations of tolerance or susceptibility by inoculating grape cultures of genotypes known to differ in tolerance. The screen we hope to ultimately develop might involve rapidly establishing a culture from a small piece of a seedling, inoculating it with nematodes, and scoring it for tolerance based on whatever expression of tolerance we fine to be most rapidly expressed and most reliably correlated with whole plant responses.

Mutant selection

Because very large numbers of cultured plant cells can be grown in a very small space and because entire plants can be regenerated from cultured cells, mutant selection strategies similar to those employed in microbial genetics can be successfully adapted to plant cells. A large number of plant cells can be plated on to a selective medium and rare mutant cells of a specifically defined phenotype can be isolated. Plants can be regenerated from the selected cells and, in many cases, the plant will express the selected characteristic. Improved tolerance to disease has been selected in this fashion and been shown to be stable and heritable. Tolerance to both chilling and salinity have also been selected but no convincing evidence for genetic transmission has been presented.

We are involved in mutant selection projects dealing with tolerance to both biological and environmental stress. The pathogen that causes Pierce's disease in grapevines is thought to produce a toxin which is both host-specific and also the determinant of pathogenicity. If further study confirms the importance of the toxin in the disease, we will use it as a selective agent to obtain grape mutants with tolerance to the toxin and, possibly, the disease.

Aluminum toxicity is an environmental stress of great significance in many of the world's soils. Mineral stresses such as this may be particularly suitable problems for cell selection programs. These stresses generally affect plants at the cellular level and are also readily simulated in culture.

We have previously shown that aluminum inhibits the growth of cultured cells and that genetic differences in aluminum tolerance can be expressed in culture. In at least three crop species, aluminum tolerance has been attributed to a single major gene. We are now using a model species, *Nicotiana plumbaginifolia*, to determine whether aluminum tolerance can be obtained via cell selection, its mode of inheritance, and its expression in regenerated plants.

Limitations

Not all stresses impinging on crop productivity can be readily investigated in cell cultures. A cultured cell is developmentally very different than a whole plant. A tolerance mechanism involving a morphological factor or some tissue specific process may not be expressed in cultured cells and so will not be selectable. The genes that confer tolerance in a whole plant may be inactive in a cultured cell so mutations in those genes will not be selectable.

Tolerance in a whole plant may also be the sum of several components, involving molecular, biochemical, and physiological processes as well as specialized tissue and organs and whole plant structure. In cultured cells, only the cellular components can be expressed. Depending upon the relative contribution of cellular components to overall tolerance, a tolerant genotype may not express its tolerance in culture. Conversely, tolerance selected *in vitro* may or may not make a significant contribution to the overall tolerance of the whole plant.

Cytogenetic Approaches To Improve Stress Tolerance

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Wild and occasionally also cultivated relatives of our major crops often possess outstanding tolerance to various forms of environmental stress. Among the relatives of wheat, for example, superior tolerance to frost and drought was found in rye (Fowler et al. 1977, Waines et al., 1979), and to saline soil conditions in Elytrigia (Shannon, 1978, McGuire and Dvořák, 1981). Although a great deal of progress has been made in incorporating into wheat alien genes conferring resistance to wheat pathogens, so far no success has been reported in achieving the same for alien genes controlling tolerance to environmental stress.

This is due to the fact that while the difference between resistance and susceptibility to a pathogen is usually due to a single gene the difference between genotypes showing a dramatic difference in tolerance to adverse environmental conditions is almost certainly in a number of loci. Inherent to this dichotomy is also the fact that the underlying physiological machinery of resistance to a specific disease is the same in all species of Triticeae whereas the physiological machinery leading to stress tolerance may be entirely different in even closely related species. As a result desirable characters of a related species are either suppressed in its hybrid with wheat, or if not, they are lost when single chromosomes are added to the wheat chromosome complement.

The first situation is exemplified by the lack of expression of superior frost tolerance of rye in wheat x rye amphiploids (triticale) which show the level of frost tolerance that is characteristic of the wheat parent (Dvořák and Fowler, 1978). The second situation is exemplified by the expression of salt tolerance in wheat x *Elytrigia* amphiploids. While the amphiploid does show an enhanced tolerance to salinity relative to the wheat parent, none of the single chromosome additions are superior to the wheat parent. Salt tolerance in *Elytrigia* is likely controlled by a complementary gene system on several chromosomes which becomes inactivated when the critical chromosomes are separated from each other as they are in single chromosome addition or substitution lines.

To accommodate these observations and maximize our chance for success in obtaining expression in wheat of *Elytrigia* genes regulating tolerance to salinity we follow a procedure of stepwise gene transfer ensuring the expression of alien genes at each step. We reason that a complementary interacting gene system is responsible for tolerance to salinity in *Elytrigia*. Only those *Elytrigia* genes which can interact with wheat genes have a chance to be expressed. Therefore, we employ the most salt-tolerant wheats to be the recipients of *Elytrigia* genes, rather than the most sensitive ones, which would be the strategy if disease resistance were being transferred. Further, to remove epistatic suppression of *Elytrigia* genes we are selecting recessive mutations of the anticipated wheat suppressors. This is being done by selecting in tissue cultures of wheat-*Elytrigia* derivatives and addition lines of single *Elytrigia* chromosomes mutations that promote the expression of salt tolerance. We hope that these mutations will result from inactivations of competing genetic systems that suppress the expression of *Elytrigia* genes. The final goal of this project is to translocate one or several *Elytrigia* genes and obtain wheat-like plants showing increased salt tolerance.

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Plant Breeding for Disease Resistance

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The major goals of breeding programs for disease resistance are to identify and develop sources of resistance and to incorporate such resistances into agronomically suitable genotypes to provide varieties that will be acceptable commercially and will provide disease control. The success of efforts to accomplish the above goals is dependent on the degree to which characteristics of the pathogen population are considered in disease screening and other evaluations of the materials.

Many types of materials can serve as sources of resistance. Collections of varieties are searched first since resistance, if found, already will be in an improved genetic background. Some collections, moreover, are accompanied by documentation regarding the disease resistances of the entries. Related species, related genera, and alien sources of germplasm also can be searched for resistance. Additionally, materials from all sources can be hybridized to produce new associations of genes which may provide the desired resistance. Genes from an unlimited number of parents can be combined using male-sterile facilitated recombination schemes.

Various techniques can be used to induce resistance if sources of resistance are not readily available. Radiation and chemical mutagens can be used to generate variability for resistance. Somaclonal variation can be exploited through tissue culture, with resistant variants identified among somaclones. Genetic engineering techniques are being developed which will allow genes from nonrelated species to be inserted into the target species.

Sources of resistance must be incorporated into agronomically acceptable backgrounds before they can be used for disease control purposes. Pedigree breeding methods easily accomplish this goal for genes with large effects. Polygenic resistance, however, is not easily handled, especially in early segregating generations, so requires special techniques. In any case, the goal of hybridization programs is to recover the level of resistance expressed in the source in the improved type.

The keys to success for breeding programs for disease resistance are the screening methods used. Combinations of field, greenhouse, and laboratory techniques are available. The utility of any technique depends on how closely it reflects the "true" resistance of the material. Therefore, careful attention is given to using pathogen isolates that represent the pathogenicity, virulence, and aggressiveness characteristics of the pathogen population and to testing under environmental conditions (light, temperature, moisture) and inoculum levels that favor the development of the desired amount of disease on susceptible plants. Plants can be screened for resistance on the basis of symptom expression at any growth stage, although screening of seedlings is the most common method used since large populations of plants can be tested in a short period of time.

Some types of polygenic resistance are not amenable to screening on the basis of symptom expression. Rather, quantitative measures of numbers of spores produced, lengths of incubation periods, and assessments of disease and infection efficiencies are needed.

Screening programs can be wide or narrow in scope. International programs, such as the CIMMYT wheat breeding program, screen materials in hundreds of locations worldwide. Materials resistant in particular areas are identified for use in those areas and also are recycled back into hybridization programs to recombine them with additional sources of resistance. Screening programs which focus on a single region take into account the environmental conditions and characteristics of the pathogen population in that region. Early generation screening normally is done in a single location. A sequence of field tests in a number of additional locations is subsequently undertaken, using progressively larger plots, to insure that the resistance expressed in nursery plots also is effective under commerical production practices.

Genetic engineering techniques offer a new dimension to screening programs. For example, suspensions of cells or protoplasts can be exposed to toxins or culture filtrates of pathogens. Mutants which are not affected by the toxins can be regenerated into plants. Very large host populations can be screened quickly, increasing the chances of identifying resistant mutants. Regenerated plants, however, must be field tested to evaluate the effectiveness of the resistance under normal growing conditions and the suitability of the plant with regard to other characteristics.

Disease resistant genotypes with suitable agronomic characteristics can be used as pure line varieties, as components of multilines or blends, or can be deployed in certain regions or used in rotation with other varieties on a year to year basis. The above strategies for using disease resistance differ in the emphasis placed on prolonging the effectiveness of resistance and delaying disease progress after disease onset. The most common way that disease resistance is used is in pure line varieties grown in monocultures. This strategy, however, places the strongest selection pressure on the pathogen population for strains able to overcome that resistance. Resistance based on a single gene is more likely to be overcome than that based on several genes. Pure line varieties with polygenic resistance do not place as strong a selection pressure on the pathogen population, so do not lose their effectiveness as readily as varieties with single genes for resistance.

Multilines, blends, and bulk hybrids can be used to delay the adaptation of pathogen genotypes to resistance, retard disease progress, and reduce losses if disease occurs. The materials mentioned differ from each other in that they contain progressively greater amounts of background genetic diversity. All of the strategies present the pathogen with a variable host population that will not favor a specific pathogen genotype. Therefore, mutations for increased pathogenicity that occur in the pathogen population will not enjoy a large selective advantage.

Resistant materials, whether pure line varieties, multilines, or blends, can be deployed according to region or time. Geographic deployment may be beneficial if the disease is subject to long distance spread and if the growing region of the crop is large and contiguous. Deployment in time, or gene rotation, may be appropriate for endemic diseases.

Combinations of the above strategies can be used to exploit the effectivenesses of individual methods at preventing the "breakdown" of resistance and disease loss. For example, a multiline variety composed of phenotypically similar (genetically diverse) components, each with two or more genes for specific resistance in backgrounds with polygenic resistance, could be deployed across a growing region, with different sets of components in different areas, and different sets of components used in successive years. It is arguable, however, whether such a strategy would have any advantage over the much simpler strategy of producing pure line varieties with single genes for resistance that are replaced at the first signs of susceptibility, before economic disease losses occur. Resistant varieties often are replaced while their resistance still is effective, since varieties constantly are being developed with improved yield, quality, and agronomic characteristics.

INTEGRATING MULTIPLE FACTORS
IN INTERPRETING TISSUE ANALYSIS RESULTS

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As we strive to maximize crop production it is necessary to know its mineral nutrient status in order to adjust fertilizer practices to meet crop needs.

Critical concentration approaches are being utilized for diagnosis of the nutrient status of many crops. There are difficulties in assaying the nutrient status from the chemical composition of field samples. The critical values are derived under specific conditions and may change for a given crop with stage of growth, plant part sampled, and management practices (irrigation, fertilization, or grazing, in the case of a forage crop), and environmental condictions (rainfall, temperature, humidity, etc.). Critical values often apply only to the most limiting nutrient, making it difficult to deal with multiple deficiencies.

One method used on sugarcane to take into account these varying factors is the Crop Log system developed by Clements (1980). It is a critical concentration approach in which the optimum level of nutrients and moisture were charted from highest yielding fields through the entire growth cycle of the crop. This was done for varieties used and at a number of location to represent different environments. This system apparently works quite well for sugarcane, which takes two years to make a crop and leaf samples are taken to monitor it twice each month. In many farming situations such detailed monitoring through the growth of a crop is not possible.

The Diagnosis and Recommendation Integrated System (DRIS) developed by Beaufils (1973) is a method of considering a number of mineral nutrient concentration ratios simultaneously. Nutrient ratios do not vary as much with stage of growth as do nutrient concentrations. Sumner (1978) points out that when a nutrient ratio has an optimal value any yield is possible, the actual level being determined by the factors contributing to yield. When a ratio is too low, a response to the element in the numerator will be obtained if, indeed, it is limiting. If the element in the denominator is in fact excessive, a yield response may or may not be recorded, depending on the level of other yield factors. When the ratio is too high, the reverse is true. Thus consideration of a nutrient ratio in isolation does not permit one to identify which of the two nutrients being considered is limiting yield. However, as the number of nutrient ratios considered simultaneously increases, identification of the nutrients limiting yield becomes easier and more reliable. The optimal or normal values for each ratio must be known. DRIS norms are derived from a population of observations representing the variability encountered by the crop in the field (Sumner, 1981). The norms and the coefficients of variation taken from high yielding plants of the population are necessary in order to use DRIS.

The DRIS system has been reported to produce slightly fewer incorrect diagnosis of nutrient deficiencies than the critical concentration approaches. This may be due to its insensitivity to factors such as age of tissue, the position of leaf, and cultivar (Jones and Bowen, 1981).

Preliminary data from subclover pastures in California indicate DRIS to be promising. Further work will be required to establish ratio norms and C.V.'s (Jones, Williams, and Vaughn, 1981).

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CATION INTERACTIONS IN POTASSIUM NUTRITION

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Potassium deficiency is a problem of economic significance in deciduous tree crops grown in California. The problem is particularly serious for prune production in northern California. Historically, soil tests have been of little value in assessing orchard K fertility status. Leaf analysis and symptom recognition have been the means for identifying K deficiency and for evaluating response to corrective measures. The recommendation for correcting K deficiency in trees growing in finer textural soils is to apply massive quantities of potassium sulfate (up to 25 lb/tree). An application of this magnitude contains a ten-year supply of K for the tree. Even with this large application of fertilizer, response during the first and second year after application is often poor.

Analysis of leaf tissue from prune orchards consistently show an inverse relationship between concentrations of K and Mg. This observation coupled with the fact that many soils in northern California are high in exchangeable Mg prompted a study of K-Mg interactions in prunes.

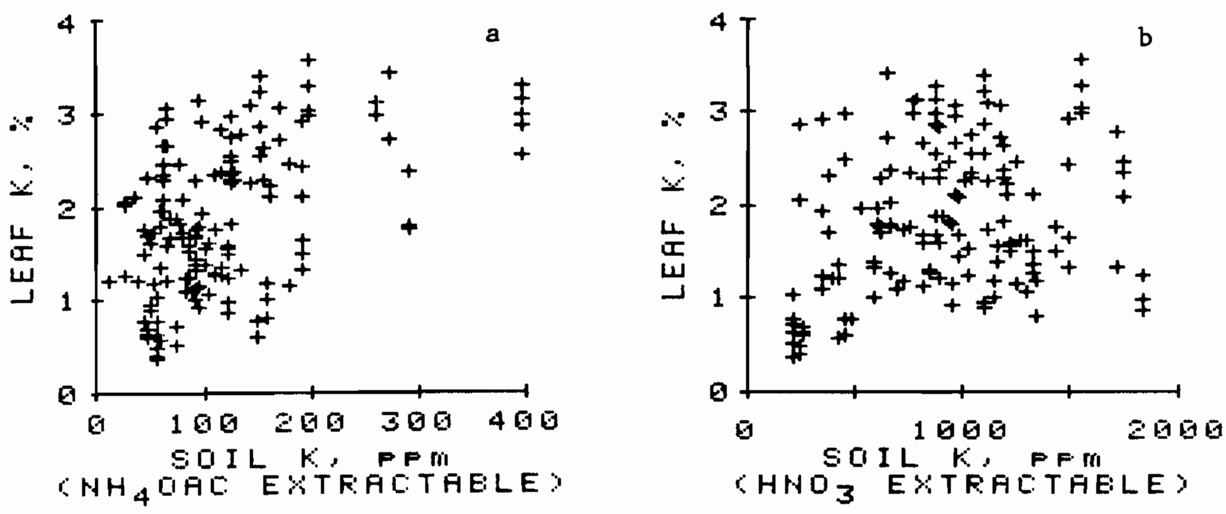

Fig. 1. Leaf K as a function of soil K test values: (a) NH_4OAc extractable K; (b) boiling 1 M HNO_3 extractable soil K.

The initial approach was to survey many orchards in northern California. Soil and leaf samples were collected at mid-season over a period of four years. Exchangeable soil K is of little value in predicting leaf K concentrations* (Fig. 1a). When exchangeable K exceeds ∿ 250 ppm leaf K is above the critical level (1.0-1.3%). However, leaf K levels are often well above the critical value when exchangeable K is low (<100 ppm). Acid extractable soil K also fails to predict deficient leaf K levels (Fig. 1b). Deficient trees were found at the highest levels of acid extractable K.

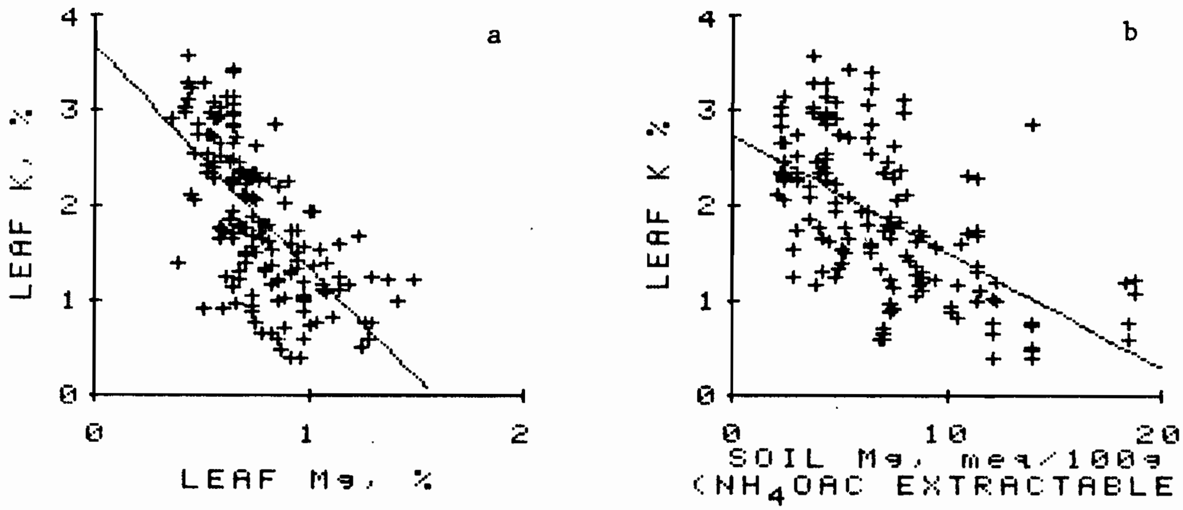

Fig. 2. (a) Leaf K versus leaf Mg; (b) leaf K versus exchangeable soil Mg.

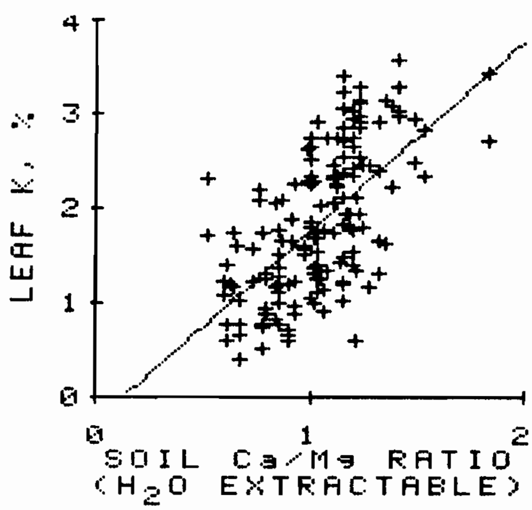

Fig. 3. Relationship between leaf K and water soluble Ca/Mg ratio in soil.

Figure 2a shows the inverse relationship between leaf K and leaf Mg (R^2 = 0.44). There is a similar relationship between leaf K and exchangeable soil Mg (Fig. 2b). The inverse relationship between leaf K and exchangeable Mg is stronger than relationships between leaf K and soil K test values. Leaf K was

*These findings agree with those published by Lilleland and Brown, Proc. Amer. Soc. Hort. Sci. 35:327 (1937).

compared with the water soluble Ca/Mg ratio as another measure of soil Mg status (Fig. 3). The leaf K-soil Ca/Mg correlation was slightly better than the leaf K-exchangeable Mg correlation (R^2 - 0.38 versus 0.35).

With the leaf K-soil Mg relationship clearly established, attention was turned to the nature of the interaction. Nutrient solution experiments were conducted to determine if Mg competes with K uptake by plant roots. Short-term competition experiments were done with the nutrient solution depletion technique. Potassium depletion from solution with Ca/Mg ratios spanning those observed in the field are shown in Figure 4. The two depletions shown were with the same plant on consecutive days; only the solution Ca/Mg ratio differed on the two days. This experiment was replicated with a total of six trees. There was no significant difference in the rate of K uptake between the different Ca/Mg ratios. This indicates that high Mg in the low Ca/Mg ratio solution does not inhibit K uptake, at least in the short-term exposure of these experiments.

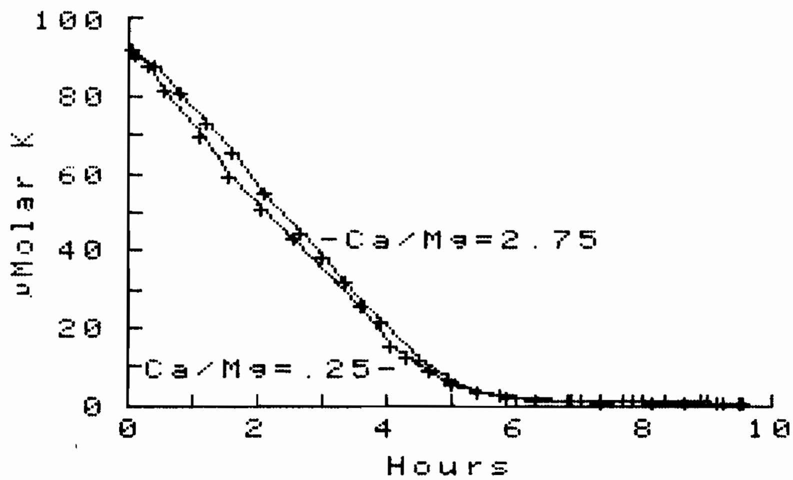

Fig. 4. Depletion of K from solution containing different Ca/Mg ratios.

A continuous flow nutrient solution culture system set up in a greenhouse was used to examine the influence of long-term exposure to various Ca/Mg ratios on K status of prune trees. Potassium was maintained at constant concentration of about 100 µM in these solutions. Plants were leaf sampled after one and a half seasons culture. Leaf Ca and Mg varied with the solution composition but leaf K was independent of the solution Ca/Mg ratio (Table 1).

Table 1. Influence of solution Ca/Mg ratios on leaf K, Ca, and Mg concentrations (% dry weight).

Ca/Mg	K	Ca	Mg
3.60	3.42	1.28	0.35
1.73	3.48	1.28	0.46
0.95	3.21	1.20	0.56
0.53	3.69	1.03	0.56
0.24	3.40	0.76	0.87

The results of the solution culture experiments do not explain the strong relationship between leaf K concentration and soil Mg levels observed in the field. The possibility remains that high levels of magnesium are associated with other soil properties that are detrimental to potassium accumulation by the trees. Further investigations in this area are required.

SOIL SAMPLING AS AN AID TO NITROGEN FERTILIZATION OF SUGARBEETS

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Data from 21 field research trials conducted throughout the sugarbeet growing areas of California during the early and mid 1970's resulted in a correlation being developed between the relationship of sugarbeet root yield to soil nitrate nitrogen determined early in the season (figure 1).[1/]

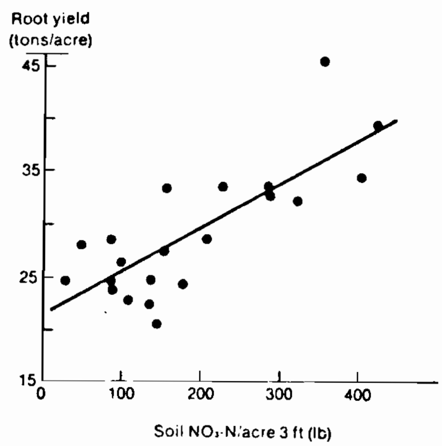

Fig. 1. Relation of sugarbeet root yield to soil nitrate-nitrogen determined early in the growing season for 21 locations; $Y = 21.1 + 0.042X$.

From this it is possible to make a rough prediction of the root yield a field would produce without additional N fertilizer. Also from the fertilizer trials conducted during this period it was determined that on the average about 16 pounds of fertilizer N was needed for each ton of increased root yield resulting from the fertilizer N. For example, a 5 ton root yield increase would require 16 lbs. of N per ton or 80 lbs. of N per acre added as fertilizer. Table 1 gives estimates of fertilizer N based on varying levels of soil NO_3-N and expected root yields.[2/]

[1/] F. Jackson Hills, Robert Sailsbery and Albert Ulrich. 1978. Divison of Agricultural Sciences. University of California Bulletin 1891. Sugarbeet Fertilization.

[2/] Ibid.

TABLE 1. NITROGEN FERTILIZER RATES ESTIMATED FROM SOIL NITRATE AND EXPECTED ROOT YIELD*

Soil NO_3-N per acre 3 ft	Predicted root yield without fertilizer N†	Fertilizer N for specified roots yields (tons/acre)‡	
		30	35
lb	*tons/acre*	*lb N/acre*	
0	21	140	220
50	23	110	190
100	25	80	160
150	27	50	130
200	30	0	80
250	32	0	50

*Root yields and pounds of fertilizer N are rounded to the nearest ton and 10 pounds, respectively.
†Root yield = 21.1 + 0.042 (lb soil NO_3-N).
‡16 [(yield with fertilizer N)-(yield without fertilizer N)].

Data provided by the research also indicated that only one out of seven trials resulted in a response to fertilizer N where soil NO_3-N exceeded 225 pounds per acre 3 feet. Although soil sampling through the 6th foot was included in most of the field studies it was found that a 3 foot depth was sufficient for appropriate correlation and was more practical from a field standpoint.

As a follow-up to the development of information and data from the field trials throughout the state, soil sampling studies were undertaken in Glenn, Butte and Tehama Counties to study the variability of soil nitrate nitrogen. In three commercial sugarbeet fields 20 three foot cores were taken from each field by walking at right angles to the beds across the center of each quarter of the field (5 cores across each quarter), figures 2,3 & 4.

Approximately 53 Acres

B_1	B_2	B_3	B_4	B_5	D_1	D_2	D_3	D_4	D_5
14.6	11.3	3.9	3.7	7.7	4.3	4.5	3.5	7.4	5.7
		B					D		
A_1	A_2	A_3	A_4	A_5	C_1	C_2	C_3	C_4	C_5
4.5	6.2	5.4	8.0	7.4	4.5	4.7	2.9	4.3	4.5
		A					C		

Figure 2. ppm NO_3-N dry soil basis to a depth of 3 feet.

Approximately 70 Acres

B_1	B_2	B_3	B_4	B_5	D_1	D_2	D_3	D_4	D_5
8.0	8.0	5.4	7.4	6.2	11.6	12.3	9.8	7.4	8.1
		B					D		
A_1	A_2	A_3	A_4	A_5	C_1	C_2	C_3	C_4	C_5
5.6	5.4	5.6	5.7	4.9	9.7	6.4	7.4	12.0	16.1
		A					C		

Figure 3. ppm NO_3-N dry soil basis to a depth of 3 feet.

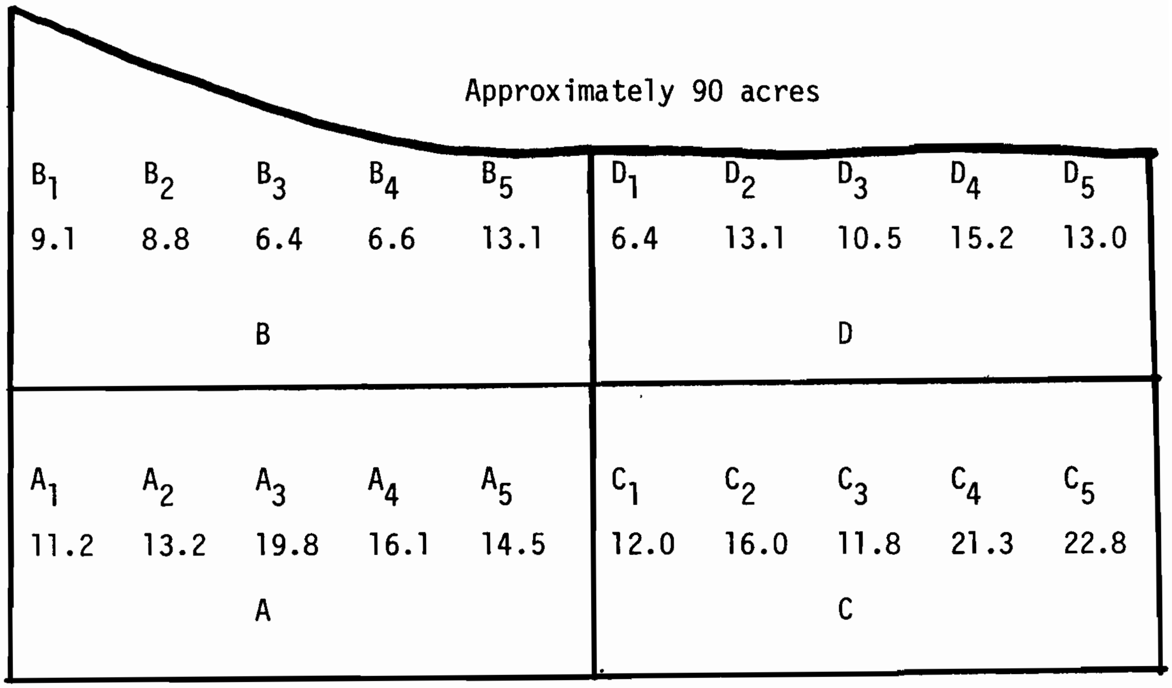

Figure 4. ppm NO_3-N dry soil basis to a depth of 3 feet.

In addition, the variability in soil NO_3-N throughout a 10 acre block was determined by taking one inch diameter cores to a depth of 3 feet involving 36 uniformally spaced samples (figure 5.)

	10 acres						Mean
	4.2	3.9	5.2	6.2	3.9	4.6	5.70
	5.4	7.1	3.5	4.6	6.8	5.5	4.45
	5.5	4.6	3.5	3.5	7.7	5.0	4.57
	3.8	3.8	3.9	5.2	5.0	5.7	4.97
	3.6	4.8	4.5	5.0	3.9	4.9	5.48
	6.0	5.8	4.6	5.0	8.0	4.6	4.67
Mean	4.75	5.00	4.20	4.90	5.90	5.05	4.97

Figure 5. ppm NO_3-N dry soil basis to a depth of 3 feet.

Size of fields, number of samples involved, means, variances and the number of cores estimated to be necessary to estimate the true mean of each field within plus or minus 20 pounds NO_3-N per acre with a confidence of 95% are given in Table 2.

Table 2. Variability in soil NO_3-N in 3-foot soil cores systematically collected from four fields.

Field	Acres	No. Samples	ppm NO_3-N/3 ft[1] mean	s^2	No. of cores to estimate u ± 1.7 ppm[2]
1	10	36	4.97	1.325	2
2	50	20	5.95	8.18	12
3	70	20	8.15	8.71	13
4	90	20	13.05	21.57	30

[1] lb N/acre 3 ft - ppm (12).
[2] ± 20 lb N/acre 3 ft.

The last column of Table 2 was calculated as $n = (t^2s^2)/1.7^2$. Note that:

$$\frac{20 \text{ lb } NO_3\text{-N}}{\text{acre 3 feet}} = \left(\frac{1.7 \text{ lb } NO_3\text{-N}}{\text{mil lb soil}}\right)\left(\frac{12 \text{ mil lb soil}}{\text{acre 3 feet}}\right)$$

The average variance of all four fields was 12.82 which would indicate the collection of 18 soil cores to estimate the NO_3-N level to within plus or minus 20 pounds per acre. The 16 to 20 cores so taken should be thoroughly mixed and immediately oven dried prior to analysis. If the soil is too wet to uniformly mix prior to drying, the entire sample should be dried, then ground and mixed prior to analysis.

Early season soil sampling for NO_3-N plus a well planned plant tissue (petiole) sampling program during the season can be useful tools in determining and monitoring a nitrogen fertilization program for sugarbeets.

ACID SOILS IN THE WEST

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Acid soils are common to California. They occur in areas of heavy rainfall, on our old terraces, as light textured, poorly buffered soils where heavy rates of acid-forming fertilizers have been used, and as peats and mucks. Not all of these soils need or respond to lime. In determining the most effective management practices for these soils, properties in addition to their acidity must be considered.

Soils become acid when the basic cations (primarily calcium and magnesium) of the soils' exchange complex are replaced by the acidic cations hydrogen and aluminum. This influences other chemical and biological reactions resulting in both increases and decreases in the solubilities of other elements. Most influenced are the solubilities of aluminum and manganese, which in many cases reach toxic levels at about pH 5, while the availabilities of calcium and molybdenum are decreased frequently to deficient levels. Also altered are the activities of the microorganisms involved in the transformations of the nitrogen, phosphorus and sulfur compounds of soils, and the effectiveness of the nitrogen fixing microorganisms associated with leguminous crops. The effects on the soil as a medium for plant growth can be large.

Acid soils are commonly identified, and for the most part characterized, by the pH of their surface layer. Characteristics of subsurface layers are generally not evaluated. In addition, soil levels of available aluminum, manganese, calcium and molybdenum are assumed to be closely related to pH. In many areas and for many soils these assumptions are reasonably correct and liming recommendations based on pH and lime-requirement tests of surface soils are adequate. For many soils, and particularly for those from intensively managed areas, additional factors should be considered. The aluminum ion concentration of the soil solution is known to be controlled not just by the solubility of gibbsite but also by the concentrations of soluble complexing anions. Among the complexing anions for which there is good evidence are phosphate and soluble organic matter. Likewise the soil's level of available calcium and molybdenum, and its potential for supplying manganese, are known to interact with lime. Other factors of concern include the exceedingly diverse sensitivity of plant species and cultivars and the strain of legume nodule bacteria to acid soil conditions. In addition the characterization of acid soils should include not just the properties of their surface layers, but also those of the deeper layers that supply much of the water and nutrients to the crop.

Fertilizers, particularly nitrogen fertilizers, are presently a major cause of soil acidification. Many of our intensively managed soils are being increasingly acidified. To assure continued production of high yields of good quality crops on these soils we need to better understand the nature and causes of acid soil infertility and to enhance our ability to characterize and predict lime requirements.

COMPARISON OF LINEAR MOVE SPRINKLER AND FURROW IRRIGATION IN COTTON

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A project was conducted in 1982 to objectively compare the fate of irrigation water and crop responses of cotton using two irrigation methods--furrow and linear move sprinkler (LMS). The principle objectives were to measure and compare the various components of the water balance, including gross application, crop water use (ET), deep percolation below the root zone, end-of-field runoff, seasonal changes in soil water storage, and with the LMS, spray evaporation losses. We recognized that it is essentially meaningless to compare two irrigation methods unless the basis for management of both systems is the same. In other words, is the same criteria used to determine the timing and amounts of water applied per irrigation? The ideal basis for comparison is the use of the best management practices for both methods, and this is arrived at by the proper judgement of technically trained personnel. Additionally, a valid comparison requires that each system be correctly designed. For these reasons, this project was conducted with a grower - cooperator that maintains a staff of engineers and irrigation schedulers who use advanced techniques of water management.

The study took place on two adjacent 75 acre commercial fields located in Kern County and classified as Wasco sandy loam. Both had similar cropping histories and were managed identically, except for the irrigation. Head ditches and plastic syphon pipes were used with quarter mile runs in the furrow field, and the LMS utilized a half mile long traveling boom that picked up water by using a travelling weir in a leveled-to-grade, concrete lined ditch. These fields were instensively instrumented and monitored to collect information necessary to calculate a water balance.

The most ambitious effort involved evaluating the application efficiency of each irrigation in both fields. While this was relatively easy with the LMS, it proved highly demanding of time and resources for the furrow field. A complete system evaluation was made using selected furrows during each of the 10 irrigations (one preplant and nine post plant). Measurements included rates of volumetric onflow, infiltration (using both ring infiltrometers and orifice plates to assess inflow and outflow from a test section of the furrow), advance, and runoff. These evaluations were complicated by the use of alternate furrow irrigation, changing syphon numbers per furrow during the season, and the widely different hydraulic transport properties of the furrows in relation to wheel traffic. With the vast amount of data collected, analysis has not been completed at the time of this writing. Without this information, it is dangerous to compare the critical aspects of water management. Therefore, currently available water balance information will not be presented piecemeal. However, the data analysis has yielded interesting water intake results that give an indication of the complex nature of surface irrigation dynamics.

The soil infiltration rate is one of the primary factors affecting furrow irrigation efficiency, and the data show wide variations, both in relation to time during the season and whether the furrows support traffic (TF) or are non-traffic furrows (NTF). Using the total amount of water, expressed as a depth in inches, infiltrated in the ring infiltrometers over a 24 hour period as a basis for comparison, replicated measurements showed 13.5, 6.0, and 3.0 inches during the preirrigation, first, and last post plant irrigations, respectively, in NTF. Equivalent data for TF, showed 3.1 during the first and 1.0 inches during the last post plant irrigations (the preirrigation was not evaluated for TF). These measurements clearly demonstrate that, 1) soil compaction due to wheel traffic significantly decreased the surface conductivity, and 2) mechanisms, that are not well defined or understood, resulted in the soil intake rates decreasing with time during the season. These phenomena, which are difficult to quantify even with direct measurement due to spatial variability, complicate the job of the irrigation scheduler who strives for best management practices. It is hoped that thorough analysis of the voluminous amount of data collected during the furrow irrigation evaluations will generate information useful in developing strategies to deal with these problems.

While varying infiltration rates present difficulties for good water management, we found that they also influenced crop yield. The magnitude of this affect depended on the irrigaion method. In the furrow irrigated field, it became apparent in early June that the plants located in beds adjacent to TF were not developing as fast as those in beds bordered on both sides by NTF. By mid July, however, the situation had reversed itself, with the smaller plants now located in the rows adjacent to NTF. No such growth differences were observed in the LMS field. To investigate the influence of these different growth habits on yield, six, six row planting patterns in both fields were harvested and weighed as individual rows, with care taken to record their position in relation to TF. Table 1 presents this information calculated in bales/acre. Note the large differences in yields measured from the surface field in relation to wheel traffic orientation; the rows inside the TF produced 28.6% less than the average yield, while the rows bordered by NTF yielded 44.2% more. The same trend is apparent in the LMS field, but the magnitude is much less. Equivalent data to the above is 6.9% less and 5.0% more. The striking variation in yield with row orientation demonstrates the different factors that control water intake with LMS and furrow irrigation.

In surface irrigation, infiltration is largely dependent on soil transport properties. The amount of water that moves into the profile depends mostly on hydraulic conductivity and the duration of the irrigation. On the other hand, infiltration with a properly designed LMS is determined by the system itself, and since the application rate should not exceed the saturated infiltratin rate, the distribution of infiltrated water should be more uniform. This means that soil water was more equally available in the LMS field with the consequent affects on yield. The disparity in water intake in the furrow field associated with traffic-induced compaction was presumably responsible for the yield differences with row orientation. This conclusion is supported by plant based measurements of leaf water potential that showed TF adjacent plants generally had lower (more negative) values.

Conclusions from this project await the complete and in-depth analysis of the sytsem evaluation data. Some preliminary observations are as follows:

1) Precise estimates of ET are more easily utilized for water management when the irrigation system can apply precise amounts of water.

2) When infiltration rates are changing in relation to wheel traffic orientation and time during the season, water management decisions are extremely difficult and

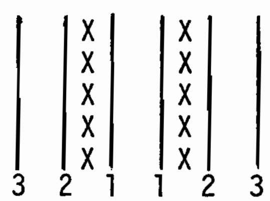
subject to error.

3) Linear move sprinklers simplify irrigation management for all members of the irrigation team, from the technically oriented irrigation scheduler to the field laborer, and seem to be the preferred and most supported method by field personnel.

Table 1. Yield comparison of rows comprising a six row planting pattern based on orientation to traffic furrows.

Irrigation Method	Pick No.	Rows Inside[1/] Traffic Furrows	Rows Outside Traffic Furrows	Rows Adjacent Non-Traffic Furrows	Six Row Pattern Average
		---bales/acre---			
Surface	1st	1.41[2/]	1.68	3.02	2.04
	2nd	0.19	0.20	0.21	0.20
	Total	1.60 (-28.6%)[3/]	1.88 (-16.1%)	3.23 (+44.2%)	2.24
Linear Move Sprinkler	1st	2.38	2.55	2.61	2.51
	2nd	0.03	0.08	0.11	.08
	Total	2.41 (-6.9%)	2.63 (+1.5%)	2.72 (+5.0%)	2.59

1/ The row orientation in a six row planting pattern is as follows:



1= rows inside traffic furrows
2= rows outside traffic furrows
3= rows adjacent non-traffic furrows
x= traffic furrow

2/ Yield numbers shown were calculated based on 500 lb bales, measured turnout percentages, and represent averages of six replications.

3/ Number in parenthesis represent the percentage differences relative to the total average yield of the six row pattern.