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1993
CALIFORNIA PLANT
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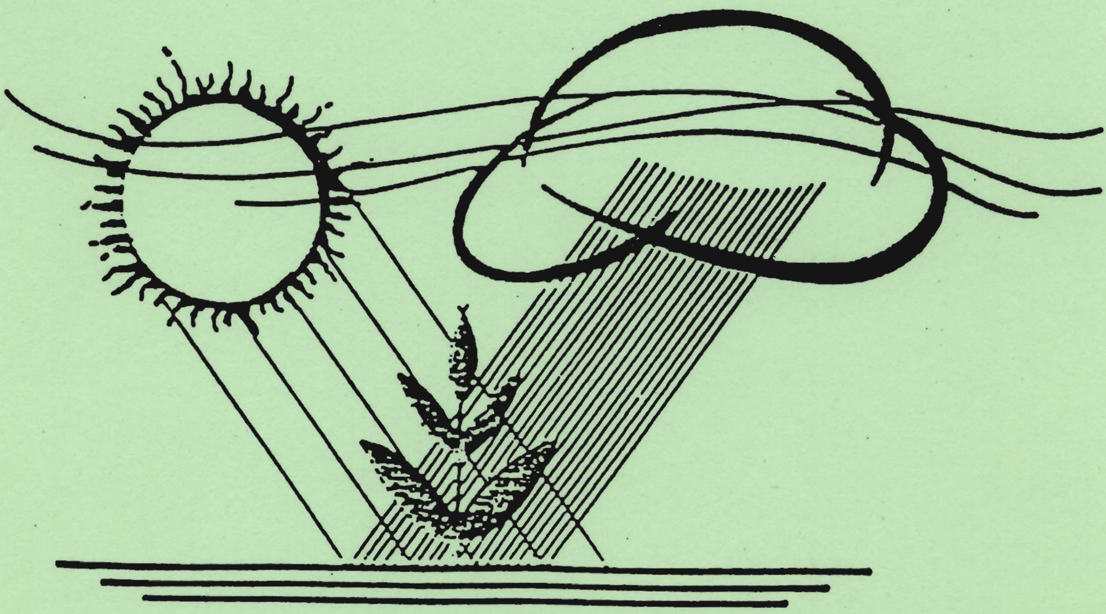
AGRICULTURE'S CHANGING ROLE IN RESOURCE MANAGEMENT



CALIFORNIA CHAPTER
AMERICAN SOCIETY OF AGRONOMY

CALIFORNIA FERTILIZER ASSOCIATION

January 25-26, 1993
Radisson Hotel
Sacramento, California

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Improving Fertilizer Management - The Objective of BMP's

Roland D. Meyer, Extension Soils Specialist
LAWR Dept., University of California, Davis

Much has been said about Best Management Practices (BMP's) as the principle means by which fertilizer and chemical applications can be used in agricultural production to improve any negative effect they might have upon our environment. Some have perhaps over estimated the beneficial effect BMP's may have on improving certain environmental impacts while others tend to minimize the potential positive effects.

A Best Management Practice or BMP can be defined as any technique used to improve land management or the utilization of crop growth inputs for agricultural production which also enhance or have no detrimental effect on environmental quality. These techniques can reduce soil erosion, improve water use, increase utilization of fertilizer nutrient applications, improve efficiency of biological or chemical application for weed, insect or disease control or optimize the use of competing alternatives to minimize environmental impact.

Nitrogen is the essential nutrient used in the largest quantities for crop production and is of greatest concern in the environment because of groundwater contamination with nitrates. Greater attention must be focused on the proper management of nitrogen in agriculture in order that groundwater not be degraded to any larger extent. This includes the proper handling of manures, fertilizers and others sources such as septic tanks, yard wastes, sewage sludge as well as other waste products.

Several key elements: the crop, fertilizer, soil and the growing environment need to be considered carefully to insure that the nitrogen applied results in the greatest benefit and the least negative impact. Each crop has a range in its nitrogen requirement depending on the yield potential for different soils and climatic regions whether it be a dryland or irrigated growth environment. Corn grown for silage requiring 250-300 lbs N/A has a greater 'crop need' than grapes which require perhaps only 20-50 lbs N/A. Fertilizers, particularly if manures are considered as well, have much different characteristics in terms of release rate, need for incorporation to reduce ammonia volatilization and ability to be leached or denitrified. Soil characteristics such as organic matter content influence the quantity of nitrogen released to a growing crop just as irrigating a sandy textured soil can result in greater leaching of nitrate-nitrogen. Whether crop production occurs in a dryland or 'rainfed' environment in contrast with an irrigated agriculture required different nitrogen application considerations.

POINT INJECTION FERTILIZER APPLICATION (PIFA)

J. Julian Smith and Paul S. Belzer[1]

ABSTRACT

Point injection of fertilizer solutions is a sub-surface placement technique that creates discrete zones (nests) of nutrients in the crop root zone. Spoke wheel, single probe and high pressure applicators have been field tested over the past decade. Agronomic performance data for a variety of cropping regimes have been promising. Benefits include sub-surface placement with minimal soil disturbance, reduced energy costs and increased fertilizer use efficiency.

INTRODUCTION

In the quest for improved agronomic, economic and environmentally sound performance, all manner of application techniques have been tested over the years. Due to the well documented effectiveness of localized nutrient supply, placement methods tend to dominate agronomic and application research. Conceptually, this aspect of crop husbandry has advanced little in nearly 150 years. In the mid-nineteenth century, the multi-coulter "water drill" of Thomas Chandler, through simultaneous placement of fluid fertilizer and seed, improved the yield of small grains 30-60 percent. However, it is the integration of modern crop agronomy with substantial advances in engineering, material and computer sciences which still makes fertilizer application a dynamic research area.

Point injection fertilizer application (PIFA) has enjoyed engineering and field research in Europe and North America over the past 10-15 years. Agronomic performance data remains encouraging, particularly as more crops over a wider geographic and climatic range are tested. The following is a brief review of point injection application history, some pertinent agronomic data and concludes with some options for future development.

APPLICATION HISTORY

To a large extent, the physical characteristics of a fertilizer material will dictate application efficacy. Despite tremendous advances in dry fertilizer placement and broadcast technology, the simple ability to pump and accurately meter homogeneous nutrient solutions means that many new and developing application technologies involve

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Paper presented at the 1993 California Plant & Soil Conference, Sacramento, Jan 25, 1993

fluid fertilizers. Irrespective of fertilizer form, application technology must keep pace with agronomic advances and must also meet the following three criteria:

1. It works (agronomics and engineering).
2. It is durable.
3. It is not cost prohibitive to the grower.

Point injection is a liquid fertilizer application technique and the criteria listed have been tested through a variety of applicator designs.

Spoke Wheel Applicators.

Although European and Florida prototypes probably pre-date it, the developmental applicator researched by Baker *et al* at Iowa State University is the model that stimulated much of the field trialling in the mid-western U.S. and Canadian Prairies (Figure 1).

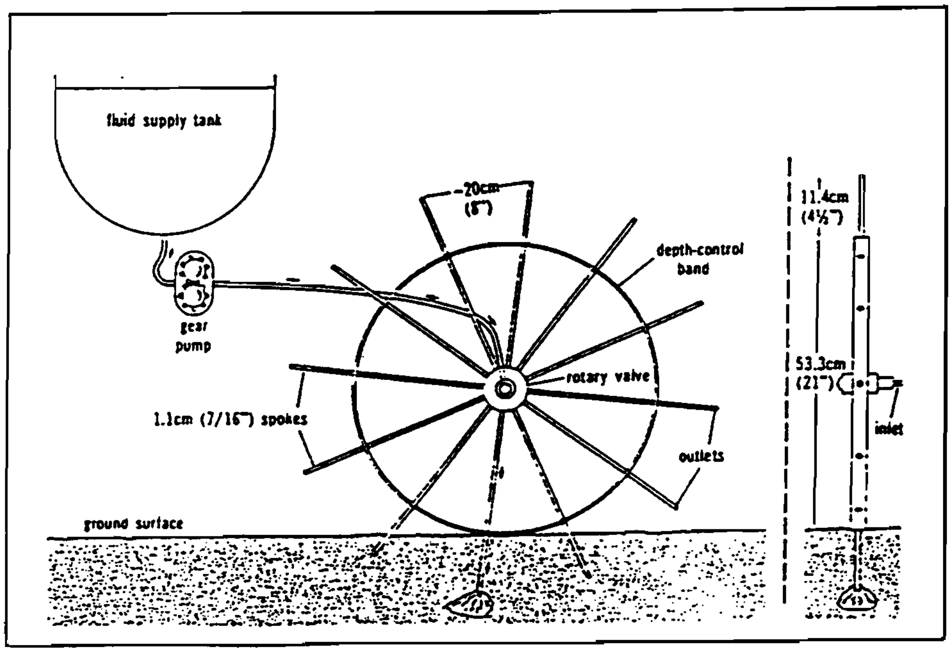

FIGURE 1. Schematic of the Iowa State University spoke wheel PIFA.

The spoke wheel PIFA is a tractor-pulled wheel device that meters fluid fertilizer in to a ported axle. The fertilizer thus flows from the spokes as the wheel rotates. The 4 to 6 commercially available spoke wheel units are mounted on a tool bar to accomodate variable row spacings and deliver fertilizer to the soil at 8 inch spacings to a depth of 4 inches. At forward speeds of 4-4.5 miles per hour, a spoke wheel applicator may have only one-third of the power requirement of certain knife injection systems.

A spoke wheel with a good track record over some 50,000 acres in the western U.S. and Canada is the applicator designed by Pattison Bros. of Lemberg, Saskatchewan. This spoke injector consists of 12 hollow stainless steel spokes which penetrate the soil as the wheel turns. Liquid fertilizer is placed ("nested") at 8 inch intervals and 3-4 inches below the soil surface. Liquid fertilizer under low pressure is supplied to each spoke through the wheel hubs. A rotary valve located in the hub meters an accurate amount of fertilizer to each spoke. Both soil penetration and wheel protection under field conditions are afforded by a spring loaded shank. A strengthened spoke tip makes for durability and the fertilizer outlet is set below the tip to prevent plugging.

The spoke wheel has proven successful for urea-ammonium nitrate (UAN) solutions and other clear liquid fertilizers. We are aware of only one spoke wheel applicator that was developed for the purpose of applying higher nutrient content suspension fertilizers.

Almost 10 years of field evaluation have produced design refinements for available spoke wheels. Concerns related to spoke plugging, coping with heavy trash, matching forward speed and fertilizer application rate, hub integrity, durability and maintenance costs have largely been addressed by manufacturers. Future spoke wheel models will continue to be improved commensurate with acres covered.

Single Probe PIFA.

Aiming for the same agronomic traits as the spoke wheel, a single probe-type fluid fertilizer injector has been developed by Tompkins and Womac, University of Tennessee, Knoxville. The hydraulically driven single spoke injector enters and exits the soil as the unit moves forward. Field evaluation of the prototype revealed that a variable injection interval of 8-24 inches at a depth of about 2.5 inches could be achieved without significant soil disturbance. Further engineering research will be necessary to increase forward speed and to improve soil penetration. A potential development of the probe injector is the linking of actuation with an "electronic eye" to ensure that fertilizer is applied only where plants are detected.

Pulse Bander PIFA.

The pulse bander applicator developed by Rogers Engineering, Saskatoon, Saskatchewan, has the potential to offer sub-surface fertilizer placement (as PIFA) with minimal soil and residue disturbance, of particular importance to the no-till farmers of the Prairies. Unlike the Nutriblast Applicator (Arcadian Corporation) which injected a continuous band of fertilizer under pressure (2,000 psi), the pulse bander utilizes a pulsating high velocity jet to inject fertilizer at various intervals to a depth of 3-4 inches. Flow volume and distance between pulses is regulated electronically and liquid fertilizer is pressurized up to 6,000 psi.

AGRONOMICS

The bulk of spoke wheel agronomic research has thus far concentrated on the efficiencies of nitrogen placement and split timing in corn and small grains. A variety of data available suggests that the following agronomic benefits can be anticipated through the use of the spoke wheel applicator.

* improved yields afforded by the efficiencies of split timing and placement, sometimes with fertilizer rate reductions (Table 1, Table 2).

TABLE 1. No-till corn yield affected by method and timing of N placement - 156 lbN/ac (Iowa State University).

Application	Timing	
	Pre-Plant	Post-Plant
	--bu/ac--	
Knife	176	172
PIFA	188	193

TABLE 2. Effect of nitrogen application method on yield of no-till winter wheat in northern Montana (Kushnak & Gallagher, Montana State Univ. 1989).

Site		Pre-plant	At jointing			LSD
	Check	Knife	Broadcast	Band	PIFA	(0.05)
			-- bu/ac --			
Dryland	28	33	40	39	37	6
Irrigated	40	36	52	53	67	11

N source as UAN, 60 lbN/ac dryland, 50 lbN/ac irrigated.
Band, knife and PIFA row spacing 10 in.

* Reduced leaching, denitrification and run-off losses. Nitrogen use efficiencies can be improved (Table 3, Table 4).

TABLE 3. PIFA reduces surface run-off in conservation tillage corn (Iowa State University).

Application	Nutrient Loss	
	Nitrogen	Phosphorus
	-lb/ac-	
Surface	5.7	0.74
PIFA	0.7	0.00

P losses above those from unfertilized plots, 5 in rain.

TABLE 4. Influence of reduced rate and delayed timing of nitrogen application on conservation tillage corn yield and N leaching (Iowa State University).

Application	Yield bu/ac	N use lb/bu	Drainage NO_3N ppm
156 lbN/ac pre-plant	139	1.12	15
112 lbN/ac post/split	139	0.81	11

* Minimal soil and residue disturbance. Fertilizer placement can be achieved with little effect on moisture loss.

* PIFA facilitates post planting sub-surface fertilizer placement with no root pruning that can be associated with conventional knife applications.

Research reports on the use of PIFA technology beyond corn and small grains are somewhat scarce. However, encouraging results have been reported for alfalfa (Havlin *et al*, Kansas State University) and sugar beets (Blaylock *et al*, University of Wyoming). A number of western dealer and grower testimonials record spoke wheel successes in grapes, orchards, melons, strawberries, raspberries, tomatoes, potatoes, shallow rooted vegetables and for fertilizing through plastic mulch.

Additional field research is needed to elucidate the agronomic relevance and benefits associated with PIFA for a variety of western crops. Those crops more suited to PIFA include row crops and others likely to respond to post-planting placement but liable to damage and moisture loss following knife applications. Some interest in PIFA has been expressed by sod growers and amenity turf specialists.

FUTURE OPTIONS

Currently available PIFA technology centers on the spoke wheel machines and will likely continue to do so. Ongoing field experience can only enhance spoke wheel engineering, durability, economics and agronomics. Cropping opportunities and resultant agronomic benefits for PIFA should be pursued for the apparently high number of candidate crops grown in the western U.S. Such studies will need to evaluate economic and environmental benefits of PIFA and compare other available placement options, such as pressure injector / thin profile coulter combinations.

The majority of information presently available indicates that PIFA offers a positive, plausible application alternative for many growers. It may well prove to be one of the most significant combinations of agronomic and application technology of the nineties.

(Additional information: contact the authors, J.R. Simplot Company, Tel. 208-238-2700).

INCREASED SOLUBILITY OF POTASSIUM SULFATE LEADS TO NEW USES

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INTRODUCTION

Potassium Sulfate or Sulfate of Potash (SOP) is an old product, but may not be very familiar to a many producers or extension agents and consultants. As an alternative potassium (K) source to potassium chloride (MOP), SOP has an industry standard analysis of 0-0-50-18S. It is a dual nutrient source, supplying both potassium and sulfur. SOP is the only potassium source that is mostly chloride free, less than 1%, and low in salt content, salt index of 0.89 per unit of K_2O. It is a dry potassium source with several grades of granulation. The solubility of the fine grades of SOP is 5.4% at 68^0 F, compared to other dry potassium sources KCl and KNO_3, at 16.1% and 14.6%, respectively (Western Fertilizer Handbook, 7th Edition). These solubilities are for technical grade materials, fertilizer grade materials would be expected to be somewhat less. This creates a problem for dealers and producers that would like to have true solutions of potassium fertilizers with high K_2O content.

INCREASED SOLUBILITY

The environmental issues of today's production schemes along with imposed limitations of water for agricultural use have created a need for precision of nutrient application and a form of nutrients that can be applied with new technology, ie. drip irrigation, point injection. A desire for liquid fertilizer materials is present. Liquids can be precisely applied with conventional equipment, can be applied with irrigation methods both old and new, and can be applied with new application methods such as point injection. The need for liquid fertilizer and the need for high K containing liquid fertilizers has led Great Salt Lake Minerals Corporation to develop an increased soluble form of SOP. A true solution liquid SOP fertilizer will fill a void and result in new uses of SOP. The enhanced soluble SOP will be marketed as a dry fine grade material that the dealer will convert to a liquid. The process requires water at a temperature of 110^0 F for mixing. When the resultant liquid is cooled down to room temperature, the same analysis is maintained, that being 0-0-8.5-3S. This new grade fertilizer is approximately twice as concentrated as the original SOP as a true solution.

NEW USES

Uses for enhanced SOP will now include foliar applications where producers want a non-chloride source of potassium that will not burn the foliage. Applications in cotton to provide K for the late season potassium deficiency syndrome at a more economical return to the producer will be a new choice. Applications of K by drip irrigation systems will be possible with this new product. Injection of liquid SOP into other irrigation systems will be possible for applications on nursery and ornamentals. Greenhouse applications of liquid SOP will be possible.

SUMMARY

The production of a new fertilizer product to meet the changing needs of the producer and dealer is just one way in which this company is adapting to a changing role in today's agriculture.

FERTILIZERS AS ALTERNATIVES TO AGRICULTURAL CHEMICALS

Dr. Dale W. Rush

The following is a compilation of information, impressions and listings of common practices which are reviewed and discussed in the light of industry experience and regulatory statutes. Nothing contained herein is provided as a recommendation or advice with respect to the use of the materials discussed.

The title of this talk could be interpreted as suggesting ways that state and federal regulations might be circumvented with regarding the use of fertilizers as substitutes for regulated ag chemicals.. Such an interpretation would be incorrect. As a clarification I will start by quoting the appropriate state (Cal EPA) and federal (U.S. EPA) regulations and definitions taken from the California Food and Agricultural Code (chapter 2. Economic Poisons) and the Code of Federal Regulations (40 CFR)

> "It is a violation of federal and state law to possess or use an unregistered pesticide."
>
> "A pesticide is defined as <u>any</u> substance or mixture of substances <u>intended</u> for preventing, destroying, repelling or mitigating <u>any pest</u> or intended for use as a plant regulator, defoliant or desiccant" (underlining is my emphasis).

The prevailing interpretation is that it doesn't matter what it is that you are using, what matters is what your intent is in using it. An example might be to think about what your intent is when you turn on a water hose in a gopher hole. In reality such an extreme example is both absurd and irrelevant to any meaningful discussion of pesticide regulations or enforcement efforts, but it is an interesting point of departure.

Perception, Reality, Intent and Degree.

Lets explore the perception and reality of the use of fertilizers as substitutes for pesticides. The common dogma is that it is OK to use a plant nutrient for a pesticidal use because "it's a fertilizer and doesn't need to be registered". I refer the you back to the above quotes from the regulations which relate to the intent of use, not the material itself.

Degree, while not specifically defined is none the less a strong consideration in deciding if and when the line or more precisely the threshold has been crossed between pesticidal and prudent crop husbandry uses. Let's look at two examples. There is good evidence in scientific literature to show that the application of potassium fertilizer can result in increases in crop yield and quality that are equivalent to the use of Chloropicrin as a preplant general soil fumigant. There are no pesticidal claims being made for the judicious application of potassium which results in better root development, increased resistance to disease, and the resultant improvements in water and nutrient absorption. Alternatively, the use of a soil fumigant falls into the realm of pesticide use. The intent in the case of the use of potassium is to improve the resistance to, or tolerance of soil pathogens, while the intended use of a soil fumigant is to eliminate or at least minimize the affects of the pathogen itself. Applying potassium to improve crop performance under soil pathogen pressure is clearly not a pesticidal use.

A case where the threshold is clearly crossed is the use of hydrogen cyanamide as a foliar nitrogen source. It is not reasonable to accept the concept of applying an exotic chemical as a foliar nitrogen source to a dormant crop with no leaves. Clearly the intent was to accelerate the breaking of dormancy with an eye toward obtaining an early marketing advantage. Because of the primary intent, the regulatory agencies have declared that such a use is pesticidal in nature, and the agent must be registered. This comparison is instructional in terms of how regulatory agencies might view the subject.

Another reason that is used to justify the use of fertilizer materials for pesticidal uses, is published research reports. Industry journals often publish university and extension research where examples are given or comparisons are made, using various methods or materials to affect some problem weed or pathogen. Examples include the use of prolonged flooding or solarization by tarping to reduce certain soil pathogens, or the application of animal manure to reduce the incidence of verticillium wilt. There is no controversy in these examples, but what about using ammonium nitrate solution sprays on vegetable crops? Has the line been crossed? The first question that must be asked is - what is the <u>primary</u> intent? Does the crop need fertilizer during this period? Is ammonium nitrate an appropriate material? Is the rate of application consistent with good agronomic practice? If the answers to these questions are yes, which in this case they are, then incidental desiccation of emerging weeds in the spray pattern is probably of little regulatory consequence. The use of ammonium nitrate as a desiccant on grape vines to remove the foliage may be another matter entirely.

There is an additional key point with respect to the reference to research reports where pesticidal activity may be noted or suggested. That is that there is no law against reporting research findings. The important test is not that performance is reported, but that of making claims and offering for sale for the purposes in the pesticide definition listed above. Written claims (tech sheets, advertising etc.) which promote a regulated use will trigger a requirement for registration with both federal and state agencies. For example, an advertisement for using ammonium nitrate solution for weed control purposes would represent a pesticidal claim, requiring registration.

An additional example is the application of combinations of urea sulfuric acid and phosphoric acid to dormant alfalfa. It is common to include a tank mix of a soil active, systemic or contact herbicide to such mixes. The primary value of this mixture is to act as a strongly acidic soil amendment, high analysis N P S fertilizer and as a carrier for the added herbicide. The physical affect that these acidic tank mixes have on any vegetation is obvious but secondary to the primary criteria for use as soil amendments and fertilizers.

It appears that there is both rigid definition and flexibility in the interpretation of the rules governing pesticidal uses of ag chemicals. Much of the potential for exercising that flexibility rests in hands of the seller and user community. If flagrant inappropriate recommendations or uses occur, then regulatory authorities must enforce the letter of the statutes and impose them impartially on all users. This is a case where the whole industry may suffer because of the impropriety by a few flagrant violators. The promotion of the use of hydrogen cyanamide as a foliar nitrogen fertilizer is a good example.

There are some other tests that can be applied in the evaluation of an intended use of a chemical or fertilizer. Probably the most significant and telling is to answer the question: Is the action and response physical or physiological in nature? If you smash a bug with a hammer,(physical) you do not need a registration for the hammer. Perhaps more subtle but also more relevant is to consider chemical frost protection agents. There are two different and unrelated modes of frost protection with chemicals. One is strictly physical and the other is physiological. The sellers of physical inhibitors (usually liquid organic polymers) claim that they function by reducing the transpiration of water by a coating effect, and thereby slow the loss of heat out of the plant canopy. On the other hand, ice nucleation inhibitors such as urea, act by modifying proteins (physiological) in living and dead leaf residing bacteria. Regulatory agencies have interpreted this activity as "modifying a plant or pest" which falls under the definition of a pesticide. Therefore, urea when applied foliarly as a fertilizer, does not require a registration. But if used as a frost protectant then it becomes a pesticide and must be labeled accordingly.

Another example is the use of acid based materials to remove or prevent the build up of minerals in low volume irrigation systems, cooling towers etc. The activity is a physical phenomenon, and as such does not fall under pesticide regulations. However if such materials are promoted to remove living matter such as algae or bacteria then they become pesticides. There are other examples including a recent case in California where a substantial fine was levied against a company for selling chlorine without a registration for use in water, where the <u>intent</u> was clearly biocidal in nature.

Urea sulfuric acid formulations are perhaps one of the best examples of intent dictating the regulatory status. One of the most common formulations is used as a fertilizer, water treatment agent, and soil anti-crustant. The identical formulation is also registered with the EPA as a herbicide and desiccant. If the primary intent is to fertilize it is not regulated as a pesticide, but if used as a desiccant or herbicide, then the user must have a valid pesticide label.

Sulfur dioxide (SO_2) is another case where if used as an oxidant or dehydration agent or as a water amendment (acidifier) it is not regulated as a pesticide. However if SO_2 is used for fumigant or fungicidal purposes it must be registered. The same is true for elemental sulfur. If used as a soil amendment it is not regulated, if used as a fungicide, it must be labeled.

Ammonium thiosulfate is a widely available, popular, liquid nitrogen and sulfur source that requires no pesticide registration when used as a fertilizer. It has also been evaluated as a bloom thinning agent, plant desiccant and nitrification inhibitor. These uses require a pesticide label and are not currently legal.

Recently, I came across a registration for sugar (sucrose). It is used as an attractant in certain pesticide baits and must be registered by the state. If you use it as a fertilizer (there are such recommendations) or put it in your coffee, the label does not have to be in your immediate possession, and the use rate is dictated by solution chemistry rather than a residue tolerance.

There is one additional criteria that can affect the requirement or lack thereof for a pesticide registration. It is more bureaucratic than use oriented but should be considered. That is the case for feed additives and preservatives. If we take the case of the addition of ammonia or urea to straw or other ruminant feed as non-protein nitrogen, it is not regulated as a pesticide but by the food, feed, and drug agencies. If we treat hay, silage, alfalfa etc. with ammonia or urea as a preservative then it is still treated as a feed additive and is not regulated as a pesticide, even though the addition may be to act as a preservative by preventing the growth of fungi and bacteria. Go figure!

Summary

The nature of how state and federal regulations are written precludes the notion of substituting a fertilizer or other chemical for a registered pesticide use. The key to any proposed use is the intent behind the application. If <u>primary</u> intent is to physiologically mitigate a plant or pest as defined in federal and state regulations (see above) then it is a pesticidal use, no matter what material is being used. If the primary intent is to fertilize a crop or otherwise physically affect the delivery to a crop such as an irrigation system, and no claims are made for any other activity, then it does not fall under pesticide regulations, assuming that the intended use is reasonable and appropriate. If there is a question, the use can be referred to the regulatory authorities, who will make a determination that will be universally and restrictively applied in accordance with the regulations.

REGULATION OF NON-TRADITIONAL FERTILIZING MATERIALS

Matthew W. Reeve
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Background

Fertilizing materials are regulated under four different categories; commercial fertilizers (specialty fertilizers are a specific category within commercial fertilizers), agricultural minerals, packaged soil amendments and auxiliary soil and plant substances. The distinction from one category to the next is based upon the content of the product and associated product claims, such as plant nutrient percentages. The majority of the nontraditional fertilizing materials are regulated as auxiliary soil and plant substances.

In order to substantiate certain product claims, companies are required to provide efficacy data. The data requirements are extensive, yet necessary to determine the product's performance in California's diverse agricultural environment. Efficacy guidelines are sent to the registrant as a tool to help the manufacturer prepare a protocol for his or her field studies.

Nontraditional Fertilizing Materials

Non-traditional fertilizing materials are among the most interesting and oftentimes challenging to regulate. Manufacturers often believe they are the only experts on their particular product and that comments from outside experts (such as University researchers) are uninformed and inaccurate. This particular group of people can also be among the most volatile and argumentative of the industry.

The majority of nontraditional fertilizing materials evaluated by the Feed, Fertilizer and Livestock branch are unable to substantiate their product claims. Yet, there are a few examples of products which are truly innovative and do show positive results in the field.

Humic acids

Humic acids have had a long and colorful history in agriculture. Miraculous results are commonplace in the agricultural rumor mill, yet few definitive studies have established the agronomic utility of the material. The majority of studies which do show positive results are conducted either in hydroponic environments, or in sand media. In addition, the suggested label rates of manufacturers are so dilute that little, if any response would be observed in the field.

From a regulatory standpoint, humic acids are a moving target. The sources of the material vary widely from leonardite to seaweed extracts, and the laboratory methods used to evaluate the existance and or percentage of the material are too general to provide any adequate information on the actual constituents of humic acids. Nonetheless, humic acids are commonly used in agriculture and will most likely continue to be as growers experiment with different materials in an effort to enhance their crop yields.

Claims for humic acids can vary from enhancing the effectiveness of fertilizers and pesticides to increasing yield substantially. The only claim acceptable for humic acids on product labels is "may increase the uptake of micronutrients" because there is some evidence supporting the complexing ability of humic acids when used in conjunction with secondary and micronutrients.

Humic acids use and popularity tend to follow a cyclical pattern in agriculture and are currently on an upswing with the resurgance in popularity of "organic fertilizers" (e.g., passage of AB 2012). There are currently no plans to revise the labelling or the laboratory method for humic acids, so it is the consumer who will make the final decision regarding the efficacy of the material in agriculture.

Examples of unsubstantiated label claims for humic acids

1. Increases water-holding, buffering, and exchange capacity of the soil.
2. Benefits the physical, chemical and biological properties of the soil.
3. Acts as a plant growth hormone.
4. Builds up humus in the soil.
5. Provides a continuous supply of nitrogen for crops in subsequent growing seasons.
6. Acts as a soil conditioner.

Low analysis fertilizers

With the revision to the law for specialty fertilizers in 1990, low analysis fertilizers were now being regulated. Generally, the lower the analysis, the greater the number of product claims on the label. Product claims include increased blooming, greater yields, increased pest resistance, reduction or elimination of additional fertilizer use, etc.. One of the more incredulous statements found on a brochure was a claim for controlling white flies and aphids on ornamentals. To add insult to injury, this product which is essentially tap water, does quite well in the marketplace (sales) and is distributed by some major store chains throughout the state.

Low analysis fertilizers sold only for agricultural use (versus home and garden use) are regulated as agricultural minerals. The main issue regarding these products are the claims (primarily verbal) for plant growth regulating compounds in the kelp extract materials. This has presented some difficulties for the regulators of pesticides and fertilizers. The Feed, Fertilizer and Livestock Drug branch does not regulate plant growth regulator claims even though these claims may be listed on fertilizing material labels. Instead, the Department of Pesticide Registration is the lead agency in this area. Continual interaction between the Department of Food and Agriculture and the California Environmental Protection Agency are necessary to address this ongoing concern of both private industry and government.

One positive result of regulating these low analysis fertilizers is that the CDFA can evaluate the product labels and advertising materials prior to distribution, thereby reducing the possibility of the manufacturer adding unsubstantiated product claims.

Examples of unsubstantiated label Claims for Low Analysis Fertilizers

1. Stimulates root and leaf growth in plants.
2. Restores vitality to stressed plants.
3. Makes plant hardier.
4. Reduces antagonisms (?)
5. Increases blossom yield.
6. Its a complete food.
7. Your plants will be sturdier and produce more beautiful vegetables that you ever dreamed possible.
8. If you use a tank-type sprayer and foliar feed along with regular root feeding once a week YOU WILL HAVE NO MORE APHIDS, WHITE FLIES OR SPIDER MITES.
9. WHITE FLIES, APHIDS & SPIDER MITES do not like potassium!! BUT YOUR PLANTS LOVE IT!! HOW MUCH MORE PERFECTION COULD YOU FIND IN A PLANT FOOD!!
10. THINK OF ALL THE INSECTICIDES WE CAN KEEP OUT OF YOUR PRECIOUS ATMOSPHERE. Incredible you say? You bet it is!!
11. YOU'LL SEE SPECTACULAR RESULTS IN ONLY DAYS!!
12. WE SAY OUR PRODUCT HAS REINCARNATION POWERS!!
13. "MAGIC JUICE"
14. No other fertilizer is necessary.

Microbials

Microbials are among the most difficult for manufacturers to register due to the label and efficacy requirements. Oftentimes what is efficacious in the greenhouse, is inconsistent in the field. The vast majority of the few products currently registered as Auxiliary Soil and Plant Substances are

Rhizobium species. In addition to the Rhizobium species, several mycorrhizal species are acceptable for registration. Other biotic products require the submission of efficacy data before they are acceptable for use in California.

In order to bypass the regulatory requirements, a few firms illegaly sell liquid solutions which they claim contain agronomically beneficial microbials. These products are generally a mystery because neither the manufacturer nor the buyer have any specific knowledge on the concentration or types of microbes (if any) in the final product.

These products can be difficult to regulate because of the transient nature of the "manufacturers". For example, a firm may "go out of business", when in fact they are conducting the same business, just under a different name. Also, the company may just move operations to another locale without informing the regulatory authorities. This ability to circumvert the law may soon change, however, with the new citation program, in which field inspectors now have the ability to fine companies selling unregistered products.

Examples of unsubstantiated label Claims for Microbials

1. A non-polluting, ecologically sound, area compost starter, biofertilizer which improves the soil structure and assures a balance in soil metabolism, with the product of stable humus.
2. _____ aids these basic biological functions to such an extent that many farmers are able to reduce the application of chemical fertilizers by up to 25% in the first year.
3. All crop residues should be recycled to the soil and ____ will help decompose them within 6-13 weeks if moisture and oxygen is available.
4. The enzyme systems, microorganisms, and microbial excipients in ____ stimulate high seed germination rates, and promote early plant vigor during the critical time of crop stand establishment.
5. ______ stimulates the production of Phytamins in the soil for the

plants. Phytamins are an important part of the soil solution, they are created by the soil life to control plant growth and vigor.

6. _____ gives you the flexibility and freedom of choice to use an alternative to chemical control of nematodes without the use of a nematicide.
7. Neutralizes chemicals and oil from the soil, in turn liberating nitrogen and minerals, thus enriching the soil.

Gel polymers

With the continuing drought in California, many homeowners have experimented with gel polymers in their potting media and turf in the hope of saving water. Yet, depending upon the soil type, level of dissolved salts in tap water, use of fertilizer, type of gel polymer, etc., these materials have had mixed results in enhancing the moisture holding properties of soil and potting mixes.

Exorbitant claims were commonplace on gel polymer labels and brochures until quite recently. A combination of regulatory pressure and declining consumer confidence essentially forced manufacturers and distributors to remove most of the overstated claims from their advertising materials and to emphasize the actual benefits of the product. This is one example of how consumers played a contributory role in reducing the spread of unsubstantiated label claims.

The currently accepted claims for gel polymers are "increases the water holding capacity of moist soils" and or "reduces watering frequency". Any additional claims would require the submission of efficacy data.

Examples of unsubstantiated label claims for Gel Polymers

1. Introducing the most absorbent product known to mankind!
2. REDUCE WATERING INTERVALS AND USAGE BY OVER 75% - WHILE PROMOTING FASTER GROWTH AND HEALTHIER PLANTS!

3. NOW, FOR THE FIRST TIME, HOUSEPLANT LOVERS CAN GO ON VACATION WITHOUT WORRYING ABOUT WATERING NEEDS OR SIMPLE TRANSPLANT SHOCK!
4. GROWERS CAN WATER LESS, PROMOTE FASTER GROWTH AND HEALTHIER PLANTS AND MOST OF ALL SHIP WITH FAR LESS CONCERN ABOUT LOSSES!
5. INCREASES INFILTRATION RATES OF WATER THROUGH CLAY SOILS BY THE CONSTANT HYDRAULIC EXPANSION AND CONTRACTION OF THE CRYSTALS AS THEY ABSORB AND RELEASE WATER TO THIRSTY PLANTS!

Conclusions

Nontraditional fertilizing materials have always been and will continue to be a part of agriculture. The majority of these products evaluated by the CDFA do not prove in the field what is claimed on accompanying advertising materials. However, that certainly does not mean that all of these products are not efficacious in the field, nor is it the intent of the regulator to prevent the introduction of the useful products from entering the marketplace. Instead, the role of the regulator is to create a "fair playing field" among fertilizing material producers, and to protect the consumer from fraudulent products. It is the responsibility of the manufacturer to provide scientific evidence to prove the viability of the product in the field.

Private industry plays an essential role in informing the responsible regulatory agency of the distribution of unregistered products and of questionable claims on product labels or advertisements. As a regulator, I strongly promote this self-policing activity within the industry because private sector can be the eyes and ears of the department. Producers of questionable fertilizing materials who are very loose lipped when discussing the benefits of their product to buyers, are less inclined to contact the local field inspector for similar reasons.

Kenaf Production on a Saline Soil and Its Effect on the Salinity of Soil and Shallow Aquifer

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The soils of the Westlands Water District located in the Central California San Joaquin Valley (SJV) areas have salinity and a shallow water table problem. The water table varies between 0.2 and 1.5 m (13). For these soils to be productive, they must be drained to keep the water table below the root zone and to lower soil salinity. Drainage water high in salt and selenium, until very recently, was disposed of in the Kesterson Reservoir and proved to be a health hazard to the fish, wildlife, and humans in the area due to accumulation of salts, selenium, and other toxic minerals. At present, the Kesterson Reservoir is closed and there is no outlet for the drainage water that is accumulating in the soil and causing the water table to rise and soil salinity to increase. If nothing is done to combat this problem, by the year 2000, 400,000 hectares (ha) of land will become highly saline and no longer suitable for crop production. This will result in serious loss in crop production, farm income, and employment (13). Although, soil salinity and shallow water table problems are acute on the west side of the SJV, California, the results of this study will not only be important to California but also to the other western states where irrigation is vital for maintaining crop productivity. The solutions being sought to overcome this problem are both short-term and long-term. A short-term, but poor solution is the establishment of on site evaporation ponds. The water in ponds evaporates, resulting in high concentrations of salts, selenium, and other toxic ions that are harmful to wildlife. In addition, there is a possibility of leaching this concentrate into the underground water and causing it to become high in salts and selenium. Furthermore, the ponds take about ten to twenty percent of land out of production. One long-term solution sought is to grow salt-tolerant trees such as Eucalyptus and Casuarina species. The other crop under study is *Atraplex canescens* (8). An alternative ameliorative practice is to grow a multipurpose annual crop that can tolerate the existing conditions and that can reduce drainage water disposal volume.

Growing a multipurpose crop, such as kenaf, that is moderately salt tolerant and can use part of its water requirements from the shallow water table, and remove substantial quantities of salt from the soil, appears to be an economically viable method of ameliorating the problem and lowering the salinity of soil and the shallow aquifer .

Kenaf (*Hibiscus cannabinus L.*), an annual crop, is a source of fiber that can be used for making high quality paper and other related products and cattle feed (3,5,9,12). It can be grown in the San Joaquin Valley as a cash crop (1). It is known to be moderately salt tolerant and can be grown on any soil type including saline soils (1,2,4,5,6,10). Curtis and Lauchli (4) reported a kenaf seedling yield decrease of 20 to 40 and 70 to 80% by 75 and 150 mmoles of NaCl, respectively in the growth medium. According to Francois et al. (6) kenaf grown on saline soil irrigated with saline water showed 11.6% yield decrease for each unit increase in soil salinity above 8.1 dS/m. These results place kenaf in a salt tolerant category. Robinson (10) reported that kenaf can be grown in the Imperial Valley, California on saline soils when 1.3 to 1.4 m of good quality water is used for irrigation. Use of saline water for irrigation of kenaf resulted in a 80 to 90% reduction in yield. Muchow and Wood (11) reported that kenaf grown in a semi-arid tropical environment can use as much as 1.2 m of water. Bhangoo and Fernandez (2) during 1990 found total dry matter and stem yield of the Indian, Guatemala 51, everglades 41 and 71 kenaf varieties to decrease substantially with soil salinity greater than 5.5 dS/m· These workers found kenaf to be effective in removing substantial amounts of salt, boron, and selenium from soil if total biomass was removed from the field. Kenaf grown on a saline soil with a shallow aquifer required only 0.76 m irrigation water. This indicates that because of its extensive root system, kenaf was able to use some water from the shallow aquifer as is the case with cotton and alfalfa (7).

This study was conducted to (i) determine production potential of kenaf grown on a saline soil irrigated with nonsaline and saline water (ii) evaluate 8 kenaf varieties for their stem, leaf, and bast fiber yield (iii) measure salt removal by kenaf varieties from soil and its effect on the salinity of soil and the shallow aquifer.

MATERIALS AND METHODS

The experimental plots were located at the Northeast corner of Adams and Derrick avenues (36^{o} 47' N, 120^{o} 53' N) in the Westlands Water District near Tranquillity, California. The soil type was a saline Nahrub clay (fine, montmorillonitic, thermic, Vertic Torriorthents) with inclusions of Cuervo clay. The effective root depth of crops grown in the area is limited by a perched water table (shallow aquifer) that generally lies at a depth of 0.9 to 1.2 m. Eight varieties of kenaf, Everglades (E) 71, C-108, Tainung (T) 2, Guatemala (G) 51, KK60, 45-9, 15-2, and an Indian variety were planted on 2 May 1991. Three irrigation treatments (0.6 and 0.76 m of nonsaline water (ECiw = 0.7 dS/m) and 0.76 m of saline water (ECiw = 2.1 dS/m) were the main plots and the kenaf varieties were the subplots with four replications. Kenaf seed was planted on one m wide rows. Plot size consisted of six rows 30 m long. Seed germination, regardless of the salinity of soil and irrigation water salinity, was excellent for each variety. Plant density resulted in about 350,000 plants/ha. Nitrogen, as urea ammonium nitrate, at the rate of 140 kg N/ha was applied in two split applications. Four observation wells, 2.4 m deep, were installed on 2 June 1991 for measuring water table level and getting water samples for chemical analysis before and after each irrigation. Soil samples to a depth of 30 cm of soil were taken from each subplot on 17 July and 18 October for salinity determination. Plants were harvested on 18 October from each subplot from middle two rows 10 m long for stem yield. Bast fiber yield was determined at harvest time from middle one meter portion of ten stems per subplot. Leaf yield included the leaves on the stem and the leaves that had abscissed and accumulated (1 m^2 area) on the ground. Plant samples(stem and leaf) were taken from each subplot on 18 October and chemically analysed for total N, P, Ca, Mg, K, Na, Cl, S, and Micronutrients. Total salt removal by kenaf was calculated based on concentration each element and yield of foliage and stems of each variety. Soil, plant, and water analysis and plant yield data were subjected to analysis of variance as dictated by the experimental design.

RESULTS AND DISCUSSION

Stem Yield and Height

Stem yield, from plots irrigated with nonsaline water, was significantly higher than those irrigated with saline water (Table 1). Since there was no difference in stem yield between the 0.6 and 0.76 m of nonsaline water irrigation treatments, these yield data were combined for statistical analysis. Stem yields of different kenaf varieties from plots irrigated with the nonsaline and saline water varied from 8.1 to 12.8 and 5.9 to 10.7 Mg /ha, respectively and were negatively correlated with soil salinity. The KK60 and the Indian varieties resulted in highest stem yield whereas the G-51, E-71, and the 15-2 were the lowest in yield. Stem yield from plots irrigated with the saline water was 16 to 18% lower than that from plots irrigated with the nonsaline water. Stem height (Table 1) of the different varieties from plots irrigated with nonsaline water was higher than those irrigated with saline water and varied from 261 to 296 and 239 to 280 cm, respectively. The KK60, 45-9, and T-2 were taller than the other varieties. The Indian variety had the shortest stems. With the exception of the Indian variety, stem height of other kenaf varieties was positively correlated (R^2= 0.707) with stem yield. The Indian variety, despite its low height produced a high stem yield because it branched more than the other varieties grown in a wide row spacing such as the one used for this study.

Leaf and Bast Fiber yield

Leaf yield as a proportion of total dry matter (%) was not significantly different between plots irrigated with nonsaline and saline water (Table 2). However, different varieties produced significantly different proportion of leaf yield. Leaf yield of different varieties ranged between 36.0% for the KK60) and 43.3% for the Indian varieties. The Indian, C-108, and 45-9 varieties produced highest leaf percentage whereas the G-51, KK60, T-2, produced the lowest leaf percentage. Dry leaf yield (DLY) in Mg/ha was significantly higher in plots irrigated with nonsaline water than those irrigated with saline water (Table 2). Plots irrigated with nonsaline water resulted in highest DLY for the Indian and KK60 varieties (6.0 and 5.6 Mg/ha). The G-51 and 15-2 varieties produced the lowest DLY. Plots irrigated with saline water showed a similar trend, however, the DLY was about 13% lower than those irrigated with nonsaline water.

Bast fiber yield (BFY), proportion of dry stem tissue (%) of different varieties, was not significantly different between the irrigation tretments, however, it was significantly different among varieties. It ranged between 35% and 40% for the T-2 and the C-108 varieties,respectively. The C-108, 45-9, G-51, E-71, and15-2 varieties produced the highest whereas the Indian variety produced the lowest BFY. Bast fiber yield (Mg/ha) in plots irrigated with nonsaline water was higher than those irrigated with saline water (Table 2). In addition, there were significant differences in fiber yield among varieties in irrigation treatments. In plots irrigated with nonsaline water, the KK60 variety produced highest BFY (4.6 Mg/ha) followed by the C-108, Indian, and 45-9 varieties. In plots irrigated with saline water similar trend was observed, however, the yield was 21% lower than those irrigated with nonsaline water. The leaf and bast fiber yield was positively correlated with the stem yield (R^2 = 0.837 and 0.753) regardless of the irrigation water quality.

Salt, Boron, and Selenium Uptake and Protein Yield

Salt uptake by different varieties in stems and leaves from the plots irrigated with nonsaline and saline water varied from 730 to 1,233 and 570 to 923 kg/ha, respectively. The amount of boron uptake in the stems was very low whereas in the leaves it was high. The amount of total boron uptake ranged between 134 and 218 kg/ha. The KK60 and the Indian varieties removed highest amount of boron. Manganese and zinc uptake was highest for the kk60 and C-108 varieties. The amount of selenium uptake by the C-108, KK60, T-2, and E-71 was higher in the stems than in the leaves with the exception of the Indian variety that contained more selenium in the leaves. Selenium removal in the total dry matter varied from 1.11 to 2.9 kg/ha. The C-108 and the Indian varieties were the highest removers of selenium from soil. Total salt uptake in total biomass was highest (2,156 kg/ha) for the KK60 variety followed by the Indian, 45-9, and C-108 varieties (Table 3). Total salt uptake was positively correlated with the total dry matter yield (R^2= 0.875). This indicates that kenaf can remove substantial amounts of salt, boron, and selenium from soil. By virtue of its salt removal capacity, kenaf can be effective in reclaiming saline soils if all the biomass is removed from the field. Protein yield (Table 4) for the KK60 and Indian varieties amounted to 3,420 and 3,509 kg/ha, respectively . High protein, salt, and selenium yield of kenaf makes it suitable for livestock feed. The only way the total biomass can be removed from the field If kenaf is used as livestock feed.

Water Table Level and Salinity of Soil and shallow Aquifer

The water table level on 10 June 1991 was 0.64 m and showed a fluctuation of about 0.6 m in the interval between irrigations during the active kenaf growing season. Later in the season, the fluctuation of water table was about 0.2 to 0.3 m. On October 19, at harvest time, the water table level was greater than 2.1 m and there was no standing water at this depth. There was no difference in the water table level in the plots where 0.6 and 0.76 m of irrigation water was applied. Average salinity level of the shallow aquifer on 10 June 1991 was 7.9 dS/m· During mid October, in the plots irrigated with nonsaline water, it decreased to 5.5 dS/m and in the plots irrigated with saline water, it increased to 9.6 dS/m . This indicates that kenaf irrigated with nonsaline water not only used water but also removed salt from the shallow aquifer. Soil salinity in the plots irrigated with nonsaline water in July was 4.3 dS/m and decreased to 3.2 dS/m by mid-October whereas in the plots irrigated with saline water it increased from 3.6 to 4.2 dS/m. This indicates that kenaf irrigated with nonsaline water removed about 1,680 kg/ha from soil. In the plots irrigated with saline water, there was as much as 440 kg/ha accumulation of salts in soil. This indicates that irrigation with saline water (2.1 dS/m) will eventually salinize the soils to the point that they will become unproductive. Studies conducted by the authors during 1990 and1991 show that kenaf grown on a saline soil with shallow aquifer required only 0.6 m of good quality irrigation water. Since kenaf irrigated with 0.6 and 0.76 m of nonsaline water produced the same yield, lowered the salinity level of the soil and underground water and used water from the shallow aquifer, it appears that kenaf grown on a saline soil can help reclaim saline soils and possibly lower or maintain the water table level where irrigated agriculture is practiced.

CONCLUSIONS

Results of this study indicate that kenaf can be grown, with 0.6 m of irrigation water, on saline soils in which the salinity level does not exceed 4.0 dS/m provided that the irrigation water is of good quality. The soils with salinity levels greater than 4.0 dS/m do not appear to be conducive for kenaf production even when irrigated with good quality water. Irrigation of kenaf with saline water on saline soils will cause the soils to become saline and will severely reduce kenaf growth and yield. The KK60 and the Indian varieties were the highest yielders, whereas the G-51, E-71, and 15-2 varieties were the lowest yielders. With its salt removal capacity, kenaf can lower soil salinity and make it more suitable for crop production. Production of kenaf on saline soils is feasible when planted to salt tolerant varieties. Further research is underway to evaluate more varieties for their salt tolerance.

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Table 1. Stem yield and height of different Kenaf varieties grown on a saline soil irrigated with nonsaline and saline water, 1991.

	Stem yield (Mg/ha)			Stem height (cm)		
Variety	Nonsaline water	Saline water	Average	Nonsaline water	Saline water	Average
C-108	9.3 bc	8.6 cd	9.1 b	277 b	261 bc	271 bc
KK60	12.8 d	10.7 e	12.1 d	296 c	280 c	291 d
15-2	8.1 a	5.9 a	7.3 a	262 a	255 ab	260 ab
Indian	11.7 d	9.3 d	10.8 c	261 a	250 ab	257 a
45-9	10.1 c	8.2 bcd	9.4 b	290 c	264 bc	281 cd
G-51	8.7 ab	7.1 ab	8.1 a	277 b	239 a	265 ab
T-2	9.2 abc	8.1 bcd	9.1 b	288 c	270 bc	283 d
E-71	8.4 ab	7.2 abc	7.8 a	269 ab	266 bc	268 bc
LSD (0.05)	1.1	1.4	0.8	10	22	11

Irrigation treatments	Stem yield	Stem height
Nonsaline water, 0.76 m	9.6 b	276 b
Nonsaline water, 0.61 m	9.9 b	279 b
Saline water, 0.76 m	8.1 a	260 a
LSD (0.05)	0.8	10

Within each column, the data followed by the same letter are not significantly different at p = 0.05 as tested by using LSD.

Table 2. Leaf and bast fiber yield of different kenaf varieties grown on a saline soil irrigated with nonsaline and saline water, 1991.

	Leaf Yield			Fiber Yield		
	Proportion of total Dry matter yield	Dry wt. (Mg/ha)		Proportion Of total stem yield	Dry wt. (Mg/ha)	
Variety	%	Nonsaline water	Saline water	%	Nonsaline water	Saline water
C-108	41.4 b	4.6 c	4.1 b	40.0 c	3.9 b	3.5 bc
KK60	36.0 a	5.6 d	4.3 b	36.3 b	4.6 c	4.3 d
15-2	39.2 ab	3.7 ab	3.0 a	39.2 c	3.3 a	3.0 a
Indian	43.3 b	6.0 d	5.5 c	31.7 a	3.8 b	3.4 bc
45-9	40.2 ab	4.6 c	4.2 b	39.8 c	3.7 b	3.6 c
G-51	35.6 a	3.3 a	3.0 a	39.5 c	3.3 a	3.2 ab
T-2	36.4 a	4.1 b	3.4 ab	35.0 b	3.4 a	3.1 ab
E-71	38.6 ab	3.8 ab	3.7 b	39.5 c	3.5 ab	3.3 abc
LSD (0.05)	4.9	0.7	o.7	1.7	0.4	0.4

Irrigation treatments	Leaf %	Leaf yield Mg/ha	Fiber %	Fiber yield Mg/ha
Nonsaline water, 0.76 m	38.3	4.5 b	37.8	3.7 b
Nonsaline water, 0.6 m	37.6	4.4 b	37.4	3.6 b
Saline water, 0.76 m	40.7	3.9 a	37.6	2.9 a
LSD (0.05)	NS	0.4	NS	0.4

Within each column, the data followed by the same letter are not significantly different at $p = 0.05$ as tested by using LSD.

NS, not significant at $P = 0.05$

Table 3. Total salt uptake by different kenaf varieties grown on a saline soil irrigated with nonsaline water, 1991.

	Salt uptake by stems (kg/ha)				Salt uptake by leaves (kg/ha)				Total kg/ha
Variety	Salt	Boron	Mn,Zn	Total	Salt	Boron	Mn,Zn	Total	
C-108	750 b	14 a	133 b	897 b	450 b	162 b	160 d	772 b	1669 c
KK60	1010 c	20 b	203 d	1233 d	530 b	198 c	195 e	923 c	2156 d
15-2	610 a	13 a	108 a	731 a	340 a	122 a	108 b	570 a	1301 a
Indian	850 b	22 b	185 c	1057 c	440 ab	195 c	76 a	711 b	1768 c
45-9	800 b	13 a	131 b	944 bc	470 b	148 b	152 d	770 b	1714 c
G-51	610 a	29 c	123 b	762 a	340 a	123 a	123 c	586 a	1348 a
T-2	700 ab	14 a	142 bc	856 b	380 a	145 b	136 c	661ab	1517 b
E-71	600 a	13 a	124	740 a	350 a	127 a	115 b	592 a	1329 a
LSD (0.05)	125	3	15	115	101	22	15	120	150

Within each column, the data followed by the same letter are not significantly differe at p = 0.05 as tested by using LSD.

Table 4. Protein yield and selenium removal by different kenaf varieties grown on a saline soil irrigated with nonsaline water, 1991.

	Protein Yield (kg/ha)			Selenium removal (kg/ha)		
Variety	Leaf	Stem	Total	Leaf	Stem	Total
C-108	1523 b	1163 b	2686 b	0.39	2.52	2.91
KK60	1820 c	1600 c	3420 c	0.68	0.98	1.66
15-2	1202 a	1012 a	2214 a			
Indian	1836 c	1673 c	3509 c	2.34	1.83	2.34
45-9	1495 b	1172 b	2667 b			
G-51	1092 a	1088 ab	2180 a			
T-2	1357 b	1040 a	2397 ab	0.28	0.83	1.11
E-71	1212 a	1159 b	2371 ab	0.38	1.43	1.81
LSD (0.05	135	125	325			

Within each column, the data followed by the same letter are not significantly different at $p = 0.05$ as tested by using LSD.

COVER CROPS FOR ANNUAL CROPPING SYSTEMS

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Cover crops are grown for their various beneficial effects on the agroecosystem; they usually are not harvested or grazed. Cover crops can influence soil factors related to fertility, tilth, water dynamics and soil erosion. They may also impact population dynamics and management of all types of agricultural pests: weeds, insects, mites, vertebrates, plant pathogens and nematodes. The proper selection and management of cover crops are essential to their successful incorporation into cropping systems (Hargrove, 1991).

In annual cropping systems, California growers are most often interested in the effects of cover crops on nitrogen fertility and dynamics. Leguminous cover crops may add significant amounts of nitrogen to a cropping system through symbiotic nitrogen fixation while non-legumes can be effective scavengers of soil nitrogen and may be used to minimize nitrate leaching.

In the Central Valley of California, winter annual legumes typically are grown from October or November until March or April. Some of these cover crops, including purple vetch (Vicia benghalensis), woolypod vetch (Vicia villosa, var. dasycarpa) and winter peas (Pisum sativum ssp. arvense) can add upwards of 200 kg N/ha to the soil upon incorporation (Stivers et al., 1991). Other commonly grown winter annual legumes, including fava beans (Vicia faba) and many clovers (Trifolium spp.), may add 100 - 200 kg N/ha. Residues of these winter legumes typically contain 3 - 4% N (dry matter basis) and thus begin decomposing and releasing plant-available N quite rapidly following incorporation (Miller, 1991).

Summer annual legumes, such as cowpeas (Vigna unguiculata) and crotalaria (Crotalaria juncea), typically are grown for a two to three month period, depending upon the particular cover crop and cropping sequence. They may contain 100 - 150 kg N/ha when incorporated. Their residues usually run 2.0 - 2.5% N, thus decomposition and N release typically begin soon after incorporation (Van Horn and Klein, 1991).

Non-leguminous annual cover crops include grasses and various dicotyledonous species. Both summer and winter annual grasses can produce significant biomass that is comparatively high in fiber and lignin and low in N (e.g., 1% dry weight). Thus, their residues tend to decompose rather slowly and may result in soil N immobilization. Some dicots, such as phacelia (<u>Phacelia tanacetifolia</u>) and various mustard relatives (e.g., <u>Brassica</u> spp., <u>Raphanus</u> spp.) may have significantly higher N contents (e.g., 2% N dry weight) and decompose very rapidly after incorporation, particularly when incorporated during the vegetative phase (Stivers et al., 1991). Using such cover crops may help prevent nitrate leaching during otherwise fallow rainy periods without creating problems associated with slowly decomposing residues and soil N immobilization.

Cover crops may also improve soil physical properties, but the net result of cover cropping practices on soil structure and related properties is quite variable (MacRae and Mehuys, 1985). Soil and crop management, particularly tillage practices, impact soil structure significantly and may have an overriding influence on soil structure. Thus, an untilled, fallowed field may have superior structure to a cover cropped field that was tilled repeatedly or when too wet during incorporation of the cover crop residue. However, cover crops have been shown to improve water infiltration rates and decrease soil crusting in California (Groody, 1990).

Cover crops often have significant effects on soil microbial ecology. In some systems, the microbial activity that results from cover crop incorporation contributes to the improved soil physical characteristics that are observed. In addition to the quantitative effects of increasing soil microbe numbers and activity, cover crops may result in important qualitative changes, as well. Cover crops may increase soil microbial diversity and promote populations of beneficial microbes including antagonists to soil-borne plant pathogens (Linderman, 1989). Although specific cover crops may harbor important pathogens of cash crops, problems may be avoided by proper selection of cover crops within a rotation.

Compared with annual cropping systems, the impacts of cover crops on arthropod populations are generally more significant in perennial systems, where the cash crop and the cover crop are in the field simultaneously. In annual systems, interactions between cover crops, cash crops and arthropods are most likely in systems where the cover crop is not incorporated (e.g., living and dying mulch systems) or when cash crops and cover crops are grown in close proximity to one another (e.g., strip cropping).

Even in systems where there are significant fallow periods, cover crops are seldom inserted into an annual cropping system without making important adjustments to the rotation. There are several ways in which cover crops can be incorporated into California's cropping systems. Probably the most popular system of cover cropping in annual systems is utilized primarily to supply N to subsequent crops and is accomplished by growing a legume or a legume/grass mix during an otherwise fallow winter period. This strategy can be very successful, given a sufficient growing season for the cover crop. For much of California, this requires that cover crop growth begin by mid- to late October, which often necessitates an irrigation to germinate the crop. Maximum biomass and N accumulation will typically occur by early April in this system, with significant growth occuring during the last few weeks of the season. Therefore, this system is most effective with cash crops that are not planted before early April.

For cash crops that are planted during late summer or fall, a summer cover crop can precede the cash crop. Such cover crops can be grown with relatively little water. In our experiments at Davis, we provide our summer cover crops with a pre-plant irrigation and only one subsequent furrow irrigation. Under these conditions, cowpeas and crotalaria frequently accumulate over 100 kg N/ha in 70 days. Given more time and water, crotalaria and some varieties of cowpea will continue to accumulate more biomass and nitrogen until fall (Van Horn and Klein, 1991).

One of the above systems can be used to precede any cash crop that is planted between early April and fall. Preceding cash crops that are planted in winter or early spring presents more of a challenge. In addressing this situation, we have conducted trials with August and September plantings of both warm season and cool season legumes in Davis. In these trials, the warm season species, cowpea and hyacinth bean (Lablab purpureus), perform well if planted during the first week in August; later plantings do not perform satisfactorily because of decreasing daylength and temperatures. Early August plantings of these cover crops perform nearly as well as June or July plantings and produce a full canopy before they are killed by frost in the fall. This mulch of frost-killed residue can be managed in a variety of ways. If left undisturbed in the fall, it may help suppress winter weeds and the need for tillage prior to planting the subsequent cash crop may be reduced or eliminated.

Despite high ambient temperatures at planting, vetches also perform well when planted in August and September. By December, early August plantings of vetch can produce the same amount of biomass and N as October plantings produce by April. Thus, early August plantings of vetches may contain approximately 200 kg N/ha by December, while those of warm season legumes would likely contain approximately 100 kg N/ha when killed by frost. However, unlike the warm season cover crops, the vetches must be killed with herbicides or tillage before planting a subsequent cash crop.

Other cover cropping systems may be used in California, as well. These include living and dying mulch systems in which the cash crop is planted through the mulch with little or no pre-plant tillage. The mulch may help suppress weeds and prevent evaporation from the soil surface. Unless the mulch is subsequently incorporated during cultivation, the nitrogen contribution of the cover crop to the cash crop in such systems may be significantly less than in systems that involve tillage prior to planting the cash crop. As mentioned above, another cover cropping system involves planting non-legumes to help reduce nitrate leaching.

There are many possible variations of these systems. In developing a successful cover cropping strategy, a grower should have a well defined rationale for using a cover crop and carefully select and manage the cover crop to optimize its effects.

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CALIFORNIA STATE UNIVERSITY, CHICO
FARM

SWEET SORGHUM AGRONOMIC TRIALS

Buel Mouser and Steve Shaffer

Introduction

Sweet sorghum [Sorghum bicolor (Sorgo)] is a summer growing annual grass varying in height from 8 to 12 feet with a dry weight production of approximately 8 to 13 tons per acre on the California State University, Chico, (CSUC) Farm. Refractometer readings of the stem juice usually range from 12 to 18 at the time of maximum sugar formation. The plant is used extensively for silage and forage in the southern states. The rapid, vigorous top and root growth, low water and fertilizer requirements, high sugar content, and high biomass production indicate a potential for the use of sweet sorghum in California as a source of ethanol, cogeneration fuel, or livestock feed. The CSUC Farm in cooperation with the California Department of Food and Agriculture, Ag Resources Branch, has conducted production trials in 1987 and 1989-92 to explore sweet sorghum as a crop for California.

Materials and Methods

The sweet sorghum trials were planted on the CSUC Farm located approximately 90 miles north of Sacramento. The soil consists mostly of deep Vina Clay loam, pH 6-7, graded for furrow irrigation. Water is supplied from deep wells on the property.

Several varieties were planted during the five years of trials including two hybrid, NK405 and G555, and three open pollinated varieties, Keller, M81E, and Cowley.

Common land preparation and row crop equipment, such as, disks, plows, chisels, furrowers, planters, cultivators, power mulchers, and liquid side dressing units, were used to prepare proper seedbeds, plant, and care for the sweet sorghum crop. Harvesting was accomplished with a silage chopper. The crop was moved from the field in silage wagons and placed into Ag Bags (large plastic tubes) to store for feeding to dairy and beef animals. Thirty inch beds were utilized for all the trials. Some of the fields were planted double row (two rows on each 30 inch bed, four to five inches apart). The later plantings were single rows (one row in the center of each 30 inch bed).

A table which accompanies this presentation shows the varieties planted for each of the five years, date planted, number of rows, plant population, number and amount of irrigations, harvest dates, and number of harvests (one or two), yield in tons per acre, percent moisture of the crop when harvested, amount of nitrogen applied, refractometer reading (Brix), acreage harvested, and comments. The only fertilizer used was nitrogen in the form of aqua ammonia. Furrow irrigation was used in all cases.

Discussion, Conclusions, and Comments

It was apparent after the first trial in 1987 that the lodging problem would likely be the greatest challenge in the production and harvest of sweet sorghum. This proved to be true with all the varieties tested, although some varieties seem to be more prone to lodging than others. A height of 8 to 14 feet with the heavy grain head at the top is very conducive to the lodging process. Therefore, in the later tests, we have attempted to address what we feel are factors affecting lodging in sweet sorghum. These factors are plant populations, irrigation amounts and timing, amount of nitrogen applied, and variety. Planting dates may also effect lodging but has not been extensively studied here.

Reducing plant populations from the 80,000 plants per acre range to approximately 60,000 plants per acre, still maintaining the double row plantings and reducing applied irrigation amounts looked promising for the NK405 variety. Changing to one row, moderately reducing plant populations, and increasing irrigation amounts was a disaster. The greatest success has been a combination of drastic reductions in plant populations and amounts of irrigation water applied along with some reduction in applied nitrogen. This was, however, successful with only two of the five varieties tested, one hybrid, NK405, and one open pollinated variety, Keller. More work needs to be done on amounts of nitrogen applied to sweet sorghum to study the effect on lodging. Lodging not only causes difficulties in harvesting, but has also resulted in a harvest loss of 15 to 67 percent through the test years because tangled stalks prevented retrieving all of the crop from the field with the harvest equipment available to us. This potentially could mean a financial loss to the producer because of lodging.

It was expected that reducing water and nitrogen would likely reduce total yields but would very probably not reduce, or may even increase, retrievable yields. In the case of NK405, a short season variety that can provide two harvests per season because of regrowth from crown buds after the first harvest, a reduction to a plant population of 22,000 per acre and a reduction to one irrigation before the first harvest in 1992 resulted in a first harvest totalling 8.3 dry tons per acre. This is more than the first harvest in any of the four previous test years (at this time the second harvest on NK405 for 1992 has not yet been completed). NK405 did not lodge in 1992. The highest yield on the Keller variety in 1992 which also did not lodge, had a plant population of 19,250, and a single irrigation was 8.7 dry tons per acre which was considerably less than 10.7 dry tons for Keller in 1991, the one other year Keller was tested. (Keller is a single harvest variety. It is long season and does not regrow after one cutting.)

G555 and Cowley varieties exhibited extreme lodging on the CSUC Farm in 1992 even under low plant populations and low amounts of irrigation water. M81E was not tested in 1992 but exhibited an extreme tendency toward lodging in 1990 and 1991, necessitating the hiring of special equipment for harvest, increasing costs considerably. G555 and Cowley, although badly lodged, was harvested satisfactorily because both varieties lodged in one direction down the row and not across the rows, which reduced tangling and jamming of the material as it entered the silage chopper at harvest time. It did, however, require harvesting in only one direction (with downed plants pointing straight ahead of the harvester) which meant "dead heading" back to the same end of the field to harvest every pass. This increased harvest time and cost. Based on past experience, if the plants had fallen across the rows less of the crop could have been retrieved and harvest costs would have been much higher because of frequent plugging of the silage chopper.

Irrigation amounts were drastically reduced in 1992. The crop was planted on rain moisture and not irrigated until June 16, 47 days after planting. Nine inches of water was applied at the first irrigation. Harvest of NK405 was on August 11, 56 days (8 weeks) after irrigating. Another irrigation of 6 inches was applied on the NK405 August 21 to encourage growth for the second cutting. The second harvest has not yet begun at this writing.

Apparently, sweet sorghum roots are very vigorous and extend rapidly into soil that is not compacted and is uniform in texture to the deeper subsoils. A backhoe trench dug to a depth of 11 1/2 feet exposed sweet sorghum roots that had extended to that depth. Apparently the deep moisture existing to this depth probably because of winter rainfall or previous year's irrigations was being used by the crop. This would explain the large biomass production from the relatively small amounts of added irrigation water. (Note: a realistic approach for a true comparison of biomass yields should be to use a dry yield figure since moisture at harvest is highly variable from year to year and from variety to variety.)

Moisture in the sweet sorghum stalks is a factor in putting up high quality silage. Ideally, the stalks should contain 65 to 68 percent water. This is difficult to attain in sweet sorghum since it is desirable to harvest at highest sugar content. The highest refractometer readings for sweet sorghum occurs between the end of flowering and the beginning of the soft dough stage of the grain as indicated by tests with a refractometer on the CSUC Farm. It seems if harvest is started 8 to 11 weeks after the last irrigation, on the soils such as those found at the CSUC Farm, harvest is possible under 70 percent moisture and results in reasonably good silage (See accompanying feed analyses). The CSUC dairy has found sweet sorghum silage to be a good low cost feed if mixed 50/50 with alfalfa or corn silage. No reduction in milk production has been noted from using this combination instead of 100 percent corn silage. Sugar content varied considerably between varieties at harvest time. NK405 seems generally to have less sugar than Keller (see accompanying table).

Tillering varies considerably between varieties. Tillers are generally much more numerous on the regrowth than they are on the original plants in varieties that can be harvested a second time in one season, i.e. NK405.

Generally weed control is adequately accomplished with cultivation, usually one time is sufficient. In 1990 the M81E field was treated with 24-D to control pigweed and for beds made in the fall, an application of herbicide may be necessary to eliminate winter weeds before planting sweet sorghum. Although corn leaf aphid and greenbug may attack sweet sorghum, no insecticide has been used to control them. Beneficial insects (ladybugs, lacewing, serfid fly, damsel flies) have always controlled the infestation of these aphids.

Recommendations

The following recommendations are based on information gained from tests on the CSUC Farm only. Sweet sorghum growth in other areas and/or soil types may require different cultural practices for best results.

1. Land preparation and bed making should be done in the fall before the rainy season begins.

2. Weed control on the pre-made beds should be done whenever necessary before planting time.
3. Planting should be done as soon as the soil warms adequately in the spring.
4. If rain moisture is not adequate in the beds made the previous fall, a preirrigation should be done.
5. A plant population between 20,000 and 30,000 plants per acre is recommended. Consider germination percentage and emergence percentage. Use seed plates or planters that will drop single seeds at the proper spacings.
6. Plant 1 to 1 1/4 inch deep into moist soil. Do not irrigate up since this will cool the soil and encourage weed competition.
7. Irrigate five to seven weeks after planting with a deep irrigation. Irrigate no more before the first harvest.
8. Choose a shorter season variety if two cuttings are desired. (Generally, higher yields are obtained from two harvests rather than from one).
9. Use a longer season variety if only one harvest is possible or desired.
10. Use nominal amounts of nitrogen fertilizer; 70 to 90 lbs. of nitrogen per acre should be adequate. Soil tests may help determine amounts of nitrogen or other nutrients that may be needed.

11. Cultivate only enough to control early weeds. After the crop gets past the six inch stage, sweet sorghum competes vigorously with weeds and, with a good stand, will outgrow most any weed.
12. Watch for insect problems but do not be too hasty in treating. Sweet sorghum's vigorous growth can stay ahead of insect damage if the crop is healthy.
13. Plant single rows on 30 inch beds to obtain proper plant populations for control of weeds and lodging.
14. Harvesting for silage should be best at the hard dough stage because the total feed value is optimum and the moisture is more likely to be in the 65-70 percent range. However, sugar content seems to be highest at the flowering to soft dough stage which would probably be best for ethanol production.

CSUC FARM
SWEET SORGHUM AGRONOMIC TRIALS

YEAR	VARIETY	PLANT DATE	APPROX. PLANTS PER ACRE-30" BEDS SNGL. ROW	APPROX. PLANTS PER ACRE-30" BEDS DBL. ROW	IRRIGATIONS 1ST CUT (#/ IN.)	IRRIGATIONS 2ND CUT (#/IN.)	HARVEST DATES 1ST CUT	HARVEST DATES 2ND CUT	YIELD AND MOISTURE % 1ST CUT TONS/AC.	YIELD AND MOISTURE % 1ST CUT H20	YIELD AND MOISTURE % 2ND CUT TONS/AC.	YIELD AND MOISTURE % 2ND CUT H20	FERTILIZER LBS. N/ACRE 1ST CUT	FERTILIZER LBS. N/ACRE 2ND CUT	BRIX READING 1ST CUT	BRIX READING 2ND CUT	ACRES	COMMENTS
1987	NK405	6-28		83000	4 / 29" (incl. pre)		9-26		11 3.3	70% dry			140		18		5	Extreme lodging 95% harvesting equip. got approx. 1/3 of crop
1989	NK405	4-27		80000	3 / 22"	2 / 14"	7-26	10-12	24.9 5.7	77.1% dry	19.2 3.7	80.9% dry	140	50	11	11	5	Lodged 80% 1st cutting
1990	NK405	3-30		59740	2 / 15.5"	2 / 15.5"	7-23	10-23	25.4 7.2	71.7% dry	18.6 6.1	67 dry	120		13.6	17.7	5	Little lodging - 15%
	M81E	5-10		77000	4 / 27"		10-5		25.8 8.3	66% dry			90		14.3		5	Extreme Lodging - 100%
1991	NK405	5-3	54000		2 / 35"	1 / 7"	8-23	11-13	22 6.8	69% dry	9.1 2.8	69% dry	125		14.3	14	9.25	Lodging 60% 1st cutting
	Keller	5-2	53000		2 / 34"		9-26		39.6 10.7	73% dry			125		16.7		4.3	Some lodging - 60%
	M81E	7-1	65780		2 / 29"		11-4		22.6 7.5	67% dry			125		10.7		4.25	Extreme Lodging - 95%
1992	NK405	4-30	22000		1 / 9"	1 / 6"	8-11	*	23.7 8.3	65% dry	*	*	105		13.2	*	2.24	No lodging
	G555	4-30	23500		1 / 9"	1 / 6"	8-12	*	24.7 7.4	70% dry	*	*	105		9.5	*	2.04	95% Lodging
	Keller (Late)	5-12	19250		1 / 9"	1 / 7"	8-28	*	31.1 8.7	72% dry	*	*	105		17.2	*	1.17	No lodging
	Keller (Early)	4-30	10670		1 / 9"	1 / 7"	8-27	*	25.1 6.8	73% dry	*	*	105		17.7	*	2.31	No lodging
	Cowley (Late)	5-12	18750		1 / 9"	1 / 7"	8-28	*	29.6 8.6	71% dry	*	*	105		15.2	*	0.78	100% Lodging
	Cowley (Early)	4-30	11750		1 / 9"	1 / 7"	8-27	*	27.7 8.6	69% dry	*	*	105		17.5		2.34	100% Lodging

*Data not available at this time

Sierra Testing Service
9450 E. Collier Rd.
Acampo, CA 95220
(209) 333-3337

NIR ANALYSIS REPORT

SAMPLE NUMBER 8239
SAMPLE TYPE Sm Grain Silage
SAMPLE ID Sweet Sorghum-CSVC Dairy (Kevin)
DATE PROCESSED 11-29-1989

NAME STOCKTON HAY AND GRAIN
ADDRESS P.O. BOX 369
Stockton, Ca 95201-0369
(209) 982-4632
COUNTY

	AS RECEIVED BASIS	-ANALYSIS- DRY MATTER BASIS	90% DRY BASIS
MOISTURE,%	81.2	0.0	10.0
DRY MATTER,%	18.8	100.0	90.0
CRUDE PROTEIN,%	1.2	6.2	5.6
HEAT DAM. PROTEIN,%	.2	1.1	1.0
AVAILABLE PROTEIN,%	1.0	5.4	4.9
DIG. PROTEIN EST.,%	.8	4.3	3.8
ACID DET. FIBER,%	7.0	37.4	33.6
NEUT. DET. FIBER,%	11.6	61.8	55.6
TDN EST.,%	12.1	64.6	58.2
ENE EST.,THERMS/CWT	10.30	54.93	49.44
NE/LACT,MCAL/LB	.12	.66*	.60

MANNA PRO
CORPORATION

REPORT OF SUBMITTED SAMPLE(S)

MANNA PRO
CORPORATION
GENERAL LABORATORY

Date 11/7/88

To: Maggs (Stockton)

cc Hogan

cc: Lane

cc:

We have received the following samples from C.S.U.C. Dairy

Thru (10/28) Hogan

Analysis as follows:

Lab No.		Prot	Fiber	Mst	Ca	P	ADF	p
1569	Sweet Sorghum Silage as fed Basis	1.8	6.6	80.2	0.08	0.04	9.2	4.
	100% Dry matter	9.1	33.3	0	.46	.20	46.4	
	T.D.N. 52% 100% Dry Basis.							

Comments:

COMPETITION FOR WASTE NUTRIENT RECYCLING LAND

W. C. Fairbank

Extension Ag Engineer, Emeritus

HIGH DENSITY CONFINED LIVESTOCK PRODUCTION where thousands of mouths are only inches apart; floor space for just a few steps between feed, water, and a place to rest; cubes of air just adequate to dissipate the heat and breath from the warm bodies; has become the world-class model of efficient animal protein production. But, as total population on a single ranch or tract of like ranches exceeds some critical mass, the environmental threat from manure and wastewater is comparable to a city of several million residents in wall-to-wall hotels without an adequate sewer system.

A TYPICAL CALIFORNIA DAIRY is now 1 000 cows, an egg ranch 100 000 layers, a beeflot 40 000 head, a hog farm 60 acres to farrow 300 sows and finish 4 800 pigs each year. A years' accumulation of air-dry manure from California's herds and flocks plus the nation's greatest resident population of horses would make a pile of 37 million cubic yards. (Imagine a windrow of manure 100-feet wide and the height of a five-story building reaching the 75 miles from Fresno to Delano, or Los Angeles to Oceanside.) And the politicians wondering where to start a new pile next year.

LIVESTOCK DO NOT PRODUCE THE SALTS in their manure. Animals are low-efficiency biological incinerators that burn carbon out of feedstuff and metabolize some of the nutrients into body mass and products. The residuals come out a blend of water-saturated undigestibles, cellular debris, and excess nutrients we call manure. This drops onto a floor usually only one one-hundredth to one one-thousandth of the area used to grow the rations. Urine and rainwater leach salts into the pen floor from where it continues down-slope. Some rides with solid manure to export. But the greater portion of salts from liquid handling systems go with the runoff and wastewater.

A 1 400 LB HOLSTEIN producing 19 000 pounds of milk each year might consume each day 24 pounds of good alfalfa hay and 12 pounds of grain. Additionally, she would receive several pounds of high energy concentrates and up to 30 gallons of drinking water. It would take about one-half acre of eight-ton alfalfa and two and one-quarter acres of twenty-sack barley to supply the basic ration for one year. It is conservative to estimate that three acres of fertilized cropland somewhere are needed to provide for each milking cow.

ONE THOUSAND LAYERS are estimated to consume 230 pounds of feed daily of which 65 percent or 150 pounds is grain. It would take no less than 27 acres of 20-sack barley to grow the grain for the 1 000 hens that would be confined for their productive life to about 1 250 square feed of cage plant. This is a grain-field-to-layer-house area ratio of a thousand-to-one.

Horses weigh on average 1 000 lbs and need each day about 14 pounds of legume hay for maintenance and up to four pounds of grain if being worked. It requires about one-acre of cropland to feed a horse which might be confined for much of its life to a box stall.

POLLUTION POTENTIAL from a mixed population of confined animals can be estimated as being proportional to their total live mass. Success or failure of a manure recycling design will be determined largely by the spreading rate, total nutrient analysis and the calculable uptake of the recycling crop. All manure recycling puts salts into the soil-plant-water loop so it is critical to determine and then not exceed safe limits.

METROPOLITAN WASTEWATER DISTRICTS in southern California began several years ago looking to farmland as a disposal outlet for their masses of sludge. Can there be much doubt that those agencies backed by public law and millions of votes may not precipitate another difficult problem for California agriculture? Some of our recommended manure disposal and farming practices could lose opportunities to the needs of cities before our feeders see what's happening. If agriculture is to prepare a successful defense of manure recycling lands, we should start by developing data showing where the livestock, people, and most probable receiving lands are, the tonnage of manure needing proper recycling, and the salt sensitivity (i.e. net salt balance) of the most probable sludge disposal region.

THE NINE REGIONS AND FOUR SUB-REGIONS forming the California Water Quality Control plan fits this exercise well. The hydrologic basins are well defined, existing waste and water sources are catalogued, and technical counsel is available (Figure 1).

SUB-BASIN 5CD includes most of the San Joaquin Valley's irrigated agriculture and the largest portion of the states' confined livestock production. It is also the most likely choice for land disposal of southern California sludge because the more southerly SWQCB Regions 3 to 9 show less opportunity, are already pollution impacted, and are water deficient.

LIVESTOCK POPULATION of the state is summarized on Table 1. California Agricultural Statistics Service reports were used with adjustments as needed to *annualized average population equivalents* for uniformity.

Manure Production and Characteristics (ASAE D384.1, 1992) was used to convert animal populations to total mass and to calculate the tonnage of manure and waste nutrients dropped from the standing livestock.

TABLE 2 summarizes the mass and volume of all manure produced in California by the major livestock.

TABLE 3 summarizes the livestock inventory, live animal mass, and human population in Water Quality Region 5 CD and compares the values to California totals. It can be noted these counties contained an estimated 7.3 percent of the total human population of California in 1990 (28 756 000) but 42 percent of the live farm-animal mass.

IMPORTED FEED is a source of salt getting into Region 5 CD. Shipments of feed grain into California in 1991 were 69 000 carloads of 190 000 lb each. It was calculated the barley, corn, oats, sorghum, and wheat contained 27 850 tons of Ca, Cl, Na, and S salts. It was calculated the human populace of Region 5 CD consumed 27 percent of its production of animal protein, leaving 73 percent exported. If 10 percent of the feed grain salt is retained in the market products, 90 percent is retained in the manure or elsewhere in the production loop.

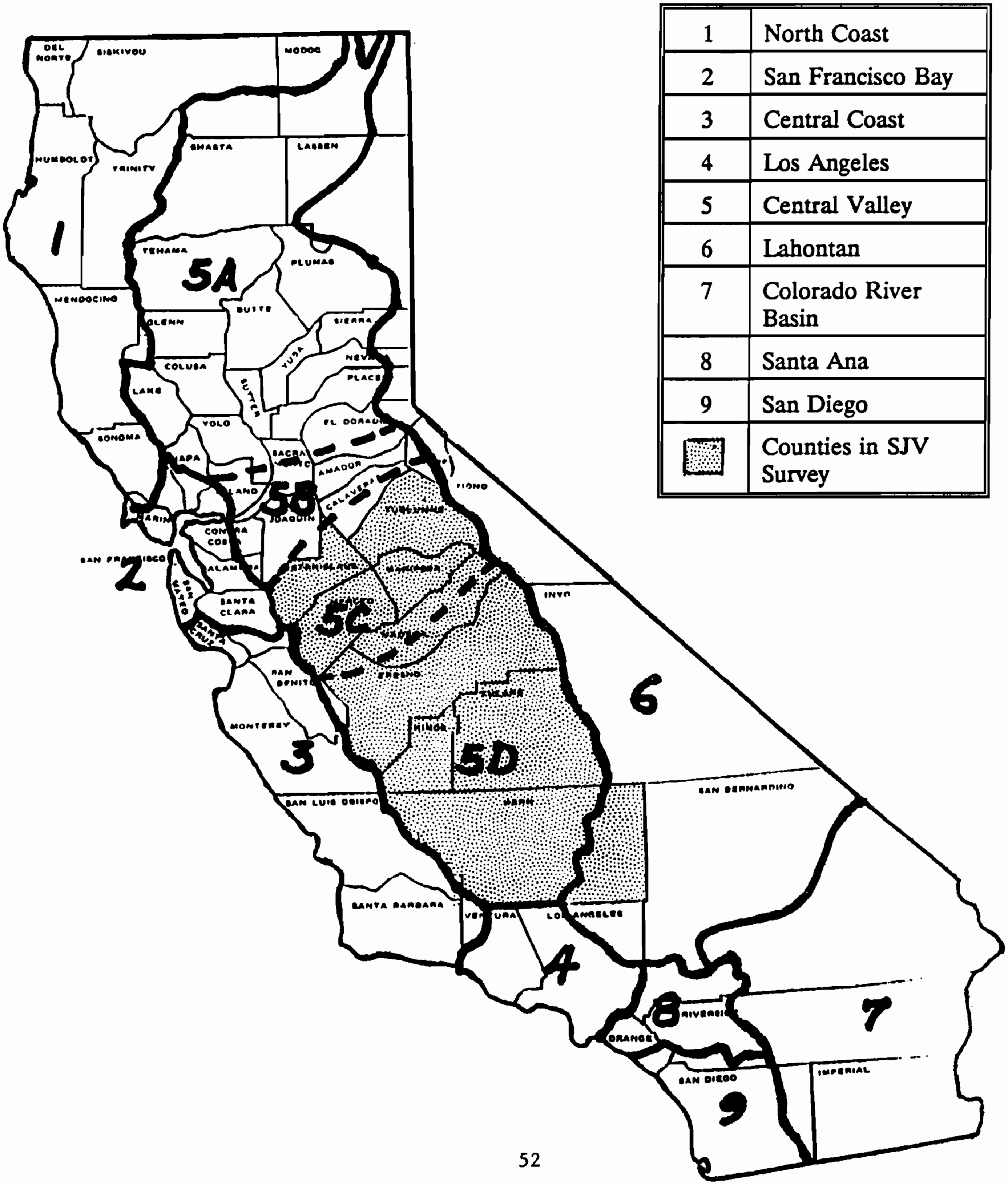
Residual Salt = Feed Intake - Export in Products
= (42% x 27 850) - (42% x 27 850 x 73% x 10%)
= 11 697 - 854
= 10 800 ton

CONCLUSIONS

CROP AND LIVESTOCK PRODUCTION in the San Joaquin Valley is a good system for organic residue and wastewater recycling within acceptable tolerances of nutrient balances. Large imports of municipal sludge could increase soil and groundwater salinity and deny livestock operators access to some traditional receiving cropland. Growers, feeders, and planners might strengthen their defense against metropolitan sludge by keeping inventory data on the four troublesome manure salts in addition to nitrate.

FIGURE 1

CALIFORNIA WATER QUALITY CONTROL REGIONS



1	North Coast
2	San Francisco Bay
3	Central Coast
4	Los Angeles
5	Central Valley
6	Lahontan
7	Colorado River Basin
8	Santa Ana
9	San Diego
▨	Counties in SJV Survey

TABLE 1
LIVESTOCK POPULATION IN CALIFORNIA
(x1000)

	CASS-CLS*		UC-CE	CORRECTED
SPECIES	INVENTORY 1/1/90	MARKETED in 1989	INVENTORY ADJUSTMENT FACTORS**	ANNUALIZED AVG. POPULATION
Beef, non-feedlot	3 400		-80%x435	3 052
in feedlots	435			435
Dairy cattle, total mature	1 115			—
milking herd			85% of total	948
non-milking herd & calves***			102% of milking herd	967
Sheep, all	955		-20% x 658	823
lambs marketed		658	5/12 x 658	274
Swine, all	140			140
hogs marketed		224		—
Horses, all (best est.)	750			750
Broilers		225 000	Six cycles per year	37 500
Layers	30 000			30 000
breeders	2 000**			2 000
Turkeys		30 000	17 wks avg. on feed	9 800
breeders	500**			500

* California Agricultural Statistics Service-Calif. Livestock Statistics-1989.

** These values and adjustments are best estimates of UCCE.

*** Non-milking herd includes dry cows (est. 15% of Milking Herd) plus calves and heifers to 26 months and is estimated to number 102 percent of the Milking Herd.

TABLE 2

TOTAL MANURE PRODUCTION IN CALIFORNIA

ANIMAL	Avg. Adjusted Population (x1000)	Hd . Marketed per Year (x 10^6)	Pounds Total Solids Per Head Per Day	Pounds Solids Per Hd Marketed	Tons Total Solids Per Year (x1000)	Air Dry Tons per year (x1000)	Manure* Ft^3 ($x10^6$)
Beef, nonfeedlot	3 052		6.8		3 800	5 400	310
feedlot	435		6.8		540	770	44
Dairy, milking	948		17		2 900	4 200	240
nonmilking	967		10		1 800	2 500	140
Sheep, less yr end lambs	823		1.9		280	400	23
lambs	274		0.66		33	47	2.7
Swine, all	140		1.5		38	54	3.1
Horses, all	750		15		2 000	2 900	170
Broilers	37 500	225	0.05	2.5	281	402	30
Layers			0.06		330	470	27
breeders	30 000		0.10		37	53	2
Turkeys	9 800	30	0.18	22	330	471	27
breeders	500		0.19		17	24	1.4
			Totals		12 M Tons	18 M Tons	1.0 G Ft^3

*Assumes all air-dry manure is at 30% moisture (mass is equal to TS/100%-30%) and has a bulk density of 35 lb/ft^3.

TABLE 3

REGION 5 CD 1990 LIVESTOCK INVENTORY AND LIVE ANIMAL MASS
(x 1000)

County	1990 Human Population	All Beef Cattle (800)	Cow (1400)	Sheep (170)	Swine (135)	Horse (1000)	Broiler (2.4)	Layer (3.6)	Turkey (15)	TOTAL ANIMAL MASS in SUB-REGION 5CD and in CA
Fresno	635	390	54	94	7					
Kern	537	215	17	129	2.9					
Kings	99.3	212	77	18.8	5.8					
Madera	86.1	106	20	14.9	1.7	*	**	**	**	
Mariposa	15.2	25	--	1.9	0.01					
Merced	175.2	337	111	43.8	30					
Stanislaus	358.1	306	112	3.4	7.6					
Tulare	303.9	362	189	1.8	40					
Tuolumne	48.1	17	--	0.8	0.01					
Sub-Reg 5CD	2 257.9	1 970	580	308	95	113	226 000	7 000	28 160	
Live An. Mass (T)		788	406	26	6	56	31	13	69	1 395
CA Total	28 756	4 900	1 115	775	140	750	230 000	28 000	32 000	
Live An Mass (T)		1 960	781	66	9	375	32	50	78	3 351
REG 5CD%	7.8	40	52	39	67	15	98	26	88	42

* No available data. CA INVENTORY is best estimate of the TOTAL. Sub-region 5CD is believed by the California Horseman's Association to contain 15% of the total state inventory.

** Specific poultry data by county is not complete. TOTALS are the best estimates of UC-CE. The number of broilers and turkeys are the reported statewide and estimated regional numbers slaughtered in 1990. Broiler mass is factored by 6/52 and turkey mass by 17/52 to adjust for their time in residency.

Land Application of Municipal and Agricultural Wastes and Its Implication for Groundwater Quality in California.

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Cropland application is a common disposal method for animal wastes. The same could become the case for municipal sludges and green wastes. Available landfill capacity is rapidly declining leaving incineration, ocean disposal and recycling as the only viable remaining disposal methods. Numerous opportunities for recycling through land application exist: yards, parks, turf farms, highway embankments, airports, forests, and agricultural lands. Application to irrigated lands is not a total win-win situation. Although the nitrogen, phosphorus, potassium and organic matter content of agricultural and municipal solid wastes can enhance soil fertility and soil tilth, its salt content intensifies another problem, finding acceptable repositories for residual salts. In hydrologically closed basins like the Southern San Joaquin Valley, salt storage in evaporation ponds, in soil strata and groundwaters beneath irrigated lands, and postponing storage by reusing drainage water for irrigation are only short-run solutions. The northern portion of the San Joaquin Valley is becoming increasingly closed to drainage water export because of stringent regulations for discharge into the San Joaquin River. Land application of human waste to irrigated lands along the Colorado River could result in similar constraints if pathogens are found in subsurface drainage water or surface runoff. Thus increased land application of wastes presses inexorably on the disposal problems of irrigated agriculture.

The primary objective of my presentation is to articulate the salinity aspects of waste disposal issues. However, health concerns need to be addressed briefly. Municipal sludges contain nitrogen, heavy metals, pathogenic bacteria, parasitic ova, and viruses. Nitrate pollution of groundwater can be controlled by not applying more nitrogen (sludge plus inorganic fertilizer) than crops can utilize. Heavy metal impacts related to plant toxicity and food chain transfer can be controlled by placing upper limits on metal loadings. Disease organisms can be inactivated by treatment (composting, heat treatment, irradiation) and most are not able to survive when incorporated in soils. However, additional safeguards will likely be required to protect against disease transmission. Examples include: 1) not growing crops which contact the soil (e.g. tomatoes) for several years after sludge application, 2) not allowing surface water to leave irrigated fields, and 3) requiring well head treatment for drinking water wells located near or beneath lands where sludge has been applied. The last requirement would stem from concerns related to possible contamination of groundwater by viruses (M. Yates, private communication).

Land requirement for waste disposal

In assessing the annual land requirements given in Table 1, I assumed nitrogen was the determining factor. An annual nitrogen application rate of 180 kg/ha (160 lb/ac) was assumed to result in nitrogen balance--crop uptake would utilize all nitrogen applied thereby reducing the risk of groundwater contamination. Green wastes were included because of mandated restrictions for landfill disposal. Green wastes would generate 236 000 Mg N/yr (260 000 tons N/yr), assuming a per capita generation rate of 0.72 kg/day (1.6 lb/day), a nitrogen content of 3%, and a population of 30 million people (Table 1). This converts to an annual land requirement of 1 310 000 ha/yr (3 223 000 ac/yr). The next highest land requirement 1 102 000 ha/yr (2 722 000 ac/yr) is for dairy manure disposal; the nitrogen discharged annually by one dairy animal would provide 180 kg/ha• y to 0.58 ha. Land requirements for humans, and confined animals (beef, chickens and turkeys) are about an order of magnitude lower (76 000 - 146 000 ha/yr). The total land area is 1 607 000 ha/yr without green wastes and 2 919 000 ha/yr with green wastes. These numbers correspond to 44 and 80% of the total irrigated land area within California. This is not intended to suggest that wastes will, or should, only be applied to irrigated lands, or that all the wastes are collectible. The magnitude of the numbers does provide a perspective: there is an urgent need for good planning.

Salt Loads

Salt loads from land application of wastes are given in Table 2. The salts included were calcium, magnesium, sodium, potassium, chloride, and sulfur. Where data were not available--human sludge and green waste--I assumed a salt content of 3%. The land areas corresponded to those given in Table 1 which were calculated based on a annual nitrogen loading rate of 180 kg/ha•yr (160 lb/ac•yr). Excluding the loading rate for layer chickens of 1150 kg/ha•yr, the annual salt loads range from 180 to 300 kg/ha•yr. For comparison, the salt loads generated by applying 760 mm (30 inches) of an irrigation water with a salt content of 500 mg/L to a hectare of land is 3940 kg/ha•yr (3520 lb/ac•yr). Consequently, the additional salt loads generated by land application of agricultural and municipal wastes are not large--with the exception of wastes from layer chickens for which the land requirement is small. However, these salts require an acceptable repository, because unlike nitrate, most of them will not be removed by crop uptake or by chemical reactions.

Groundwater Implications

Disposal sites for salts generated in irrigated agriculture in California currently include: 1) soil, geologic strata, and groundwaters beneath irrigated lands, 2) on-farm evaporation ponds and inland lakes like the Salton Sea, 3) rivers which flow to the ocean. Irrigated agriculture is not sustainable unless salts are removed from the rootzone by leaching. Without leaching, salts will eventually accumulate to levels which are toxic. Consequently, a salt repository is a necessity for irrigated agriculture. And, because the gradient for water flow in the soil usually includes a downward component, downward salt movement and groundwater pollution is almost inevitable even if a clay layer overlies the groundwater body. For example, the Corcoran clay layer in the San Joaquin valley has a hydraulic conductivity of about 70 mm/yr (Belitz et al, 1992, Letey and Oster, 1993). Use of groundwaters beneath the Corcoran clay layer creates a downward gradient for water flow which ultimately will result in pollution from overlying saline groundwaters and irrigation practices.

Within California there are several examples of groundwater pollution caused by agriculture. In the Turlock-Modesto area, nitrate and pesticide levels in the groundwater resulting, in part, from irrigated agriculture have resulted in negotiations with irrigation districts to obtain surface water in exchange for groundwater to avoid treatment costs. In Riverside, groundwater contamination with salts, nitrate, and DBCP occurred due to fertilizer and soil fumigant applications to orange groves planted in the late 1800's. Houses have replaced these groves, increasing the need for drinking water. Using a low interest loan of $15 million, made available by the Water Conservation and Water Quality Bond Law of 1986, the Santa Ana Watershed Project Authority (SAWPA) has built a reverse osmosis plant to reclaim 26 million liters (6 million gallons) of groundwater per day. A waste stream of 3.7 million liters is discharged into the sea via the Santa Ana Regional Interceptor. In the Chino Basin, about 15 miles west of Riverside, dairies are a major contributor to nitrate and salt contamination of underlying groundwaters. Plans have been made by SAWPA to construct another groundwater treatment plant similar to the one in Riverside.

Conclusion

Irrigated agriculture is not especially well situated with regard to intensifying competition for water and rising concerns about water quality. In California, particularly within the San Joaquin Valley, it has not been successful in finding acceptable repositories for residual salts imported in the irrigation water. Land disposal of wastes introduces an urban salt loading which presses inexorably on the problem. The agricultural community needs to participate constructively in development of policies which address the problem realistically.

- Both agriculture and municipalities require an acceptable repository for salts in irrigation water and in wastes applied to irrigated lands.

- There will be an ultimate sacrifice of groundwater quality beneath irrigated lands even with the very best irrigation and waste management practices.
- Comprehensive source control--water, nitrate, pesticides, salts, and pathogens--must be the focus of agricultural practices to minimize and delay groundwater pollution.
- Well head treatment of groundwater to create acceptable drinking water may be the ultimate technological fix of the future.

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Table 1. Annual land requirements for waste disposal associated with a nitrogen application rate of 180 kg/ha·yr for California.

Source	Per capita production rate	Population	Nitrogen content		Land requirement in hectares per year
	kg/day	millions	%	Mg/y	millions
Green waste	0.72[a]	30.0	3.0[e]	236,000	1.31
Dairy	7.71[b]	1.90[d]	3.71[b]	198,000	1.10
Municipal sludge	0.080[c]	30.0	3.0[f]	26,300	0.146
Feeder cattle	3.08[b]	0.435[d]	3.97[b]	19,400	0.108
Turkey	0.082[b]	9.8[d]	5.17[b]	15,100	0.084
Chicken					
layer	0.029[b]	30.0[d]	5.16[b]	16,400	0.091
broiler	0.020[b]	37.5[d]	5.00[b]	13,700	0.076

[a] Appendices B.9 (Table 6-2) and B.11 (p84). Science and Technology Research Priorities for Waste Management in California. Ca. Council on Science and Technology, 1992.

[b] Fresh manure production and characteristics. ASAE D384.1.

[c] Lo, P.M. 1977. Municipal Sludge Characteristics, City of Los Angeles, Sanitation District of L.A. County and County Sanitation Districts of Orange County. LA/OMA Project. August.

[d] W. Fairbank. 1991. California's other 73 million population-equivalent residents. Office Report, Soil & Environmental Sciences, University of CA. Riverside CA 92521.

[e] Assumed value.

[f] Appendix, B.11 (p. 81). Science and Technology Research Priorities for Waste Management in California. Ca. Council on Science and Technology, 1992.

Table 2. Salt loads resulting from land application of wastes associated with a nitrogen application rate of 180 kg/ha·yr.

Source	Per capita production rate	Population	Salt content (Ca, Mg, Na, K, S, Cl)	Salt load[c]
	kg/day	millions	%	kg/ha·yr
Green waste	0.72	30.0	3.0[a]	180
Dairy	7.71	1.90	6.2b[b]	301
Municipal sludge	0.080	30.0	3.0[a]	180
Feeder cattle	3.08	0.435	5.5[b]	245
Turkey	0.082	9.8	8.4[b]	292
Chicken				
layer	0.029	30.0	33.0[b]	1150
broiler	0.020	37.5	8.0[b]	288

[a] Assumed values.

[b] Fresh manure production and characteristics. ASAE D384.1.

[c] Land areas given in Table 1, this paper.

PROTOCOLS FOR EVALUATING SOIL CONTAMINATION

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Characterizing the risk to human health and the environment from soil contamination is a difficult problem. The primary guidelines used by the Federal Superfund program, and generally followed by non-Federal cleanup programs, are embodied in "Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual." There are essentially no generic Federal or State cleanup levels for soils. One must first characterize (1) the nature and extent of contamination, (2) potential biological receptors, (3) potential migration pathways, and (4) potential routes and durations of exposure. With information on the toxicity characteristics of contaminants to organisms, a risk assessment is conducted to evaluate the potential threat to these organisms, and possible remedial measures.

As soil serves as both a sink and a source of contamination, it is critical that the extent of soil contamination and soil physical and chemical factors controlling the migration and fate of contaminants in soil be well understood. Migration pathways from soil that one must consider include (1) leaching to groundwater, (2) volatilization of chemicals into the atmosphere or building structures, (3) wind and water erosion of contaminated soil particulates, and (4) uptake of contaminants by plants and soil organisms. Routes of human exposure include (2) ingestion of food, water and soil, (2) inhalation of dust and vapors, and (3) dermal contact.

Risks can be eliminated or controlled by removing contaminated soil, by reducing contaminant levels via soil treatment, by preventing migration (such as capping a soil to prevent leaching to groundwater), or by removing biological receptors or changing their behavioral patterns. The future land use scenario will often determine the nature and extent of remediation. For example, an industrial zone will generally require a less stringent cleanup than a residential zone. Although there are many consulting firms who advertise their capabilities to do "remedial investigations" and "risk assessments," there is generally a lack of appreciation and knowledge of the chemical and physical processes in soils that control the transport and fate of soil contaminants and, thus, the extent to which organisms are exposed to toxic substances.

FROM WASTE TO ENERGY--CASE STUDIES OF ANAEROBIC DIGESTION OF AGRICULTURAL WASTE IN THE UNITED STATES

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SUMMARY

Seven anaerobic digestion projects are discussed with brief history, operating results and operation experiences. A 10 year old dairy mesophillic plugflow digester at a 400 head dairy has been operating a generator with a 90% service factor and excellent results. A six year old mixed mesophillic digester has provided electricity and heat to a 15,000 head pig farm. A four year payback and elimination of odor nuisance is reported. A 200,000 bird chicken manure digester was operated for 4 years until a drastic change in the off-site sales price for electricity ended the project.

Anaerobic lagoons with methane recovery are reported. A single owner is operating 3 covered lagoons at pig farms. The oldest project is 10 years old. Lagoon methane fuels generators, producing electricity for sale to utility. A covered lagoon digester at a small university dairy has been operating for 4 years with virtually no problems. Methane is used to heat water.

A short discussion of the type of problems that contribute to failures or non-operation of digester systems is included. Digester failures, unfortunately, are more numerous than digester successes. Three causes of failure or non-operation are found: 1) poor design; 2) poor operation or 3) lack of profitability. These types of problems may be found in combination at a single site.

Green waste compost for landscaping--A demonstration project.

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The mandate of California Assembly Bill 939 to reduce disposed green wastes has stimulated production and use of composted and fresh green waste products. These materials are widely sold yet qualities of their performance as mulch or soil amendment is not well understood. Green waste recycling is not a new concept, other states and regions of the United states have long recognized the importance of this resource (2,12,13). Mulching is also a recognized practice of benefit to plant culture (11). Green-waste mulches produced from chippings of shade trees have been associated with growth increases by some researchers (5,6,7,14,15) but not by others (1,8,9). Popular belief is that some sources of yardwaste such as eucalyptus are toxic to plants growing around them. Surveys of professional horticulturists revealed over 50% believe eucalyptus mulches are toxic to plants (graph 1). Allelopathy may be a mechanism of eucalyptus inhibition of plant growth, but the toxic nature of eucalyptus may only be to seedlings (3,4,10).

We designed a study to determine if eucalyptus mulches reduce growth of woody ornamental plants growing under them. Forty eight sycamore (*Platanus racemosa*) were planted from 1 gallon containers into a gravely loam soil in Ojai California in April 1991. *Eucalyptus caladocalyx* branches from a recently pruned tree were chipped with a commercial drum-type tree chipper and composted. After composting was finished, fresh chips were collected and chipped with a drum chipper producing large (1-6in.) chips and with a disk chipper producing small (.5-.75 in.) chips. Commercial mulch products, Growmulch (a sewage sludge compost) and Xerimulch (pine bark) were also applied. These five mulches and an unmulched treatment were replicated eight times in a randomized complete block arrangement. Mulches were applied four inches thick and replenished once. Weeds were not controlled in unmulched plots.

Soil moisture was monitored with gypsum blocks and by time domain reflectometry. Caliper was measured monthly. Irrigations were scheduled by moisture depletion estimates of the gypsum blocks in the first year and by evapotranspiration estimates in the second year. Dormancy was estimated visually as a color rating (fall color) and stomatal conductance was measured with autoporometer.

We found that mulched trees grew more than unmulched control trees (graph 2). This difference was significant at the end of the first year until present. Mulched trees resist dormancy by retaining their leaves thus producing more growth in the fall than unmulched trees. Soil under mulches retained more moisture between irrigations than unmulched plots (graph 3). Diffusive resistance (a measure of stress) was highest in unmulched trees at the end of many irrigation cycles. Weeds proliferated in unmulched plots, while mulched areas were almost weed free at the end of the second season (graph 4).

Weeds are strong competitors for soil moisture and their presence in unmulched plots may have contributed strongly to moisture deficits and sycamore stress as measured by autoporometer. Unstressed (mulched) trees grew rapidly under minimal irrigation (Applied water was approximately 20% of reference evapotranspiration in the first year). Eucalyptus mulches were not toxic in this study. The largest trees were grown under small chips of fresh *Eucalyptus camalduensis*.

Further work is planned with weedy and weed-free unmulched plots to better estimate the deleterious effects of weeds and beneficial effects of mulches.

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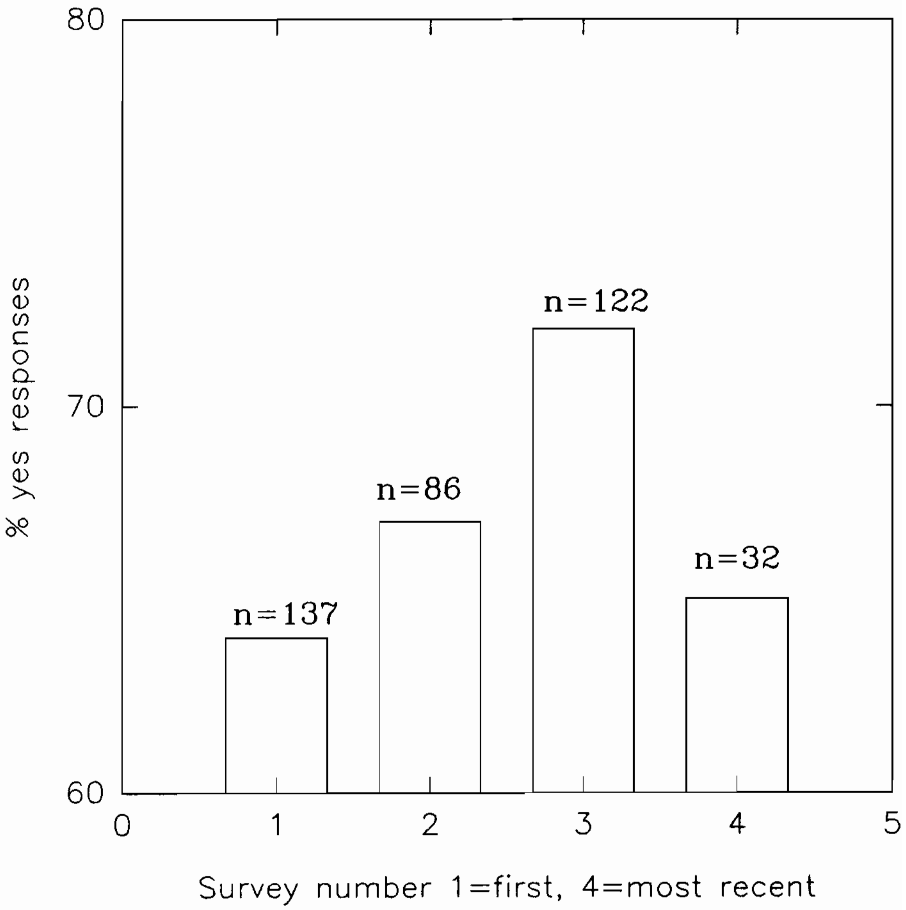
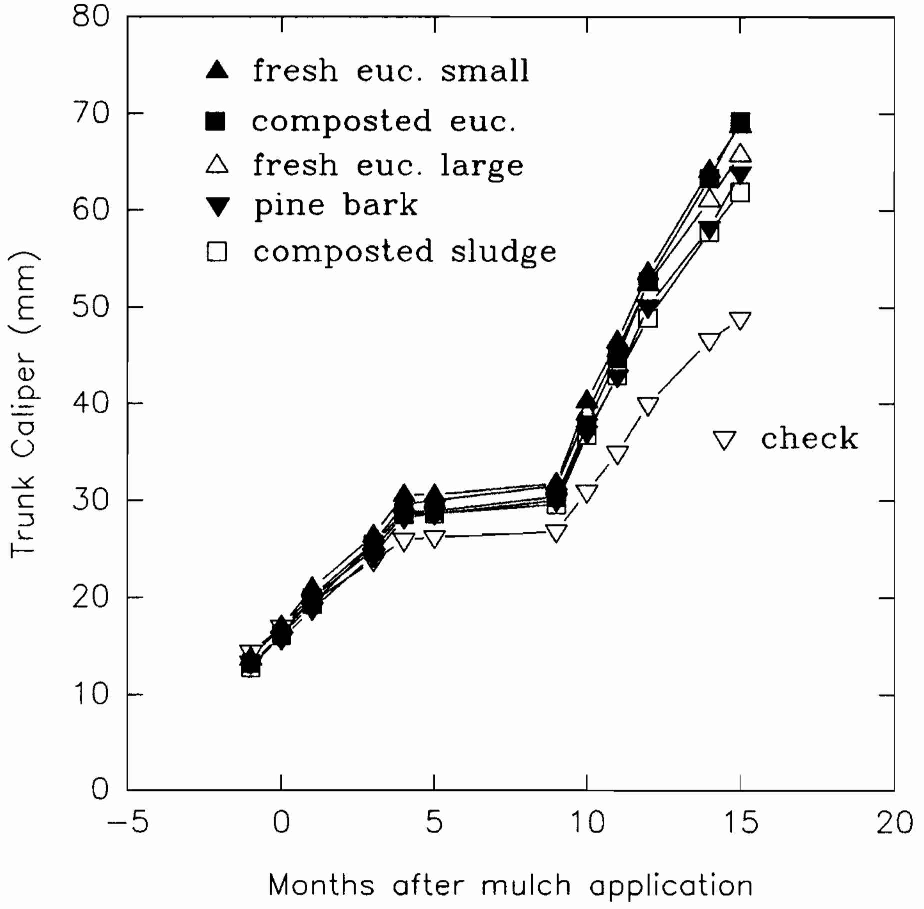
Graph 1.

Responses to the question "Fresh Eucalyptus mulch is toxic to plants? [ ] yes [ ] no



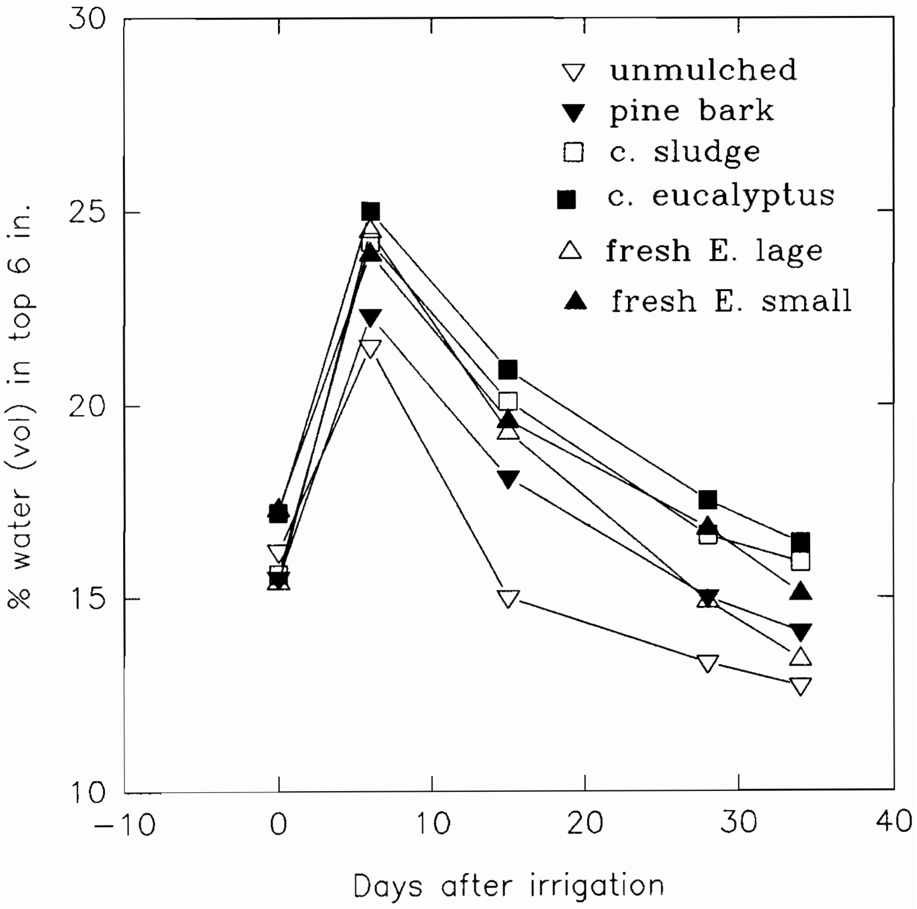
Graph 2

Trunk growth of California sycamore under various mulch treatments.



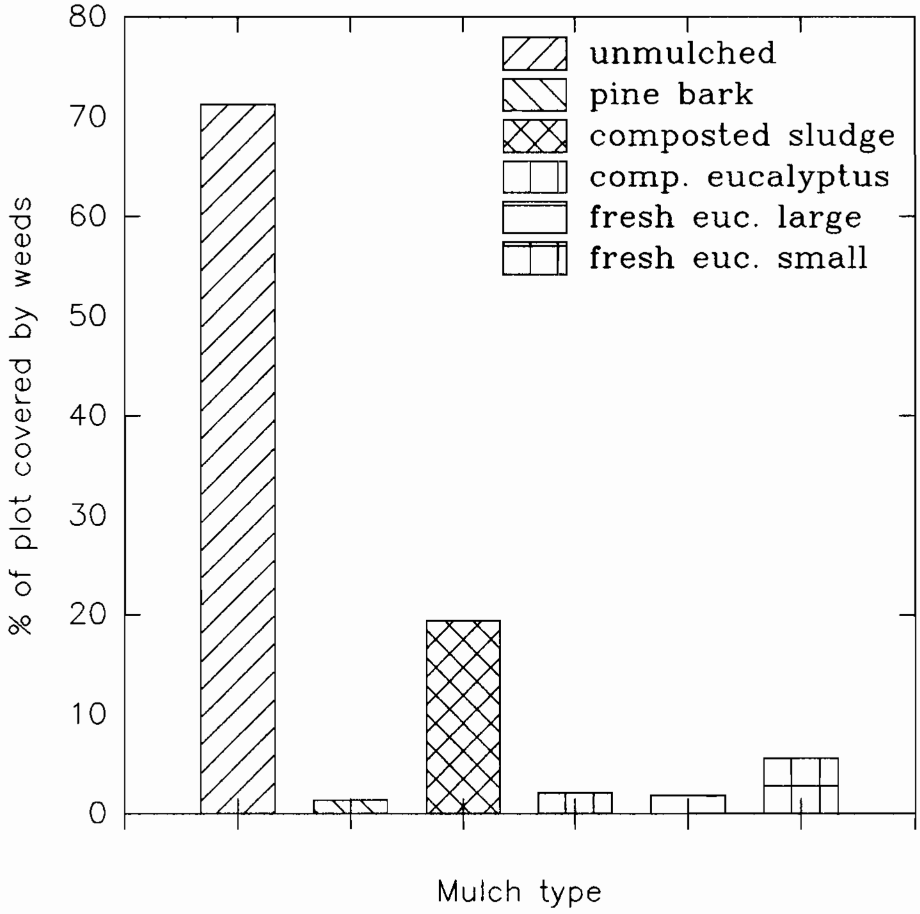
Graph 3

Soil moisture under various mulches after irrigation (August 1991)



Graph 4

% cover of mulched plots by weeds on 11/3/92. Plot size is 8x8 feet.



Design of Sewage Sludge Loading Rates

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Background

Every day in the United States, over 100 billion liters of liquid wastes are flushed into municipal sewers. Treatment of this effluent leaves over 7 million Mg (dry weight) of residue each year in the form of sewage sludge, most of which is buried in landfills or incinerated (Bastian, 1986). A 1988 survey found that California Publicly Owned Treatment Works (POTWs) were producing approximately 375,000 Mg (dry weight) of wastes each year, a quantity expected to rise to 500,000 Mg by 1998 (Chang, 1992). Sewage sludge contains important nutrients, which for centuries have been used to fertilize agricultural land and the USEPA (1989) now actively promotes "beneficial use" of these nutrients through land application. Today there are approximately 12,000 land application systems operating in the United States (Goldstein, 1986) disposing of approximately 16% of the nation's municipal sewage sludge. In California, approximately 13% of municipal sludge is directly land applied. An additional 13% is incorporated as processed soil amendments so that a total of 26% of the state's sludge is disposed of on land.

Municipal sludges can threaten the environment if improperly applied, however. The components of municipal sewage sludge that have attracted the most concern include metals, pathogens, toxic organics, salts, and biochemical oxygen demand (BOD), and nutrients. The concentrations of these constituents are determined by the characteristics of the waste stream and by the sewage plant treatment processes used to generate the sludge.

Design Concerns

As other non-beneficial, technologies such as landfilling and incineration become less attractive due to financial, regulatory, environmental, and political concerns, public interest in land application of municipal sewage sludge has increased. In order to comply with Section 405 of the Clean Water Act, the USEPA has recently introduced 40 CFR Part 503 which regulates land application systems. The new regulations set down by the USEPA in Part 503 may allow significantly higher amounts of certain sludges to be applied than have been permitted in the past.

The nutrients held in sewage sludge can be an important resource if managed properly. A dry ton of sewage sludge contains nitrogen, phosphorous, trace nutrients, and organic matter with a fertilizer value of 50 to 60 dollars (USEPA, 1989). Excessive sludge application rates can quickly pollute groundwater with nitrate, however. Nitrate-nitrogen concentrations in the United States are limited to 10 mg/L for potable drinking water (USEPA, 1983). Heavy metals, on the other hand, tend to accumulate in the soil where they can reach phytotoxic levels or enter the food chain through plant uptake. The impact of sludge nitrogen on area water quality limits application rates in the short term, therefore, while cumulative heavy metal additions constrain the total amount of sludge that can be applied to a given system. Other sludge contaminants are usually controlled through proper sludge treatment, sound crop water management, and soil conservation practices.

Heavy Metal Loading Constraints

Heavy metals sorb to the sludge solids fraction and are generally immobile in soils. In small amounts, many heavy metals serve as vital micronutrients. Larger concentrations may have toxic effects on both plants, animals, and microbes, however. The threshold for heavy metal toxicity varies from species to species and from element to element. Because most metals do not leach readily, they are regulated on a cumulative rather than annual basis. At the time of this writing, 40 CFR Part 503 had been signed but not formally released. Table 1 presents the cumulative site metal application limits expected to appear in the regulation (A. C. Chang, 1992, personal communication). Average metal concentrations for California sludges also appear in the table (Chang, 1992). These terms are then used to calculate the maximum amount of sludge that could be applied to a site for each element as well as the corresponding potential operating life of the site with a 10 Mg/ha-yr application rate.

Table 1. *Proposed 40 CFR Part 503 cumulative loading rate restrictions for an "average" California sludge.*

Metal	**Average California Sludge Metal Concentration** *mg/kg*	**Cumulative Metal Site Application Limit** *kg/ha*	**Cumulative Sludge Site Application Limit** *Mg/ha*	**Disposal Site Operating Life** *years*
Arsenic	7.8	54	6923	692
Cadmium	13.1	39	2977	298
Chromium	144	3000	20833	2083
Copper	656	1600	2439	244
Lead	126	300	2381	238
Mercury	4.4	38	8636	864
Molybdenum	3.5	32	9143	914
Nickel	72.4	290	4006	401
Selenium	8.5	27	3176	318
Zinc	962	2800	2911	291

The "average" California sludge represented in Table 1 should not be considered to be representative of the state's residuals since the metal concentrations represent mean values for the state. Actual metal concentrations are quite variable. It is not unusual for the sludge generated by a specific municipality to have concentrations for a number of metals that are significantly lower than in Table 1, along with one or two metals at levels significantly higher than average. Because Part 503 regulates each metal independently so that none can exceed its respective cumulative loading limit, a single elevated element can significantly shorten the operating life at a given site. Fortunately trends in industrial pretreatment technology are steadily decreasing the concentrations of metals in many municipal sludges lengthening the time required to reach Part 503 cumulative limits.

Nitrogen Loading Rates

Although concentrations vary from sample to sample, sewage sludges contain approximately 1 to 10 percent nitrogen as a fraction of their dry weight (USEPA, 1983). Nitrogen is found in both the solid and liquid fractions of municipal sewage sludge. In the solid fraction, nitrogen is bound into sludge organic matter, while dissolved nitrogen is primarily in inorganic form as ammonium ions and aqueous ammonia. For most sludges, 25 to 50 percent of the total sludge nitrogen is in dissolved inorganic form, but dewatered sludges may contain as little as 10 percent inorganic nitrogen as a fraction of total sludge nitrogen (USEPA, 1983).

For design purposes, it is usually assumed that 50% of dissolved ammonium is volatilized during the application process for surface applied liquid sludges (USEPA, 1983), although volatilization rates as high as 100% have been observed (Kaufman and Haith, 1986). No ammonia volatilization is assumed for injected or dewatered sludges (USEPA, 1983). Organic sludge nitrogen contains a labile fraction that mineralizes to ammonium rapidly after application. The remaining fraction stabilizes, and is slowly mineralized over time (Brockway *et al.*, 1986; Haith, 1983). With repeated applications, the system will eventually reach a steady-state condition where the unvolatilized mass of nitrogen applied with the sludge equals the mass available for plant uptake or for leaching. Design application rates are therefore initially elevated, eventually dropping to a steady-state level. Rates can be set so that sludge inorganic and mineralized nitrogen meet crop needs, or so that nitrate-nitrogen concentrations in percolating groundwater meet environmental standards.

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MOLECULAR APPROACHES FOR CONTROL OF TOMATO BUSHY STUNT VIRUS

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Tomato bushy stunt virus (TBSV) is a pathogen of tomatoes which is associated with the appearance of tomato decline disease in the field. TBSV, the type member of the tombusvirus group, is a small isometric virus containing a single positive sense RNA genome of ca. 4800 nucleotides which encodes five genes (Figure 1). Infectious cDNA clones are available (Hearne et al., 1990) and RNA transcripts are routinely used for infectivity assays in plants and protoplasts. These studies suggest that the larger of the two 5' terminal gene products results from a readthrough of a termination codon of the smaller gene and that both genes are required for replication. The third gene encodes the coat protein which is translated from a subgenomic messenger RNA. The coat protein is dispensable for replication and for systemic movement in plants. In addition, foreign reporter genes substituted for the capsid protein are efficiently expressed in protoplasts and in inoculated leaves, although deletion events occurring during replication effectively prevent expression of the reporter genes in systemically infected leaves (Scholthof et al., 1993). The 3' terminal region contains two nested genes encoding different proteins which are also expressed from a subgenomic messenger RNA. The larger gene encodes a 22 kD product, and a 19 kD "out of frame" gene is completely contained within the 22 kD gene (Figure 1). Our recent molecular genetic analyses have indicated that at least one of these proteins is required for systemic movement in plants and that foreign genes substituted into the open reading frame can be expressed in protoplasts.

Under certain conditions where TBSV is serially passaged from plant to plant at high multiplicities of infection, defective interfering (DI) RNAs are generated from the parental TBSV genome (Figure 2). These small DIs of 400 to 600 nucleotides are composed of conserved parts of the genome (Knorr et al., 1991) and are very efficiently replicated by the parental virus. During this process, DI's greatly suppress the replication of TBSV and dramatically attenuate its symptoms in certain host plants. For example, TBSV normally induces a lethal necrosis in Nicotiana benthamiana and infected plants survive only in the presence of DI's. Infectivity studies with protoplasts have indicated that the ability of the DI's to interfere with TBSV replication probably involves a preferential association of the DI with the replicase gene product to diminish synthesis of the TBSV parental genome while greatly accentuating synthesis of the DI RNAs

(Jones et al., 1990). These DI's thus have the potential to protect plants against disease development if they can be effectively delivered to the site of infection.

We are currently investigating several molecular strategies for development of virus control in plants. Transgenic plants harboring the coat protein gene are being tested for the effect of engineered cross protection on virus infection. In addition, we plan to transform plants with replicase gene segments of TBSV which could provide protection in a manner analogous to that recently reported for other RNA plant viruses. Currently, however, we are directing most of our efforts towards the construction of transgenic plants expressing DIs which could potentially interfere with the infection process. Transgenic tomatoes have been generated which supply endogenously transcribed DI transcripts, but these DIs are not replicated by TBSV. We believe this is due to the presence of extra nucleotides on both termini of the DI RNA which resulted from the genetic engineering steps necessary for plant transformation. To overcome this problem we have generated new DI constructs that contain cis-acting ribozyme sequences that cleave the transcripts at the appropriate positions thereby facilitating replication of the DIs in plants upon inoculation with the virus. These DI transcripts efficiently inhibit TBSV replication when mixed with virus inoculum and may be useful for eliciting resistance in transgenic plants. In a related approach for development of resistance, we have constructed synthetic defective RNAs from which foreign reporter genes can be expressed during the infection process. Transgenic plants expressing these constructs have some potential for monitoring movement of the virus and also may have some applications for disease control.

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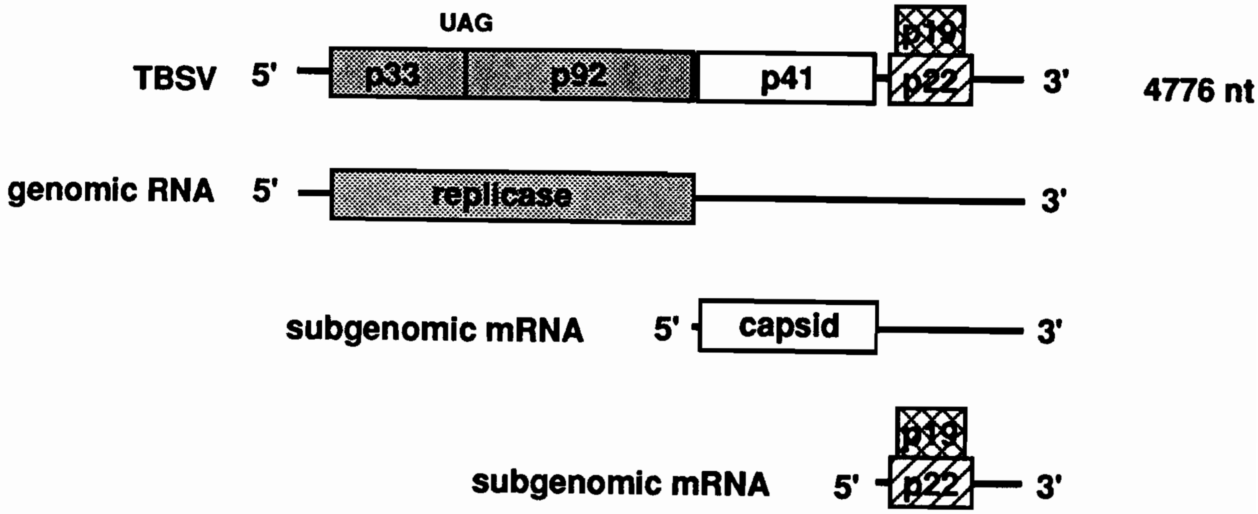

Figure 1. The schematic at the top of the figure illustrates the TBSV genome. The replicase genes (P33 and P92) are shaded, the coat protein gene is white and the two nested genes (P22 and P19) are hatched. The lines below the virus indicate that the replicase genes are translated directly from the genomic RNA, while the coat protein and the nested genes are translated from subgenomic mRNAs.

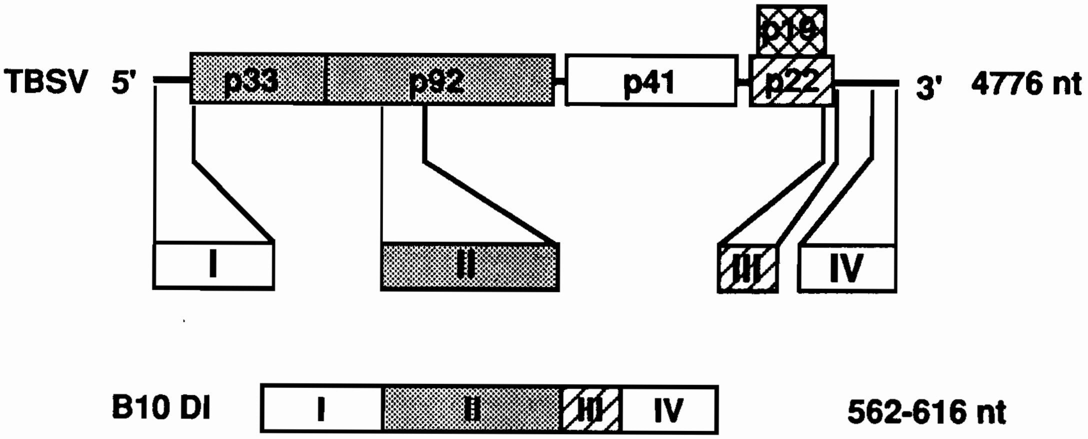

Figure 2. The schematic at the top illustrates the TBSV genome and the conserved blocks of sequence required for generation of natural DI RNAs, which occurs via deletion events during replication of TBSV. The schematic below shows how the conserved blocks have been joined to form the B10 DI RNA.

Monitoring Molecules and Microbes In the Agricultural Environment with Antibody-based Diagnostics

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Immunoassay is an analytical technique that was developed and commercialized for various applications in human medicine. The method is based on antibodies, which are key components of the immune systems of animals. Antibodies are proteins produced by specific white blood cells when those cells encounter a foreign organism or substance in the body. These proteins have the ability to recognize and bind to a specific molecular configuration. Scientists harnessed the precision of the binding to create tests that detect and measure the targeted material or organism. Some typical medical applications of immunoassay include:

- ☐ Diagnosis of disease by:
  - Detecting markers such as disease-specific proteins
  - Detecting pathogenic microorganisms
  - Detecting antibodies in patients' blood that indicate infections
- ☐ Diagnosis of medical conditions:
  - Measuring hormone levels to determine pregnancy and fertility
- ☐ Measuring levels of drugs in humans:
  - Accurately analyzing levels of therapeutic drugs
  - Screening blood and urine samples for drugs of abuse

Once these techniques were well established in the clinical arena, they were applied to other areas as well. Veterinary medicine presented several obvious and analogous applications. More recently it was recognized that the characteristics of immunoassay make it applicable to analyzing crop and environmental samples. Many of the attributes of immunoassay that made it a primary medical testing method are also applicable to agricultural testing. A remarkable advantage of immunoassay is that it can be applied to detect and quantify both large biological molecules such as proteins and small organic chemicals such as toxins, pesticides, and chemical pollutants.

In the following sections we will list key attributes and examine the advantages and possible drawbacks of this method.

Advantages of Immunoassay

Immunoassay has penetrated the medical diagnostics market because it offers accurate determinations quickly and at a lower cost than other "classical" methods. The developers of an immunoassay must conduct extensive testing to demonstrate that the assay delivers accurate results and that it meets or exceeds the accuracy and precision provided by other methods. While accuracy is not an advantage of immunoassay *per se* it is an essential characteristic for any analytical method and is one that many environmental immunoassays meet.

The relative speed of the method results from analyzing multiple samples simultaneously rather than sequentially. For example, drug screening by gas chromatography (GC) or high performance liquid chromatography (HPLC) typically requires from 15 to 45 minutes per sample. After a single determination another sample can be injected into the instrument limiting data output to 1 to 3 samples per hour per instrument. Immunoassay, on the other hand, allows an operator to set-up from one to a hundred or more samples at one time and complete the testing procedure in an hour or two.

Traditional crop disease diagnosis relies on microscopic examination of infected tissue, culturing pathogens, and laborious identification of pathogens. This process frequently takes days or weeks and usually requires a well equipped laboratory and a thoroughly trained diagnostician. Immunoassay eliminates a good deal of the time required for diagnosis, allows a broader range of people to diagnose diseases, and even makes it possible to accurately diagnose disease in the field.

For the analysis of chemicals such as pesticides sample preparation adds a good of time and labor to analysis by conventional methods. The target analytes must be extracted from the matrix being analyzed and, frequently, the resulting extract must pass through several steps before it is ready for chromatography. Immunoassay typically requires little or no sample preparation because the binding of the analyte to the antibody is specific and can occur even in the presence of a good deal of contaminating substances.

Water analysis presents an interesting challenge for conventional analysis. U.S. and foreign regulations limit chemical contaminants in water to extremely low levels. For conventional analysis water samples must be extracted and the contaminants must be concentrated so that they can be detected by GC or HPLC. Immunoassays typically allow analysis of water samples directly with no extraction or concentration. This is possible because the binding of the target chemical to antibodies is relatively strong and because the methods of determining the binding are extremely sensitive. Enzymes are one class of markers used to indicate binding and produce an amplified signal that results in a color change. Fluorescent chemicals are also used as highly sensitive markers for immunoassay.

Because of the types of markers used for immunoassay the instrumentation required to read and record test results are relatively low cost when compared to instruments used for HPLC, GC, or GC-mass spectrometry (GC-MS). This, combined with the speed, limited sample preparation, and simultaneous analysis normally make immunoassay significantly less expensive than conventional analysis. Some authors claim that analysis by immunoassay costs only 10% - 20% as much as GC methods.

Another advantage for immunoassay is that the method can be made portable. While GC, HPLC, sterile culture, and microscopy are largely limited to central laboratories immunoassay can be designed to operate under a wide range of conditions. Perhaps the most commonly cited example is the home pregnancy test kit, an immunoassay for the hormone HCG that has been developed for occasional use in the home by people who are not trained medical technicians. Other examples of "portable" immunoassay include test kits for physicians and veterinarians, physicians' office immunoassay workstations, test kits for crop diseases, and test kits for pesticides and chemical contaminants.

The following table summarizes key advantages of immunoassay.

Table 1. Advantages of Immunoassay for agricultural analysis

Immunoassay Characteristics	Advantages and Comments
• Specificity	IA detects only targeted chemicals or organisms avoiding most interference from sample components and secondary microbes.
• Sensitivity	IA can be developed to detect sub-ppb levels of most contaminants, reducing the need to extract and concentrate samples.
• Reduced sample preparation	The characteristics listed above greatly reduce the complexity and extent of sample preparation needed for testing most types of samples. Results in time, labor, materials savings.
• Adapted to laboratory and remote applications	Simple procedures, standardized materials, and widely available instruments allow for IA use in centralized labs, remote or temporary labs, and field sites.
• Speed of analysis	Samples are tested simultaneously, greatly reducing overall analysis time.
• Quantitative results	IA is a quantitative method. IA typically correlates well with conventional methods.
• Low cost relative to conventional procedures	Testing by IA routinely costs only 10-20% of conventional methods. Makes IA attractive for large monitoring programs.

Limitations of Immunoassay

Any analytical procedure has its limitations and it would be a mistake to present immunoassay as a technique that should be used for all agricultural analyses. In fact, some of the characteristics that make immunoassay valuable may limit its use.

A particular antibody binds exclusively to a single molecule or a few closely related chemical structures. This specificity avoids most interference from non-target chemicals and organisms. However, it limits a particular immunoassay to that narrow range of targets.

A chromatographic method typically provides the opportunity to scan for a range of chemicals. The range has its limits, but these are normally broader than those provided by a single immunoassay. If an investigator wants to know whether Compound X is in a sample, an immunoassay for Compound X is a cost-effective means to answer the question. If the sample is completely uncharacterized and the investigator wants to know what chemicals are in that sample, a chromatographic method may be a better choice.

Immunoassays are simple and easy to conduct, but their development requires a sophisticated laboratory and a range of technical skills. Chemists and plant pathologists can develop or implement methods from experience and by reviewing scientific literature. Immunoassays must be provided as finished kits to assure standardized and consistent results. Currently, only a relatively small number of commercial immunoassay kits is available for water, crop, and soil analysis. The number of analytes that can be detected with commercial immunoassay is growing, but the modest number of test kits can be viewed as a limitation.

Immunoassays are simple to conduct and the instrumentation is widely available at a modest cost. Because of this many more people have access to this analytical method than to chromatographic methods. A possible drawback of this is that the ability of the operator to conduct immunoassay may outpace their ability to interpret the results, trouble-shoot problems, and perform quality control checks. These concerns primarily affect the reliability of the quantitative results generated by the operator. Consequently, immunoassays conducted by those other than trained analysts or diagnosticians are generally used for screening. That is the results are judged to be semi-quantitative and specified samples are submitted for confirmatory analyses by another method.

As discussed above, sample preparation for immunoassay is generally simpler than that required for conventional analysis. Solid samples must be extracted for analysis. Immunoassay must be conducted in an aqueous sample, which means that a solid sample such as soil must be extracted and the extract must be mixed with water before immunoassay is carried out. This process is generally much simpler than the soil extraction and clean-up procedures used for chromatography, but it is an important step in immunoassay.

Is immunoassay a screening method or is it a quantitative analysis method? This is a frequent question that may place a limitation on immunoassay. Basically, immunoassay generates a dose-response curve that provides a quantitative output. However, the conditions where the testing is conducted may constrain the absolute accuracy of the results. For example, testing in the field or a storage building may introduce temperature variations or contamination that will affect the accuracy of the test results. The results, however, will normally indicate the relative level of the analyte and can be used to guide further testing.

Table 2. Limitations of Immunoassay for agricultural analysis

Immunoassay Characteristics	Limitations and Comments
• Specificity	Limits a particular immunoassay to just the chemicals it specifically detects. No broad, general screening currently available.
• Limited range of IA products	Laboratory methods can be used to analyze for a much larger number of compounds and oganisms than IA. The number of IA products is growing rapidly, however.
• Sample preparation	Although sample prep for IA is simple, matrices such as soil, grain, crop tissue and animal tissue must be extracted before IA can be conducted.
• Training and interpretation	Non-chemists and non-plant pathologists are conducting IA, raising concerns about quality control of the analysis and interpretation of results. This may limit quantitative use of IA.
• Field screening	Under field conditions it may not be possible to obtain totally accurate results with IA. The method may be more appropriately used for screening where accuracy can not be assured.

Conclusion

Immunoassay is a useful tool that can provide sensitive, accurate analytical testing of water, soil, and crops. As with any analytical method each immunoassay must be carefully developed and rigorously evaluated to define the applications to which it can successfully be applied. Where applicable, immunoassays are faster and less costly than conventional analytical and diagnostic methods. This technique is quantitative, but many investigators choose to use immunoassay as a screening method where its low cost, high throughput, and portability are especially useful. End-user training is important since many of those employing immunoassay are not trained analytical chemists. As more immunoassay kits become available environmental scientists, water chemists, agronomists, crop consultants, entomologists, plant pathologists, and engineers are recognizing the advantages of the method and are adopting it for monitoring programs, site assessments, research projects, and field screening.

Comparison of Stem Water Potential and Canopy Temperature as Indicators for Water Management in Peach and Plum

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Numerous instruments have been suggested as management tools for assisting in irrigation scheduling of crops. These include both soil-based and plant-based instruments. Soil based instruments measure some attribute of soil water and include tensiometers, neutron probes, gypsum blocks and many new recent inventions.

Plant-based instruments are designed to measure some aspects of water flow through the trunk or leaves or to quantify the degree of stress being experienced by the plant. Some examples include porometers, trunk heat flow gauges, pressures bombs, infrared sensors, and trunk dendrometers.

We have had experience with many of these instruments as we have tried to find practical tool for irrigation management in fruit trees. To be practical, the instrument must meet certain basic criteria as follows:

1) Provide data that correlates well with some measure of tree growth or productivity.

2) Be relatively easy to use.

3) Provide results that can be easily interpreted in terms of irrigation scheduling.

4) Provide consistent and predictable results with well-watered trees.

5) Provide measurements that are consistent among trees, years, varieties and fields.

Most instruments fail to satisfy one or more of these criteria. However, there are two approaches to measuring tree water stress that we have studied in some detail since they have shown some promise. One uses canopy temperature, as measured with an infrared sensor, plus air temperature and vapor pressure deficit to calculate a crop water stress index (CWSI) (Idso, 1982). The method has been used with some success in field crops (Braunworth and Mack, 1989; Idso et al., 1982). It is particularly appealing because it is very simple to use and theoretically provides a single value that could be compared to a threshold level for irrigation scheduling.

The second approach is to estimate stem water potential (SWP) by measuring the water potential of a leaf near the trunk which has been bagged for at least one hour. This allows the leaf and stem water potentials to reach equilibrium with each other. The method has been shown to be less variable than sun-exposed leaf water potential and to have potential in irrigation scheduling of fruit trees (Garnier and Berger, 1985; McCutchan and Shackel, 1992).

Both these methods were tested extensively over a three year period in an irrigation experiment on 'O'Henry' peach trees where eight irrigation strategies were imposed. Limited testing was also conducted in a 'Red Beaut' plum orchard where three postharvest irrigation strategies were imposed over two years.

In the 'O'Henry' peach experiment, final fruit weight correlated well with mid-day SWP measured about 1 month before harvest. This relationship held up for all three years of the experiment. The seasonal pattern of SWP in the well-watered control was very consistent in each of the three years. It started early in the season at about -0.5 to -0.6 MPa and dropped off gradually to about -1.0 MPa. Furthermore, the variability among trees within the control treatment was very low. Results from the 'Red Beaut' plum experiment were quite similar. The average SWP readings during the postharvest period in one year correlated well with yields in the following year. The seasonal pattern in the well-watered control showed the same gradual decline, although slightly lower than the peach trees.

The CWSI values showed less promise as an irrigation management tool. They showed a significant correlation with final fruit weight in the 'O'Henry' peach experiment, but the fit was not as tight as the SWP correlations. Furthermore, there tended to be greater variability among trees within a given treatment. Finally, CWSI for the well irrigated control changed erratically over the season and did not follow a consistent pattern from one year to the next.

In summary, CWSI still has lots of problems but SWP appears to have the potential for a practical irrigation management tool. It is relatively easy to use, shows a consistent pattern in well watered trees, and correlates well with several measures of productivity.

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Stem Water Potential as a Diagnostic for Irrigation Management

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A number of reports in the literature (eg., Sinclair and Ludlow, 1985) have questioned the usefulness of water potential (Ψ) as a reliable indicator of plant water stress. For the most part this has been due to the lack of any clear relation being found between transpiring leaf Ψ and 1) physiological symptoms of stress (eg., stomatal closure, plant growth) or 2) environmental conditions known to increase plant water availability and plant productivity (eg., irrigation). In some, but not all cases, the low or highly variable leaf Ψ values that have been reported for plants under well irrigated conditions can be attributed to methodological errors in the use of the pressure chamber (Turner and Long, 1980). Even when measured correctly however, transpiring leaf Ψ represents a potentially complex weighted average of the within-leaf Ψ gradient that is associated with the rate of individual leaf transpiration (Shackel and Brinckmann, 1985). Hence transpiring leaf Ψ may not consistently measure the Ψ experienced by the cells or tissues in the leaf that determine leaf function. By the same token, transpiring leaf Ψ may not measure the Ψ that is important in determining whole plant function.

Recent results in prune (McCutchan and Shackel, 1992) and peach trees (Garnier and Berger, 1985) have demonstrated that covered leaf Ψ, which measures the Ψ of the stem to which the leaf is attached, may be a more sensitive measure of plant stress than transpiring leaf Ψ. In some cases, irrigation treatments have caused large differences in stem Ψ, and for the same trees, no difference in leaf Ψ. It is clear that stem and leaf Ψ are different measures of plant stress, both physically and physiologically. In prune (McCutchan and Shackel, 1992), the stem Ψ of well irrigated trees was closely related to vapor pressure deficit (VPD), as expected from the soil-plant-atmosphere continuum (SPAC) model. In addition, the stem Ψ of water limited trees was closely related to reductions in both stomatal conductance and orchard water use, indicating that a 50% reduction was associated with a decline in stem Ψ of only 0.5 - 0.6 MPa from that of the well irrigated trees.

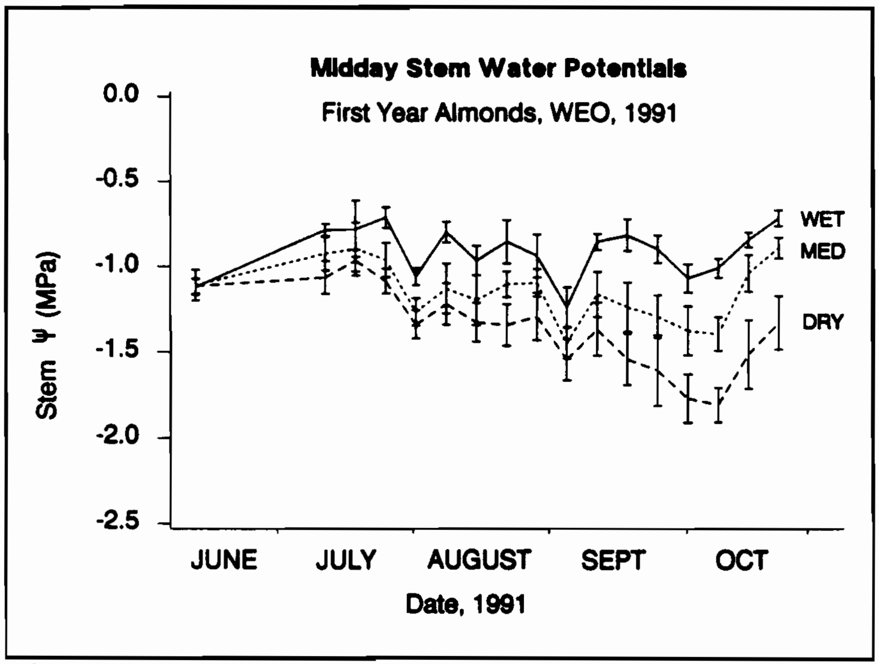

Figure 1. Stem Ψ for the first year of an almond experiment.

An experiment was designed to establish 3 contrasting irrigation regimes (Wet, Medium and Dry), based on stem Ψ, in a first year almond orchard. The three regimes established clear differences in stem Ψ during the season (Fig. 1), and corresponding differences in tree growth. Under the wet regime, tree to tree variability in Ψ was small and not statistically significant. However, under the dry regime, individual tree differences in Ψ were highly significant, and increased as the season progressed (Fig. 2). Tree behavior in the medium regime was intermediate. After two growing seasons (1991,

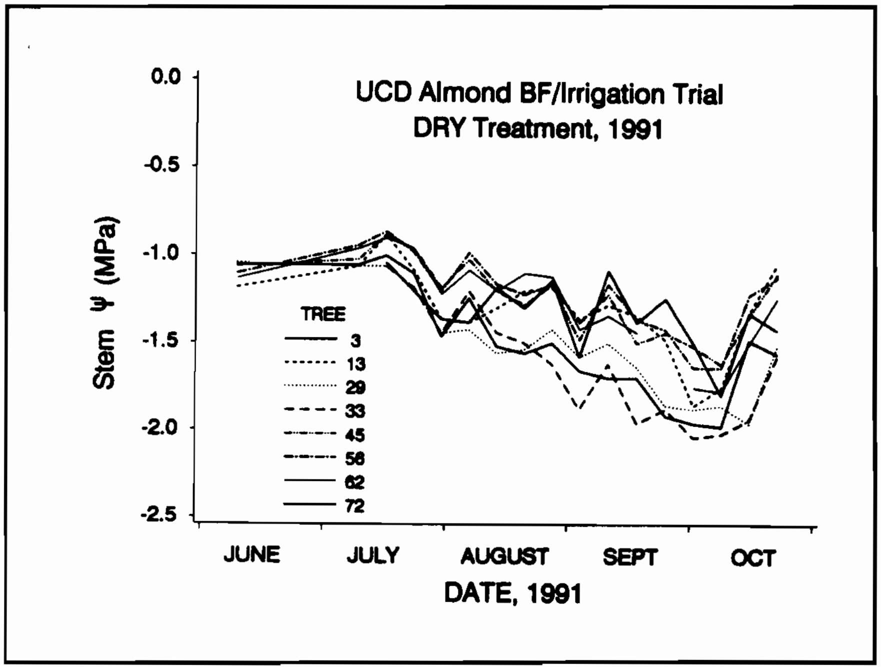

Figure 2 Individual tree Ψ for almonds under the dry irrigation regime.

1992) the size of individual trees, as measured by their trunk cross-sectional area, was very well correlated to the average Ψ exhibited by each tree over the two years (Fig. 3). These results indicate that stem Ψ can be used as a basis for irrigation, and that tree growth response can be expected to follow stem Ψ differences. Similar results of good correlations between stem Ψ and other important aspects of tree productivity such as yield (pistachios) and fruit size (pear) have also been obtained. The results with almond indicate however, that tree to tree variability may increase as tree water availability decreases, hence site differences may become an increasingly important aspect of irrigation management if programs of withholding water (eg., CDI) are to be used effectively. One surprising result from the almond experiment was that the water applied to the trees under the medium irrigation regime was slightly in excess of the water requirement predicted based on CIMIS ET data (Fig. 4). This was surprising because the trees clearly responded to a much higher level of applied water than that predicted based on both Ψ (Fig. 1) and growth (Fig. 3). These results may indicate that the currently accepted crop coefficients (K_c), or their use for young trees, should be reevaluated in almond.

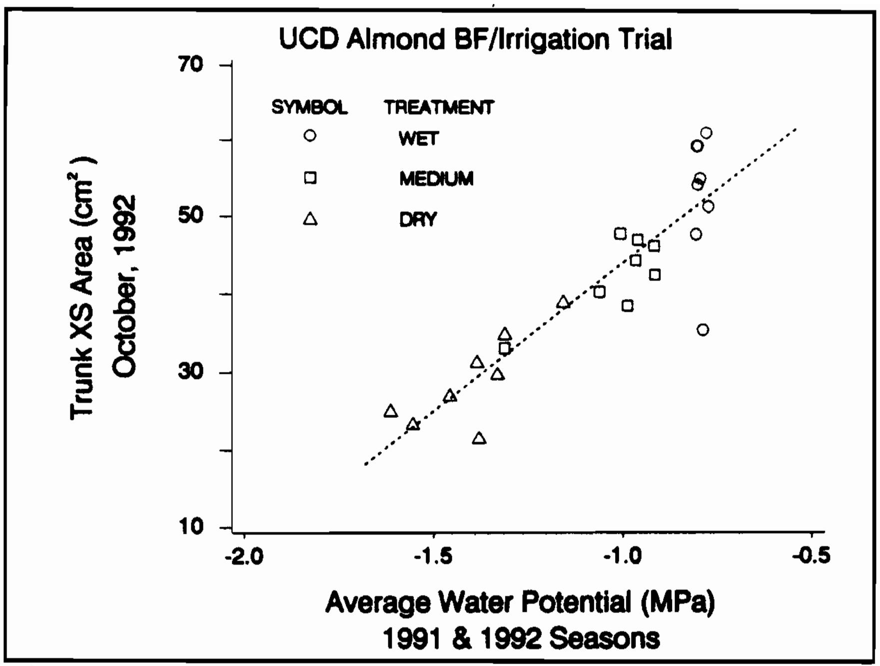

Figure 3. Correlation of tree size (trunk cross-sectional area) at the end of two growing seasons (1991, 1992) with average tree Ψ over the same period.

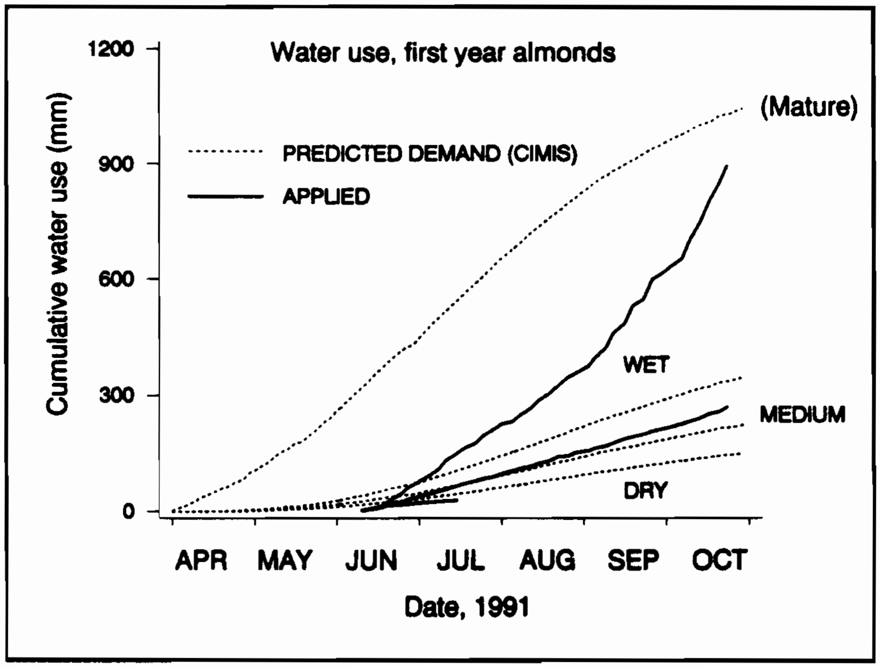

Figure 4. Applied vs. predicted water requirements for trees under the three irrigation regimes of Fig. 1. Differences in predicted values resulted from observed differences in canopy size at the end of the season.

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T_f.

Plant-based Responses of Alfalfa, Seed Alfalfa, and Cotton to Applied Water

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The efficient production of food and fiber in arid and semiarid irrigated regions depends on proper irrigation timing and the application of an optimum water amount at each irrigation event. To achieve this requires good information on soil water retention and transmission properties, soil and crop characteristics that impact crop rooting depth and intensity, and crop response characteristics to stress imposed by water deficits. Irrigation scheduling is done by direct or indirect assessment of the water status in one or more components of the soil-plant-atmosphere continuum. Because plants integrate their total soil and atmospheric environments, an increasing emphasis on plant based water status evaluation for irrigation scheduling has occurred in recent years.

Following the Ohm's law analog of van den Honert (1948), transpirational flux (T_f) can be related directly to the liquid phase soil to leaf water potential gradient and inversely to total resistance along this pathway:

$$T_f = \frac{\psi_s - \psi_L}{R_{sl}} \qquad \text{[Eq. 1]}$$

where ψ_s is soil water potential, ψ_L is leaf water potential, and R_{sl} is the combined soil to leaf water flow resistance. On rearranging eq. 1 to

$$\psi_L = \psi_s - R_{sl} T_f \qquad \text{[Eq. 2]}$$

it is evident that ψ_L will decline with soil drying as ψ_s is lowered and R_{sl} increases. Climatic evaporative demand affects T_f as does pronounced soil drying when R_{sl} increases to the point where an increased potential gradient (ψ_s-ψ_L) can no longer sustain an unrestricted T_f.

Two commonly used techniques that assess field level plant water status are the pressure chamber (Scholander et al., 1965) that indicates plant water potential (ψ_w) (xylem pressure potential) and infrared thermometry that provides a measure of leaf/canopy temperature. Since ψ_w fluctuates diurnally, measurements are usually done either at predawn (maximum) or midday (minimum) when relatively stable readings can be obtained. An adjustment technique (Grimes et al., 1987) allows estimating cotton ψ_w for evaporative demand conditions other than that existing when the measurement was made. With infrared thermometry, foliage-air temperature difference is normalized by a vapor pressure deficit climatic parameter and a crop water stress index (CWSI) value is calculated (Idso et al., 1981; Howell et al., 1984). This presentation relates alfalfa and cotton crop responses to defined levels of plant water status.

MATERIALS AND METHODS

This report contains summary results of field studies conducted on alfalfa grown for herbage (Grimes et al., 1992), alfalfa seed production (Grimes and Roberts, 1991), and Pima and Acala cotton (Grimes and Kerby, 1992). The study sites in the San Joaquin Valley present divergent soil characteristics. Alfalfa herbage investigations were done on Hanford sandy loam at the U.C. Kearney Agricultural Center, alfalfa for seed production was on Tulare clay loam with a perched-saline shallow water table, and cotton studies were done on Panoche loam to clay loam at the U.C. West Side Research and Extension Center. Procedural details are given in the indicated references.

RESULTS AND DISCUSSION

Alfalfa herbage

The relationship between declining average profile soil water content of a Hanford sandy loam and alfalfa midday plant water potential (ψ_w) is illustrated in Fig. 1. Soil drying below 0.14 $m^3\ m^{-3}$ (60% of plant extractable soil water remaining) progressively lowered ψ_w linearly until very little available soil water remained. Stomatal conductance (g_s) (Fig. 2) declined linearly as ψ_w dropped below -1 MPa with essential full stomatal closure observed at -2 to -3 MPa ψ_w. Some cultivar difference in stomatal response was evident.

Declining transpiration and CO_2 entry for photosynthesis can be expected with stomatal closure and accompanying increased leaf to atmosphere gaseous flow resistance. Figure 3 illustrates the decline in alfalfa transpiration as a reduced ratio of crop evapotranspiration (ET_c) to the ET of a well watered grass sword (ET_o) as a soil water deficit is imposed. The ET_c/ET_o ratio declined linearly as ψ_w dropped below -1 MPa. A similar decline in net photosynthesis (P_n) was observed with ψ_w reduced below the -1 MPa threshold (Fig. 4); P_n was essentially reduced to zero at a ψ_w of -3 to -4 MPa and full stomatal closure.

The impact of these responses is shown in Fig. 5 as alfalfa herbage yield shows an initial yield reduction at the -1 MPa ψ_w threshold that culminates in essentially no growth as midday ψ_w decline to about -3 MPa. As observed in other responses, some individual cultivar variability is noted.

Alfalfa seed

Expansive growth of many species is more sensitive to water deficit stress than is their reproductive growth; this is true of alfalfa. In fact, a water deficit sufficient to reduce expansive growth enhances alfalfa seed production. Figure 6 illustrates a season-long pattern of midday ψ_w that was optimum for alfalfa seed yield on a Tulare clay loam having a shallow-saline water table. The decline in ψ_w to about -2.5 MPa before stress alleviation with irrigation substantially restricted expansive growth and lowered P_n. However, seed development becomes a preferred sink for fixed carbon with seed yield maximized with this regime. Prolonged stress prior to mid-August served as a "dry-down" period to enhance desiccation and harvestability.

Myers (1988) integrated season-long trends in ψ_w to a single value that can be related to growth. The shaded area of Fig. 6 demonstrates this method for an optimum alfalfa seed production regime that has an integrated "water stress index" (WSI) of -108 MPa*day. Figure 7 presents a relationship of WSI to alfalfa seed yield observed in a 1990 field experiment. The maximum yield identified by the yield-WSI function was observed at WSI = -120 MPa*day.

A strong correlation exists between crop water stress index (CWSI) and ψ_w (Fig. 8) and alfalfa plant water stress can be accurately characterized by either ψ_w or infrared thermometry measured CWSI. For alfalfa herbage production, only moderate yield loss has been observed as midday ψ_w is allowed to decline to -1.3 MPa or 0.2 CWSI prior to a scheduled irrigation. During early seed-set a seed-yield irrigation regime may be optimized by allowing midday ψ_w to decline to -2.5 or -2.6 MPa (CWSI = 0.5-0.6). This stress level results in a good expansive-reproductive growth balance. During heavy seed-set, ψ_w = -2.5 MPa or CWSI = 0.5 should not be exceeded. Higher stress levels are desirable during pre-harvest dry-down.

Cotton

Cotton undergoes a conditioning response to periods of water deficit or stress that are normal for field growing conditions (Grimes and El-Zik, 1990). Even though conditioning occurs with a desirable irrigation schedule, net photosynthesis (P_n) per unit of fully light exposed leaf near the plant terminal is lowered (Fig. 9) as leaf water potential (ψ_L) starts to decline with soil drying following an irrigation. Similar responses are observed for both Pima and upland cultivars.

Expansive (vegetative) growth has a similar initial response as P_n to water deficit, but expansive growth essentially stops at midday ψ_L near -2.3 MPa (Fig. 10 and Grimes and Yamada, 1982).

Young boll retention (Fig. 11) shows an initial reduction as midday ψ_L declines below -1.8 MPa for Pima. A similar threshold for upland is observed at a slightly higher (ψ_L = -1.6 MPa) midday ψ_L (Guinn and Mauney, 1984).

Seed and fiber growth are the least sensitive cotton growth parameter to increasing water deficit (Fig. 12). Acala 'GC-510' shows boll growth to be affected by water deficit stress at about -2.0 MPa midday ψ_L, however, Pima 'S-6' was not affected until ψ_L declined to about -2.4 MPa. At these stress levels P_n in low, but photosynthate that is produced is directed to maintaining boll development for those boll sites retained by the plant.

Pima and upland cotton production optima have resulted from similar soil water regimes in our studies at the U.C. West Side Research and Extension Center on Panoche soils. A greater water flow resistance for Pima causes a slightly lower midday ψ_L than is characteristic for Acala cultivars (Fig. 13). Generally, midday ψ_L that declines to -1.5 MPa before the first season irrigation is desirable. Lower values (ψ_L = 1.7 to 1.8 MPa) can usually be tolerated after the initial irrigation. For the second irrigation on sandy soils, it may be desirable to irrigate as ψ_L declines to about -1.6 MPa.

Howell et al (1984) demonstrated the effectiveness of infrared thermometry measured crop water stress index (CWSI) for irrigation scheduling. These workers define a strong correlation between CWSI and midday ψ_L that is defined by the function

$$\psi_L = -1.52-1.28(CWSI). \qquad \text{[Eq. 3]}$$

This function defines a midseason decline in ψ_L = -1.8 MPa equivalent to a 0.22 CWSI. Early season irrigation scheduling may pose some difficulty with infrared thermometry due to a low level of canopy development. Sensing individual leaves may overcome this difficulty.

CONCLUSIONS

Plant-based water-status measurements provide a practical and reliable index for assessing the adequacy of supplied irrigation water. Knowing plant response to identified plant-based water-stress intensities make such measurements valued tools for irrigation management.

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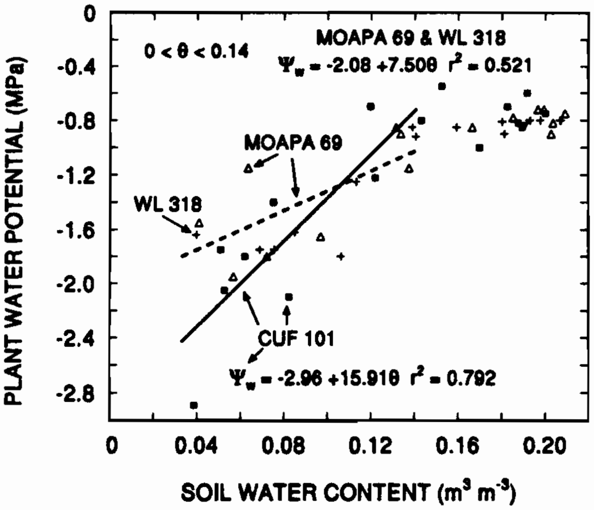

Fig. 1. The relationship between midday ψ_w of three alfalfa cultivars and average soil water content of a 2.4-m Hanford sandy loam profile (from Grimes et al., 1992).

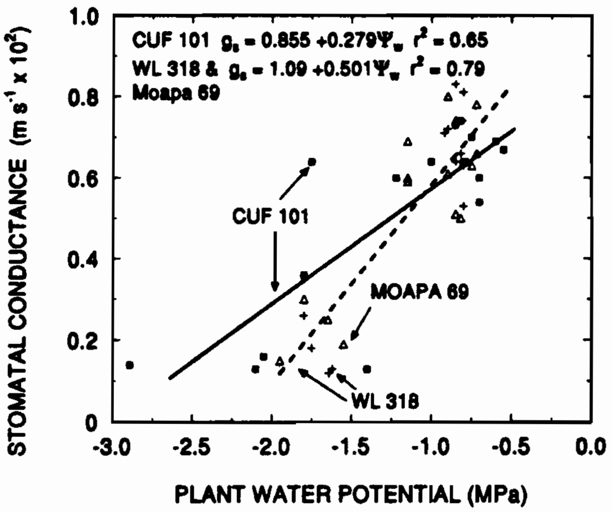

Fig. 2. Stomatal response of three alfalfa cultivars to water stress severity (from Grimes et al., 1992).

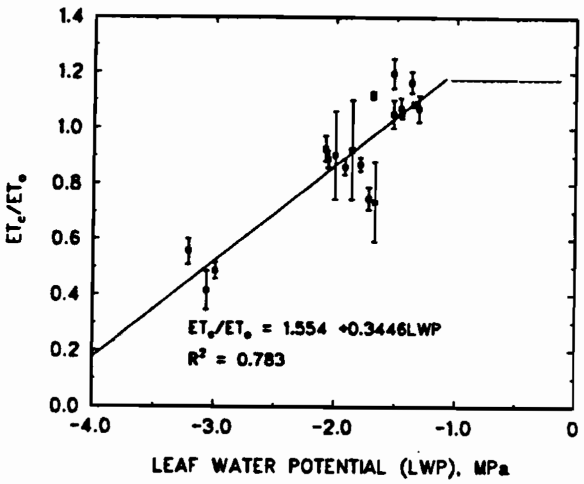

Fig. 3. Cropevapotranspirationreduction associated with declining alfalfa plant water potential (from Grimes and Roberts, 1991).

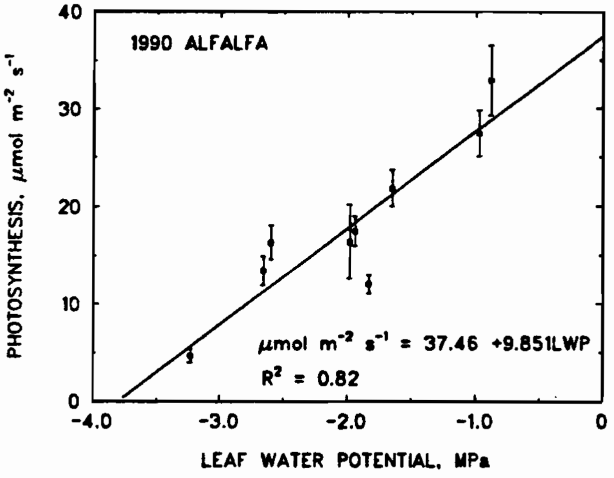

Fig. 4. Relationship between alfalfa net photosynthesis and plant water deficit intensity (from Grimes and Roberts, 1991).

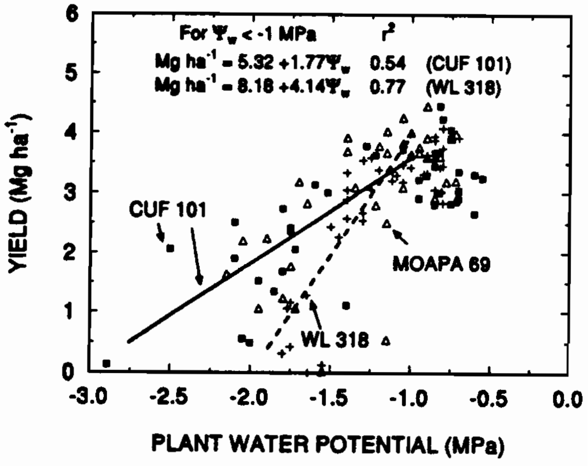

Fig. 5. Alfalfa hay yield loss for contrasting cultivars with increasing severity of water deficit (from Grimes et al., 1992).

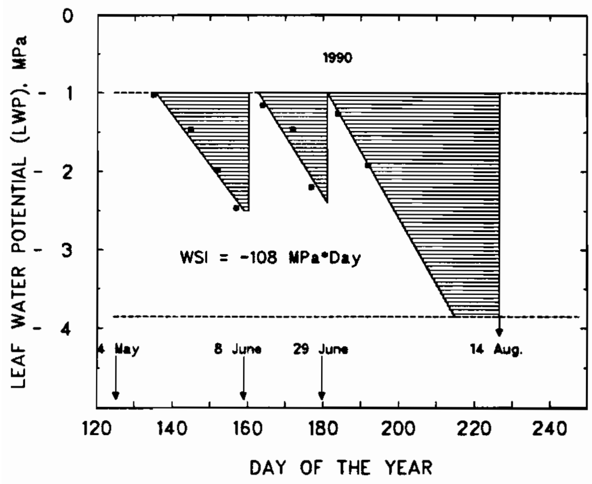

Fig. 6. Computation of a single-value water-stress integral in alfalfa seed production (from Grimes and Roberts, 1991).

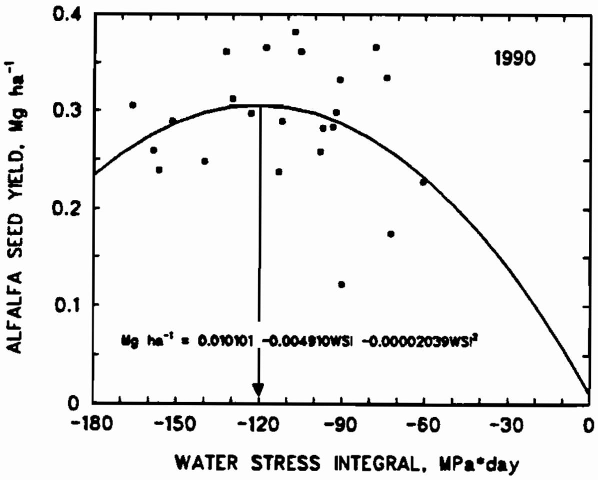

Fig. 7. Relation of alfalfa seed yield to a single-valued season water-stress integral (from Grimes and Roberts, 1991).

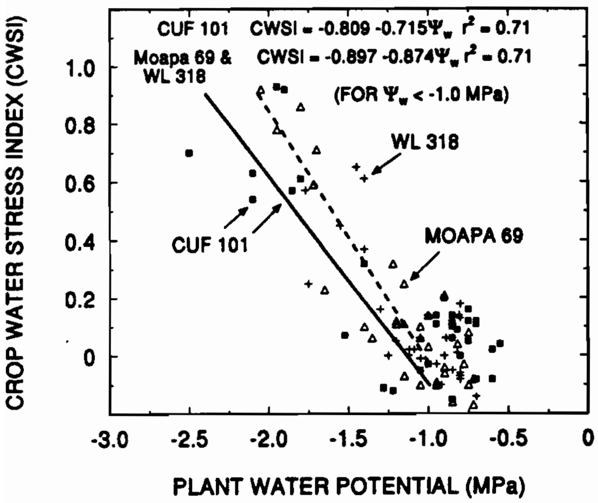

Fig. 8. Relation of crop water stress index to midday alfalfa plant water potential on a Hanford sandy loam (from Grimes et al., 1992).

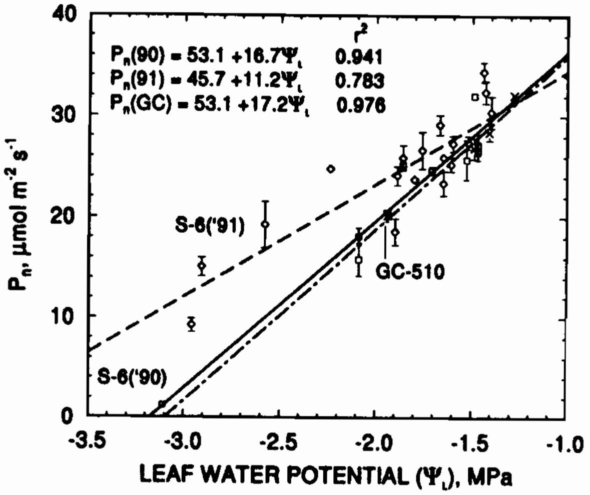

Fig. 9. Relation of Pima 'S-6' and Acala 'GC-510' cotton leaf net photosynthesis to water stress (ψ_L). Vertical bars are standard errors of nine observations. The figure is from Grimes and Kerby (1992).

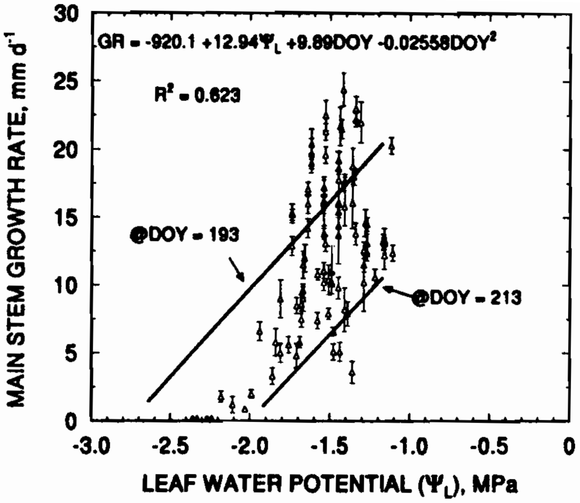

Fig. 10. Influence of increasing water stress (ψ_L) on expansive growth reduction of Pima 'S-6' cotton (from Grimes and Kerby, 1992). Vertical bars are standard errors of 10 measurements.

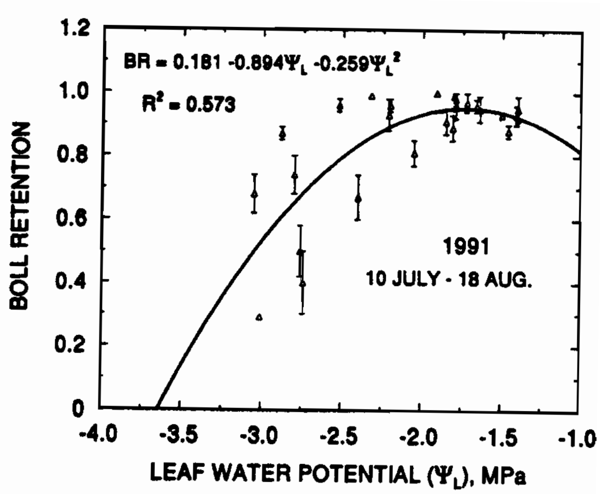

Fig. 11. Impact of increasing water stress (ψ_L) on young boll retention of Pima 'S-6' cotton (from Grimes and Kerby, 1992).

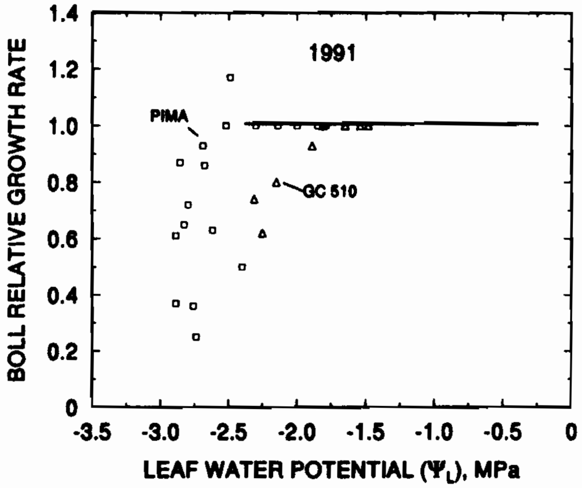

Fig. 12. Association of Pima 'S-6' and Acala 'GC-510' relative boll growth rate to plant water stress (ψ_L) (from Grimes and Kerby, 1992).

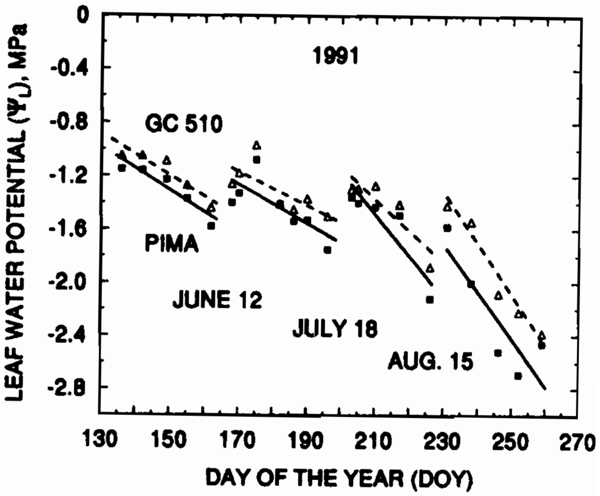

Fig. 13. Midday leaf water potential (ψ_L) for Pima 'S-6' and Acala 'GC-510' with the same optimum irrigation schedule (from Grimes and Kerby, 1992).

IMPACT OF WATER CONSERVATION ON ALFALFA IN IMPERIAL VALLEY

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Abstract: Optimum irrigation was compared to lesser amounts to determine the effect on yield, stand and soil salinity of CUF 101 alfalfa. Yield loss from withholding irrigation in July, August, and September was 44%, withholding in August and September 27.5% with water savings 85 and 49 cm respectively. Salinity accumulation was greatest at an interface of a clay over sandy horizon at 50 to 75 cm depth in the driest treatment. Stand was greatly reduced during the first of the three year trial but showed no significant differences due to the irrigation. Weed growth was greater in the driest treatments. Yield reduction and water saving were used to calculate the value of water which could be transferred to municipal use during a drought.

Keywords: Alfalfa stand, soil salinity, yield, neutron probe, ground cover, weeds, CUF 101.

INTRODUCTION

In times past it was common in summer to withhold irrigation from alfalfa in Imperial Valley California to limit loss of stand from root pathogens. Development of varieties resistant to the root pathogens allowed culture through the summer. The drought of the past six years prompted a restudy of the effect of withholding water on alfalfa to determine the yield loss for increments of water withheld. The data would be used to set a price of water for sale by farmers to stressed municipalities.

METHODS

A three year project was initiated using a CUF 101 variety of alfalfa that had been developed in this area. Six other varieties were compared to the CUF 101 in yield reduction from the treatments presented in Table 1.

Table 1. Irrigation treatments first year 1991.

Irrigation Treatment	Number of irrigations July	August	September	October to June
Optimum check	3	2	2	10
Minimum stress	3	1	1	10
Short stress	3	0	0	10
Long stress	0	0	0	10

The soil was a Holtville series, clayey over sandy, montmorillonitic (calcarious), hyperthermic Typic Torrifluvent with a surface clay layer 50 cm deep on the east and to 70 cm on the west side of the plot area. The alfalfa was planted in a 9 meter wide strip 84 meters long. Plots of different varieties were planted in the center 2 meters of the strip leaving 3.65 meters of CUF 101 border on each plot boundary. Irrigation was by border check. A 5 meter unplanted strip of soil was left between the border and the planted alfalfa to keep the soil moist and prevent soil cracking. Figure 1 is a diagram of the layout. Each of the smallest plots contained seven randomized varieties: CUF 101 UC Cibola, Dofari, Mesilla, Moapa 69, UC 150, and Wilson. Neutron probe soil moisture tubes were placed in the CUF border to monitor soil water changes in each end of the 12 irrigation treatment plots. The moisture in the top 15 cm was determined gravimetrically. Moisture readings were taken before and after harvest and before and after irrigation. Stand was counted prior to and after the treatments in harvested plots using a 0.1 m^2 steel circle. The center was marked with a steel spike and located with a metal detector so the same area could be located for counting. Weeds were counted in each of the 252 plots in December after the first years treatments. Soil samples were taken for saturation extraction in 30 cm intervals to 122 cm.

RESULTS

Plots were harvested as shown in Figure 2. Cumulative yield up to the latest is shown in Figure 3 where significant differences began and remained after July 1991. The water extraction pattern of the four treatments is shown in figure 4. The total water applied is in Figure 5. Stand in Figure 6, the average salinity of the entire profile Figure 7, and the average salinity of each 30 cm horizon in Figure 8. The weed count taken in December is shown in Figure 9.

VALUE OF WATER

Costs of production were obtained from Guidelines to Production costs and practices , Imperial County. Figure 10 shows a result of calculating profit from the optimum and Figure 11 the short treatment. The difference in profit from the two treatments divided by the difference in water application of the two treatments produces the value of water data shown in Figure 12.

ACKNOWLEDGEMENTS

UC-LAWR Project 4453. Sponsored by Metropolitan Water District of Southern California, University of California Water Resources Center, Imperial Valley Conservation Research Center Committee. The authors gratefully acknowledge the assistance of Larry K. Gibbs, Doyle D.Freeman, J. Marcos Jimenez.

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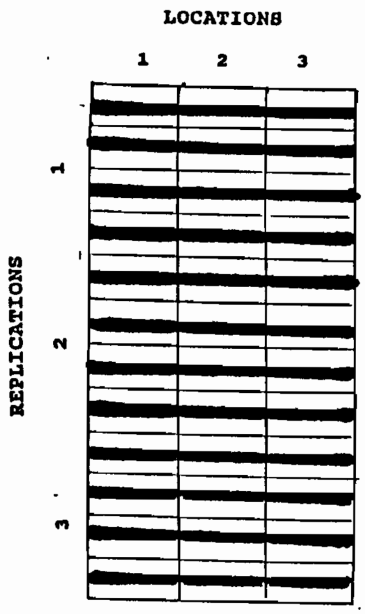
FIGURE 1. PLOT LAYOUT



EACH PLOT HAS UC CIBOLA, CUF 101, DOFARI,
MESILLA, MOAPA 69, UC 150 AND WILSON
RANDOMIZED IN 1 X 6 METER PLOTS WITH
3 METERS PLANTED BORDER AND 5 METERS
UNPLANTED BORDER TO PREVENT SOIL CRACKS.

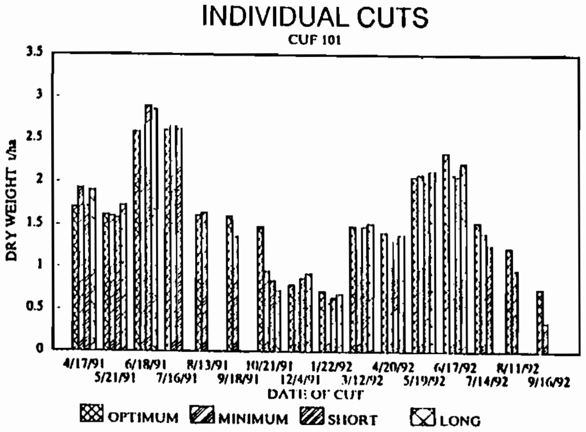


Figure 2. Individual harvests of four irrigation treatments.

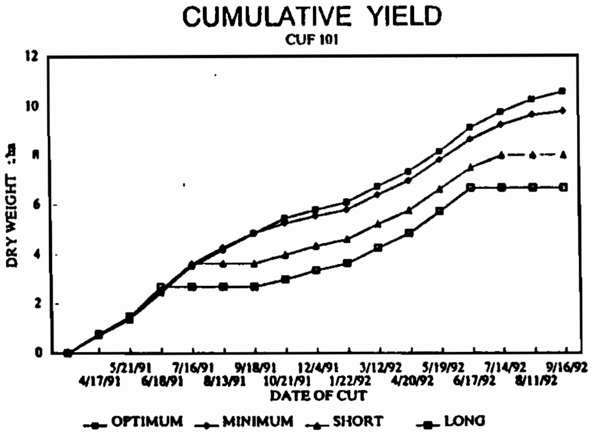


Figure 3. Cumulative yield of four irrigation treatments.

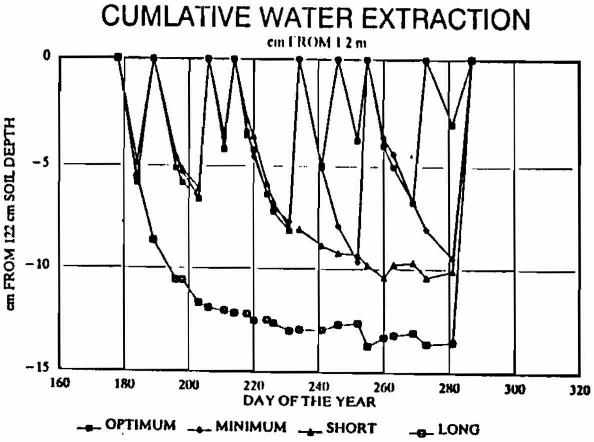


Figure 4. Soil Water extraction from 122 cm profile in four irrigation treatments.

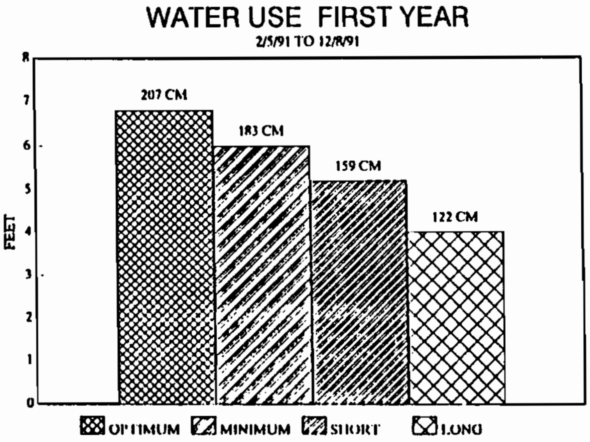


Figure 5. Total water applied to four irrigation treatments.

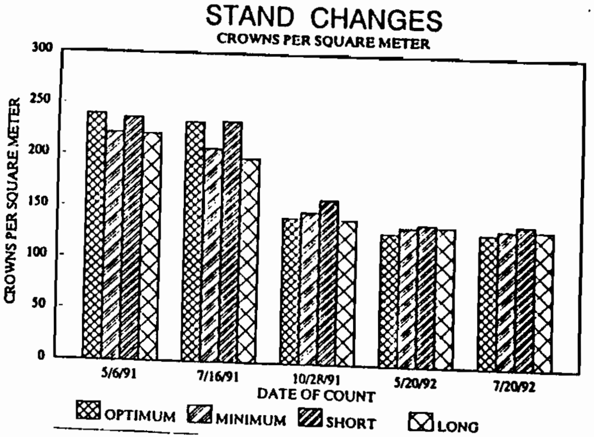


Figure 6. Stand of four irrigation treatments.

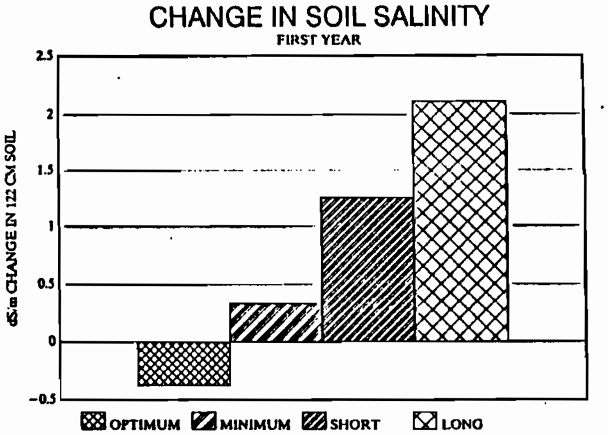


Figure 7. Average salinity of a 122 cm profile.

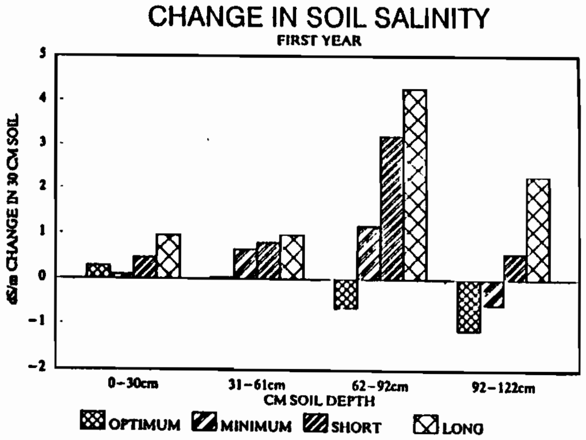


Figure 8. Average soil salinity of four 30 cm increments in four irrigation treatments.

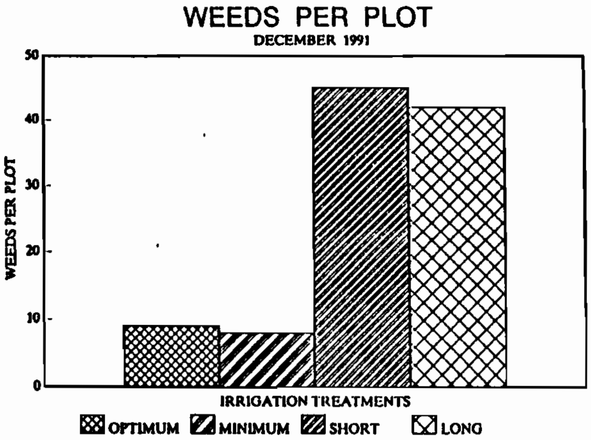


Figure 9. Weeds per plot in December after first year treatments.

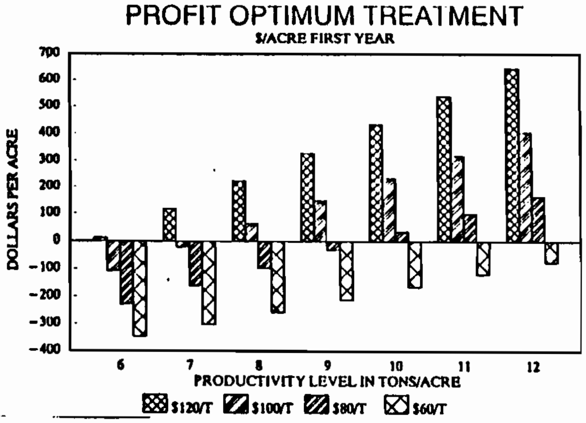


Figure 10. Profit per acre of Optimum irrigation treatment at four market values of alfalfa and four productivity levels.

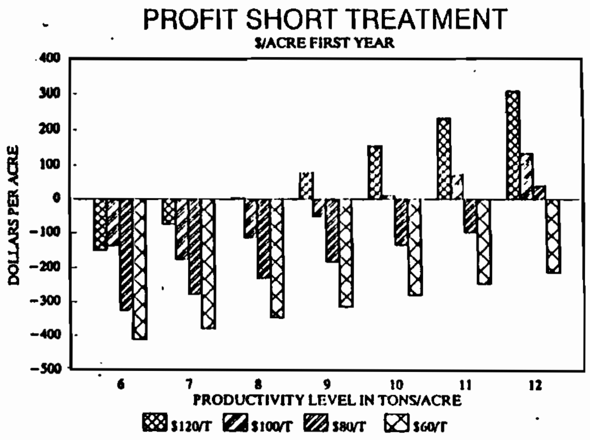


Figure 11. Profit per acre of Short irrigation treatment at four market values of alfalfa and four productivity levels.

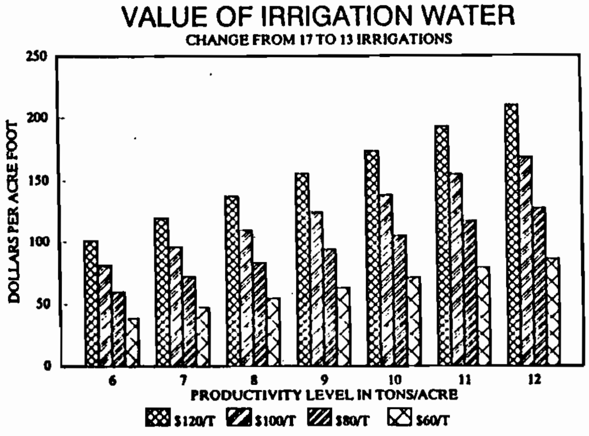


Figure 12. Value of water when changing from the Optimum to the Short irrigation treatments at four market values and four productivity levels.

WATER STRESS MANAGEMENT OF WINEGRAPES WITH AN INFRARED THERMOMETER

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Traditional irrigation scheduling or water management is a decision-making process that is generally said to result in the answers to two questions: **When should an irrigation take place, and how much water should be applied?** Typical techniques for dealing with the two questions include the various methods of soil water measurement, (tensiometers, moisture blocks, the neutron probe), and water budgeting. The first question is both the most difficult and the most important to answer. The irrigation should take place, for some crops, just prior to the beginning of water stress that could reduce growth. Allowable Depletion or Management Allowed Deficit is a quantification of this concept that irrigation should take place prior to the advent of significant water stress. This philosophy of water management might be termed "stress avoidance". It is unquestionably the proper method for many crops, especially vegetables, forage crops and others that are grown for vegetation rather than flowers, fruit or seeds.

Some crops, however, are capable of tolerating a certain degree of water stress at particular stages of growth and a few may even benefit from a water deficit. A soil water content below the allowable depletion for a crop will require the plant to reduce transpiration to match the reduced availability of soil water. The metabolic changes caused by the deficit will usually decrease vegetative growth and yield for a crop such as alfalfa. If the deficit occurs during the later stages of maturity for a fruit crop like wine grapes the physiological effects on the plant may not be detrimental to the yield and may even improve the quality. Since the stressed condition reduces the rate of transpiration, the water use by the crop is decreased and, if no yield loss results, water use efficiency is increased. Unfortunately, it is difficult to apply the traditional soil water monitoring or water budgeting methods to stress management rather than stress avoidance for which they are ideal. The problem is one of determining the precise point at which water stress begins, the allowable depletion.

Water stress is best defined as the condition where uptake of soil water can no longer equal the transpiration rate of the plant. If the transpiration rate were constant the uptake rate would be constant and the minimum soil water content at which that uptake rate could occur, the allowable depletion, would be constant. But transpiration is not constant. When it is high the rate of uptake required can only happen at a high water content. If the water content of the root zone is less than that, stress occurs. If the Et rate decreases the next day, that water content may be sufficient for the lower required uptake rate and there will be no stress even though the water content is the same or less than the previous day. Consequently the allowable depletion would be lower for the decreased Et rate. If the Allowable Depletion where stress begins is a "moving target" as the rate of Et changes, the only practical method of stress management is to ignore the Et rate of the water budget and the soil water content as determined by the various instruments and in some manner measure the presence and degree of water stress directly in the plant. An established technique that is reasonably practical for commercial use is the pressure chamber that determines leaf water potential by equilibrating it with external gas pressure. Values for leaf water potential for cotton were developed in the San Joaquin Valley. The recommended pressure chamber value for an irrigation increases, indicating a decreased leaf water potential, after bloom so it is most likely an example of a desirable degree of stress. The recommended pre-bloom irrigation point is the higher leaf water potential at which stress begins.

Another method of measuring the presence and degree of plant-water stress utilizes a measurement of the difference between the temperature of the leaf and the ambient air. The process, developed by a group at the USDA Water Conservation Laboratory in Tucson, Arizona, has a number of advantages for use in the field compared to the pressure chamber. The equipment is more portable, the data collection is non-destructive and much more rapid, and the sensors are more adaptable to an interface with a microprocessor to automatically calculate and store the results. The principle is based on the energy that is required for transpiration. Transpiration is an evaporative process and therefore heat is absorbed when it occurs causing a decrease in leaf temperature compared to that of the air. It is possible to predict the leaf temperature of both an unstressed and a totally stressed crop from the air temperature and humidity or vapor pressure deficit (VPD). A portable infrared thermometer (IRT) can measure leaf temperature rapidly in the field and compare it to the predicted leaf temperatures for those conditions. This numerical comparison is a ratio called the Crop Water Stress Index (CWSI). The particular utility of the CWSI is the fact that values between 0.0, unstressed, and 1.0, total stress, indicate the relative degree of water stress of the plant. The ability to quantify the stress level enables the manager to maintain a plant-water stress level in a crop using an IRT and a high frequency micro-irrigation system. A stress level can be chosen and water withheld until the CWSI reaches the chosen limit. An irrigation decision is made by measuring the CWSI and only applying water when the stress limit has been exceeded. In practice this results in water being applied when the Et rate is high or increasing. When the weather moderates, irrigations are eliminated because the soil moisture is sufficient for the lower Et rate.

A series of trials began at the CSU Fresno Viticulture and Enology Research Center in 1989. Initially the method was applied to Thompson seedless grown for raisins on the campus farm-laboratory. In that first trial, the CWSI of well irrigated vines was used as a control and the treated vines were not irrigated unless they exceeded the CWSI of the controls by a selected amount. Two facts became apparent after the 1989 season. One was that a mild stress beginning at veraison was successful in that it accelerated maturity with only a small reduction in yield. The second was that the scheduling method was too complicated and resulted in excessive stress at high Et's. Beginning in 1990, the technique was modified to maintain the stress levels at selected "targets" rather than trying to relate the treatments to a presumably unstressed vine. At the same time, the research effort focused on wine grapes because of industry interest and the fact that they are more likely than raisins to be drip irrigated. Trials on Cabernet Sauvignon, Chardonnay and Chenin blanc were established in commercial vineyards in Madera, Paso Robles and Santa Maria.

The basic experimental plan was to be the same for each trial. Three treatments; a control (the grower's normal practice), a mild stress target of 0.2 and a higher stress target of 0.3 were to be maintained on plots of twenty vines with each treatment replicated five times. The stress was to begin at veraison and continue to harvest. Berry sampling was done each week to document the maturity process and the twenty vines in each plot were harvested at the same time as the rest of the vineyard. The trials were planned to continue for at least three seasons to evaluate the effect of repeated stress on the following year's crop. The trial on Cabernet at Paso Robles had two additional treatments added to it that included stress beginning earlier at the beginning of berry sizing. An additional trial on French Colombard in Madera was set up in the 1992 season utilizing stress beginning at bloom. This last trial was done on a certified organic vineyard and used large plots in order to evaluate the insect population differences that might occur.

The preliminary data from these trials, while not conclusive, is consistent. In each case, the imposition of controlled, low level water stress produced a significant decrease in water application with little or no affect on yield. First season data from three of the trials are presented below as examples.

Madera Cabernet Sauvignon - 1991

		Seasonal		Yield		Soluble		Titratable
Treatment	Target	Water		Fresh Grapes		Solids	pH	Acidity
	CWSI	cm	(ft.)	mT/H	(T/Ac)	Brix		g/100 ml
Control	0	111	(3.6)	23.6	(10.5)	20.8b	3.33	0.74
Low Stress	0.2	83	(2.7)	22.7	(10.1)	23.4a	3.35	0.72
High Stress	0.3	77	(2.5)	24.3	(10.8)	22.4a	3.36	0.72
				ns			ns	ns

Paso Robles Cabernet Sauvignon - 1991

		Seasonal		Yield		Soluble		Titratable
Treatment	Target	Water		Fresh Grapes		Solids	pH	Acidity
	CWSI	cm	(ft.)	mT/H	(T/Ac)	Brix		g/100 ml
Control	0-0.2	40	(1.3)	18.6	(8.3)	25.1	3.61	0.49
Low Stress	0.3	37	(1.2)	18.6	(8.3)	25.1	3.62	0.49
High Stress	0.4	36	(1.2)	16.4	(7.3)	24.8	3.43	0.51
Early Low Str.	0.3	35	(1.1)	17.1	(7.6)	24.5	3.51	0.45
All Season Low	0.3	32	(1.0)	17.1	(7.6)	24.3	3.56	0.50
				ns		ns	ns	ns

Madera French Colombard - 1992

		Seasonal		Yield		Soluble		Titratable
Treatment	Target	Water		Fresh Grapes		Solids	pH	Acidity
	CWSI	cm	(ft.)	mT/H	(T/Ac)	Brix		g/100 ml
Control	0	56	(1.8)	25.9a	(11.9)	21.0b	3.23	0.96a
Low Stress	0.2	40	(1.3)	21.6b	(9.9)	22.9a	3.28	0.72b
High Stress	0.3	34	(1.1)	17.0c	(7.8)	23.1a	3.29	0.67bc
Low/High	0.2-0.3	39	(1.3)	18.9c	(8.7)	23.0a	3.31	0.66c
							ns	

Results for the other individual trials were similar. The savings in water were less for the Chardonnay and Chenin blanc because the period from veraison to harvest is less (5-7 weeks) than it is for Cabernet Sauvignon (10-12 weeks). The only significant affect on yield was in the 1992 French Colombard vineyard in Madera. These treatments were the longest stress period attempted (bloom to harvest) and either the length or, more likely, the fact that the stress occurred early in the development of the berries caused a significant decrease in berry size. The number of clusters were the same, the yield differences were due to berry weight. There was a significant increase in the sugar content of the stressed Cabernet vines in Madera that may correspond to the fact that the highest water applications were on that vineyard. The reported water applications were for the entire season, the applied water during the 12 weeks of treatment was much less than half of the control application. The use of "normal grower practice" as a control treatment is a variable that needs to be considered in comparing the different vineyards on which this scheduling technique was applied. The Paso Robles trial is a good example of the opposite situation. Water was applied abundantly in Madera and the emphasis was on tonnage. The water supply is quite limited in Paso Robles and quality was important to the extent that some tonnage would be sacrificed for better berry chemistry and color. The grower used the CWSI for scheduling and it became almost the same as the "low stress" treatment used on the other trials. The results indicated no significant differences in the parameters reported here but there was a visible increase in color development in the stressed treatments compared to his control. Wine was made from all five of the treatments from Paso Robles. The first tasting recently occurred and the panel agreed that there were definite differences among the lots. It is too early to assess the quality of the wine samples but it is apparent that the water stress treatments resulted in differences in the product.

It would appear that the effect of a mild, controlled stress during the period from veraison to harvest has potential for reducing water applications. That period occurs in July, August and September when the Et rate is highest so the elimination of an unnecessary irrigation reduces the seasonal application more than it would earlier in the season. The most significant impact of the stress management on the daily routine of the irrigation scheduling was the ability to eliminate some irrigations due to the sensitivity of the technique to the weather. The typical summer weather pattern is a slowly increasing temperature and decreasing humidity that is relieved by the breakthrough of marine air that produces lower temperatures and higher humidity. As long as the weather remained cool and moist, the CWSI values would be below the target even when the irrigation system had been off for several days. As soon as the weather began to warm up, the drier plots would quickly reach their CWSI targets and irrigation would commence. At times, the weather would cool before the target was achieved and the CWSI would again decrease even though no water had been applied. August and early September of 1991 were much cooler than normal in the Madera area and some of the high stress Cabernet Sauvignon plots did not receive water for the entire six weeks until normal weather returned. One of the major advantages of the IRT technique may be that it enables the water stress manager to eliminate irrigations during mild weather when the vine stress does not increase rapidly and there is the potential for excessive water use by the crop.

ACOUSTIC EMISSIONS AS AN INDICATOR OF VINE WATER STATUS

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ABSTRACT

Although the axial resistance to water transport is usually assumed low and constant, there are several reports of increased hydraulic resistance in woody stems subjected to desiccation. Therefore, experiments were conducted to determine whether stem resistance is sensitive to water stress in the range that is important to shoot growth, and to determine whether cavitations could be detected and correlated with vine water status. When water was withheld from potted vines for 13 days, stem resistance increased several fold as shoot growth was inhibited. The increased resistance was associated with an increase in the number of gas-filled vessels. Acoustic emissions could be detected when evaporative demand increased or when xylem water potential decreased. When water was withheld from field-grown vines, a non-linear regression of the daily rate of acoustic emissions on midday leaf water potential was highly significant ($R^2=0.95$). These results are interpreted as evidence that vine water status may be automatically detected in the field with this technology.

INTRODUCTION

The radial resistance to water transport from soil to stele increases under water and nutrient deficits, but it is not known whether axial resistance to water flow is also environmentally sensitive in grapevine. Although the axial resistance is usually assumed to be low and constant, there are several reports of increased hydraulic resistance in woody stems subjected to desiccation (Tyree and Sperry, 1989). The water in the xylem of plant tissues comes under significant tension during evaporative water loss. Early work in grape suggested that stem xylem may cavitate if xylem tension becomes sufficiently large (Scholander *et al.*, 1955). If this occurs, cavitation may be detectable as ultrasonic emissions (ae's) (Sanford and Grace, 1985). Therefore, experiments were conducted to determine: whether stem resistance to water transport is sensitive to water stress in the range that is important for shoot growth; and whether cavitations could be detected and correlated with vine water status.

MATERIALS AND METHODS

The first set of experiments was conducted to test whether shoot resistance to water transport was sensitive to water deficits in the range that is important for shoot growth. These were conducted with potted 'White Riesling' in controlled environments (30/20°C, 50/90 RH, 13-h photoperiod with approx. 1000 μmol photons m^{-2} s^{-1} PAR). Water deficits were imposed by withholding water when vines were approximately 40 days old and 75 cm tall.

The second set of experiments was conducted to determine whether acoustic emissions were detectable in grapevines and responded to changes in xylem tension. For these experiments potted 'Thompson Seedless' grown in a glasshouse at UC Davis were used, but the measurements were made outdoors. Shoot length was approximately 1 m for the 30 day old plants.

For the first and second sets of experiments, soil and tissue water potential were determined by isopiestic thermocouple psychrometry. Water transport was determined from rates of transpiration. Conductance was calculated as the ratio of flow to the pressure gradient driving flow (Darcy's Law). Xylem water potentials were estimated from the water potentials of bagged leaves at apical and basal positions (see Schultz and Matthews, 1988).

Field experiments were conducted in a commercial 'Cabernet Sauvignon' vineyard. Vines were drip irrigated every other day; water deficits were imposed by withholding water. Vine water status was determined using the pressure chamber technique, taking care to avoid changes in leaf water potential after excision.

Acoustic emissions were detected with a piezoelectric detector and signal processing equipment that allowed selection of a threshold signal level to avoid ambient acoustical noise (Acoustic Emissions Technology, Inc.).

RESULTS AND DISCUSSION

Water potential differences between soil and roots and between soil and shoot apex at predawn were determined during the course of a drying cycle. The soil-root difference did not increase over 12 days, but the soil-apex difference increased approximately 2.5 fold. Thus, the axial gradient of water potential within the plant was highly sensitive to moderate water deficits required to inhibit shoot growth. This would be predicted for a decrease in xylem water transport due to embolized vessels.

From estimates of the gradient in shoot xylem water potential and transpiration, the apparent shoot resistance to water transport was estimated during the drying cycle. Shoot resistance increased approximately in order of magnitude by the cessation of growth (Fig. 1). Both leaf and shoot growth were inhibited completely after 12 days without water, and showed a high sensitivity to increasing shoot resistance, particularly early in the drying cycle. Age controls confirmed that the change in shoot resistance was not associated with shoot development, but was due to increasing water deficit.

Experiments were then conducted to determine whether moderate water deficits caused a reduction in the number of functional xylem vessels. Before and after imposing water deficits, entire shoots were harvested, frozen, and saffronin dye solutions introduced under pressure. Sections were then taken several nodes above the cut surface and assayed for the presence of dye in each vessel. The data indicated that the number of gas-filled (stained) vessels increased several fold during water deficits (from 5 of 257 to 81 of 248).

This suggested that water deficits may lead to cavitation in stem xylem. Acoustic emissions have been detected in plant tissues subjected to water deficits, and these are often assumed to arise from xylem cavitations. Therefore, we investigated whether acoustic emissions could be detected in grape stems. Detection is via a piezoelectric transducer affixed to the stem; counting of ae's is accomplished by establishing a threshold voltage (Sanford and Grace, 1985). Acoustic emissions were readily detectable even in well watered vines. The phenomenon is well-behaved in that the rate ae's was nil in the dark; exposing the plant alternately to sun and shade resulted in corresponding periods of rapid ae and almost no ae, respectively.

When ae's of stems were followed during a drying cycle in the greenhouse, a clear pattern was observed which included a morning peak in the rate of ae's regardless of vine water status. As the water deficit developed, a relatively high rate of ae's was maintained longer in the day. The daily total of ae's was well correlated with vine water potential.

Following the demonstration of stress-induced ae's in potted vines, preliminary experiments were conducted in a commercial vineyard in 1991 to test the feasibility of using acoustic emissions technology for automated estimation of vineyard water status. Sensors were attached to the basal internodes of two sun shoots on vines that were continuously irrigated and vines from which water was withheld over eight days. Daily totals of ae's were recorded and regressed onto the midday leaf water potential for the same shoots (Fig. 2). The data show that there was a close correlation between accumulated ae's and shoot water status.

CONCLUSIONS

The results showed that when moderate water deficits were imposed, the water potential gradient within the shoot increased several fold. Estimates of the axial resistance to water transport also increased several fold during a drying cycle, and were associated with inhibited leaf and shoot growth. The increased resistance is tentatively attributed to xylem cavitation because acoustic emissions were readily detected under conditions that create xylem tension, and because the number of gas-filled vessels increased during water stress. Field experiments proved that application of acoustic emission technology to estimate vineyard water status is feasible. A nonlinear regression of daily total ae's to midday shoot water potential produced $R^2 = 0.95$. The potential to use this technology for automating irrigation control is under investigation.

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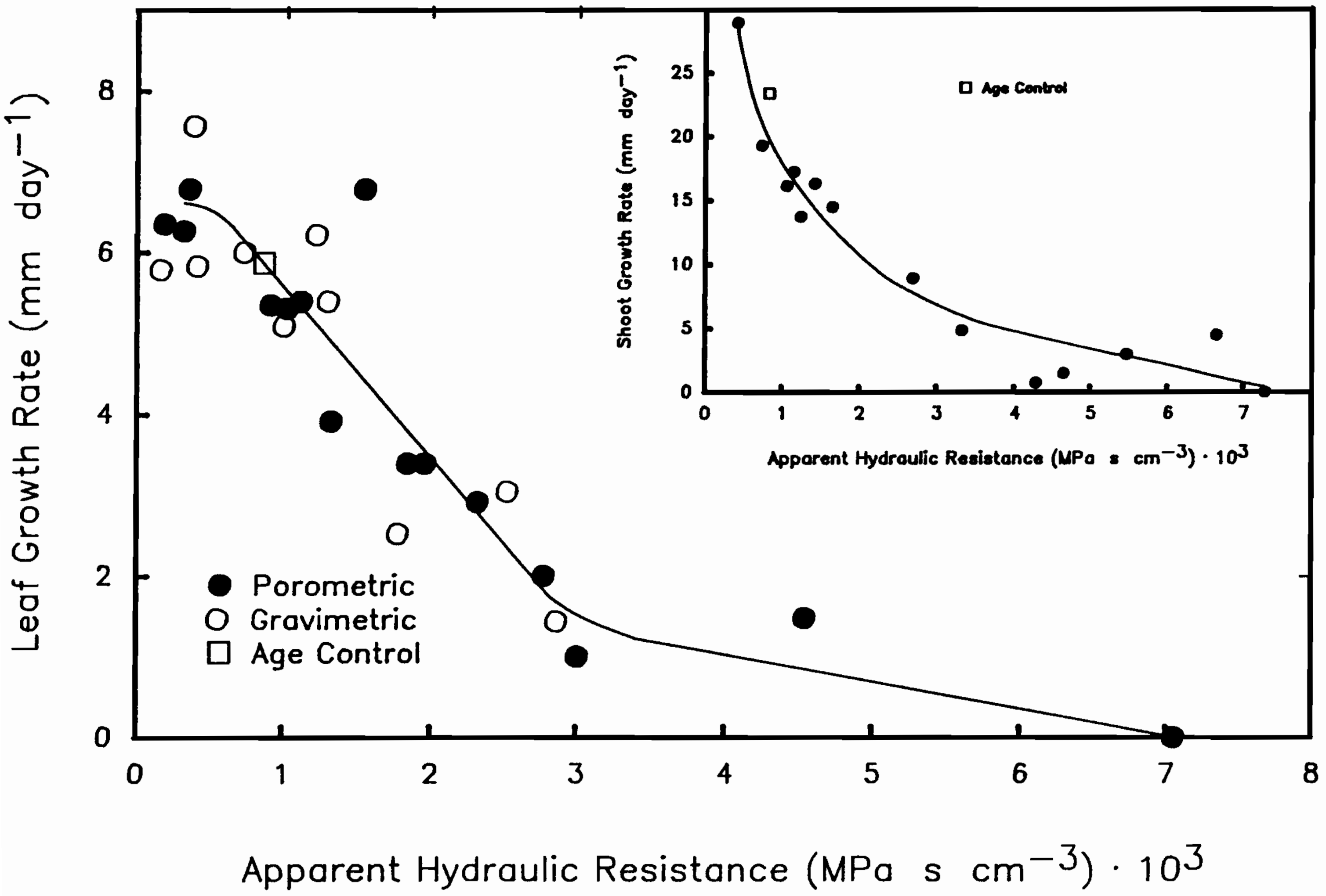

FIGURE 1. Relationship of leaf and shoot (inset) growth to the apparent hydraulic resistance in the stem when water was withheld over 14 days. Each datum represents a single determination from a different plant. Age controls were well watered continuously.

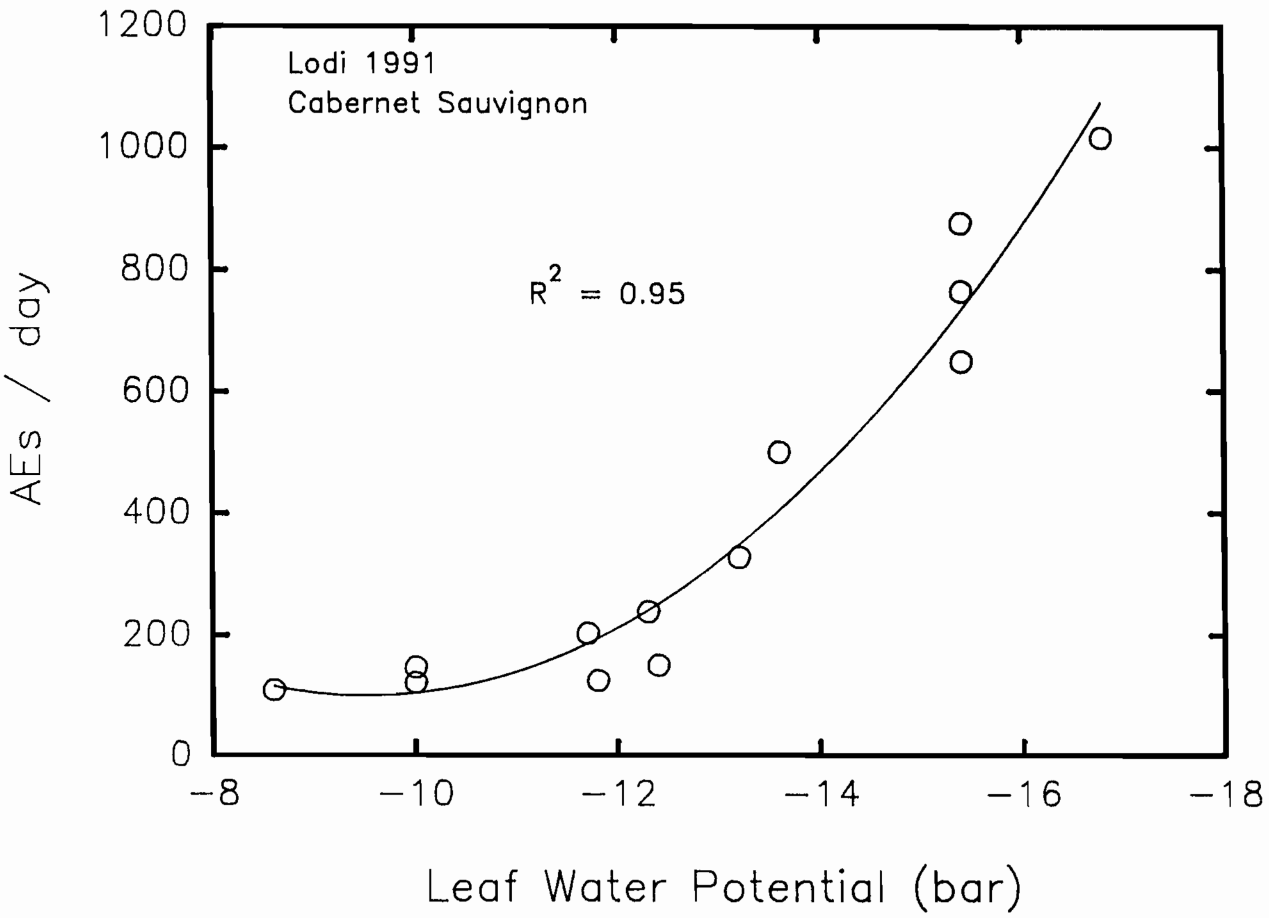

FIGURE 2. The daily total of ae's from field-grown shoots at various water potentials. Vine water status was decreased by withholding water over eight days.

MODELING SOIL-PLANT SYSTEMS

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INTRODUCTION

Mathematical models have been used in agricultural science for a long time. For many years though, these models were empirical in concept and can be viewed as black-box or input-output models. With the advances in the understanding of the fundamental description of soil-plant processes, we increasingly proceed to include these processes in mathematical models. Moreover, with the enormous increase in power and availability of computing, we are able to apply these models for simulation and prediction. In there lays also a hidden misconception. Model results are not necessarily close to the truth. But, the unexperienced modeler might not question the outcome of a model, and be perfectly satisfied with the model predictions. One should not forget, however, that a model is a simplified version of reality, and that its output is only as good as the quality of the input. In his general criticism on modeling, Philip (1991) states '*from the viewpoint of natural science, and indeed from any viewpoint concerned with truth, a disquieting aspect of computer-based modeling is the gap between the model and the real-world events*'. He continues with '*A disturbing aspect is that computer modeling has largely supplanted laboratory experimentation and field observation as the research activity of both undergraduate and graduate students. Computing is said to be cheap and other forms of research expensive.*' In that regard, one should realize that a model is most likely tested for only a limited range of experimental conditions. Moreover, I always stress the students that model results can easily be misinterpreted, if one does not understand (1) the differences between reality and the system model or model assumptions and thus its limitations, and (2) the mathematics applied in the system model. Specifically, if the model is used to make management decisions, it is imperative that the model is as correct as possible, and that the user understands the model and its limitations.

In this paper I will give a general introduction to the mathematical modeling of soil-plant systems, define model attributes and describe procedurial steps in model development, and pinpoint limitations of a mathematical model. Useful references in this regard are France and Thornely (1984), Addiscot (1992), Brockington (1979) and James and McDonald (1981). A specific example will be used to demonstrate model application. This model attemps to simulate the transport and depletion of selenium in Kesterson Reservoir (Toorman et al., 1992), with soil selenium being removed by plant uptake and microbial volatilization.

MODEL DEFINITIONS AND DEVELOPMENT

A mathematical model represents a simplified version of the behavior of a system by a set of equations. These equations contain dependent and independent variables, as well as one or more parameters. The independent variables are fixed to give numerical values for the dependent variable(s). Variables take different numerical values, whereas parameters are constant quantities in the equation for a particular case, but could vary between cases. For example, the quantity of water held at a given hydraulic potential can be considered constant for a given soil, but is variable between soils. In most cases, models also need input data which condition the system. For example, most soil-plant systems need precipitation, and other weather related input data to estimate evaporation and plant transpiration.

At the onset we must make distinction between mechanistic and functional models. Mechanistic models attempt to describe the mechanisms of the system in the most fundamental way possible, while a functional model only gives a general description of the system. The latter are also called empirical or black-box models. These models are generally simple, and have few constraints. One is generally interested in what happens in terms of variation in the outputs according to changes in input, but not how those responses come about. As an example one could study and model crop response to fertilizer application, and be concerned with describing the change in yield resulting from varying fertilizer input. In its simplest form this might be summarized as a regression equation describing how the yield response per unit of fertilizer input varies with different levels of fertilizer. A mechanistic model by contrast is designed to depict not only what occurs, but to describe, also how the response comes about, by filling in the details of the cause-effect relationships within the system (Figure 1) . In the fertilizer example, the model would attempt to mimic some of the physical, chemical and biological processes within the soil-crop system, to describe the end response of crop yield to fertilizer application.

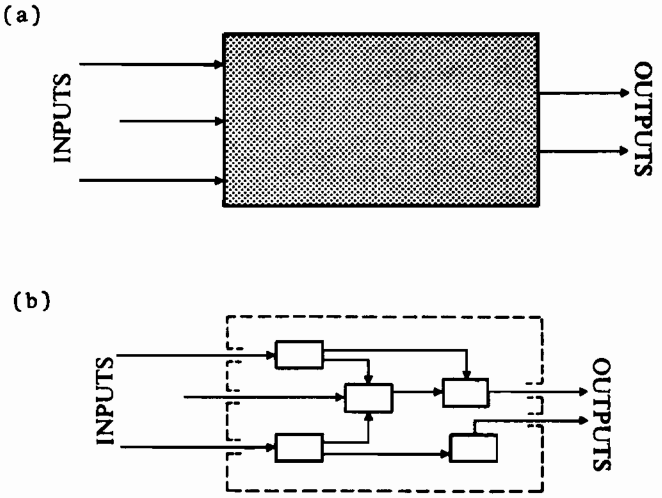

Figure 1. Difference between input-output or black-box model (a) and mechanistic, white-box model (b). From N.R. Brockington, 1979.

In many cases, a mechanistic computer model is not different from theory. In fact, a model is derived from theory. It differs, however, from analytical models, in that a computer is used to find the solution. This becomes necessary, if the system is too complicated and no analytical solutions exist. Moreover, plant-soil systems are so complicated that it is generally not clear in advance which details are important and must be included in the model. One might argue that most of the mechanistic models are in fact functional models, since the real system is much more complicated than described. In many cases, the parameters in mechanistic models are fitting parameters, and their physical meaning is not clear. For example, when developing a model, there is an underlying assumption about the scale on which the model is to be applied. Often, parameter values are obtained in the laboratory on small samples and applied in a mathematical model to simulate the system at a much larger spatial scale. Soil hydraulic properties measured from small soil cores are used in water flow models simulating soil water behavior for a profile, farm field or watershed scale. In the model calibration, effective parameters are determined that are not necessarily related to their physical meaning. In doing so, one might argue that the mechanistic model is downgraded to a functional, lumped parameter model (Beven, 1989). Irrespective of the model type, one must remember though that also a computer model is a model, **a simplified version of reality**, and thus not perfect. But it can be used to identify and simulate the most important aspects of the system, as long as the model assumptions are valid for the system to be modeled.

Mathematical models can be deterministic and have an uniquely definable outcome, or stochastic. A stochastic model contains random elements in the input data (boundary conditions or parameters), so that in addition to an expected value of a quantity, also the variance is a model result. Stochastic models, therefore, include the uncertainty of the modeled system. In reality, all natural systems have intrinsic uncertainties in them, but these are ignored in determinstic models. Justification for ignoring uncertainties will depend on the degree of system uncertainty as well as the relative contribution of input data uncertainty on output results.

One might also make a distinction between research and management models, although the distincion is not very clear. The research model is used to increase basic knowledge, while management models apply knowledge. A management model must have a small proportion of guess work, and is used to give information better than existing practices. For research purposes, the model may not be correct, but is used to improve our understanding. For example, this is done by a sensitivity analysis. Sensitivity analysis is a prerequisite in model development. One is interested in how output variables are affected by a change of one or more parameters/dependent variables (Figure 2). Different parameters/variables may differ in sensitivity and hence differ in importance with regard to the system model.

The comparison of model results with experimental data is called model **validation**.

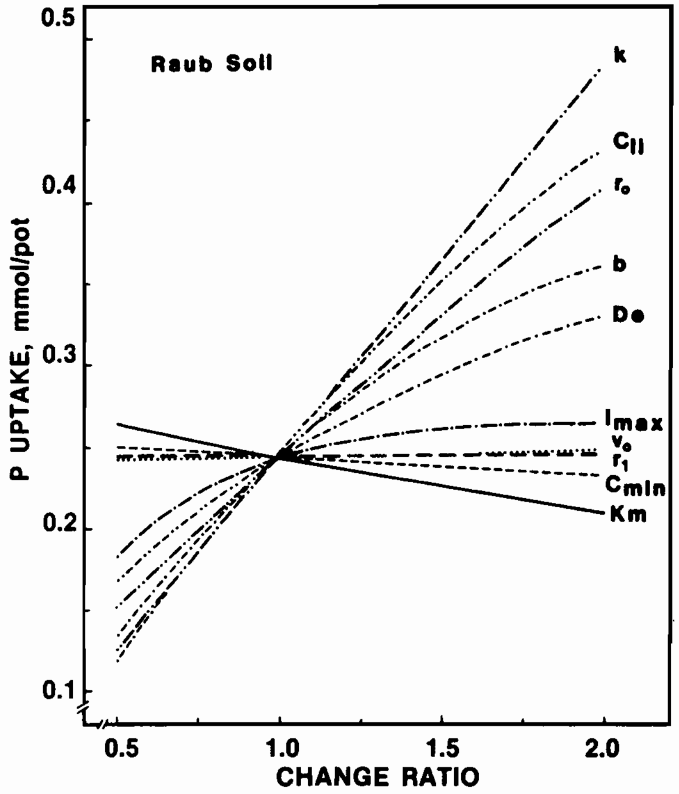

Figure 2. Sensitivity analysis for P-uptake. From Barber and Silberbush, 1984.

System equations, assumptions and parameter values are revised and retested, such that the model results compare favorably with experimental data. Obviously, the validation phase requires reliable experimental data. Preferably, these data must be collected with the specific intent for model validation (replication and appropriate range of parameter and variable values).

The ultimate results of a modeling project are the predictions by the model of system behavior. For example, the model may be used to suggest alternatives for water, soil management or farming practices in general. An excellent reference on the application of computer simulation to evaluate agronomic systems is edited by Hanks and Ritchie (1991). Chapters in the monograph include models for plant development (CERES-Wheat, CERES-Maize, SOYGRO), water flow as infiltration and drainage (DRAINMOD), soil evaporation and plant transpiration, root water uptake, nitrogen dynamics (CERES-N), solute transport, soil heat flow, water and wind erosion (EPIC), and irrigation scheduling (SOIL WATER BUDGET).

A model was developed with the objective to predict the long-term effects of various soil and irrigation management practices on the fate of selenium (Se) in Kesterson Reservoir (Figure 4). Kesterson Reservoir (Los Banos, CA) has served as a storage area for excess drainage water from irrigated lands

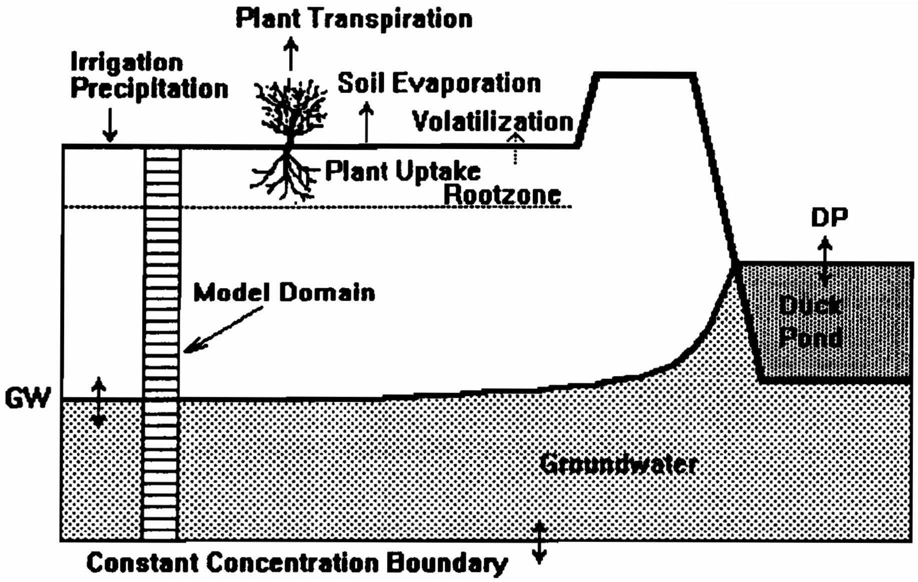

Figure 3. Schematic representation of Kesterson Reservoir. From Toorman et al., 1992.

in San Joaquin Valley, CA. Evaporation led to hazardous concentration of Se in the Reservoir, causing deformity and mortality of waterfowl hatchlings in 1986 (Tanji et al., 1986). Drainage flow into the Reservoir was halted, and ephemeral pools were filled with soil material free of Se in 1988. Varous cleanup options are currently under investigation. Investigators at the University of California in Davis, are currently investigating whether certain irrigation practices in combination with specific plant and tillage treatments can effectively contain and dissipate the Se in the surface soils of Kesterson Reservoir.

In this paper the terminology and process of model development is introduced. The application of a mathematical model is demonstrated by a Se transport model. The one-dimensional model that will be presented can simulate the behavior of water and solutes in the vadose zone over long periods (years) with root water and solute uptake, and allows interactions with the groundwater and atmosphere. A special sink term was developed to include volatilization and plant uptake of selenium. In the current development stage, the selenium model is a research model. Further testing, field data and model validation are required to prepare it for management applications.

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MODELING RESPONSE OF COTTON TO SOIL WATER CONDITIONS

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INTRODUCTION

Modeling is the art and science of simulating a system by means of a computer program. The objectives of modeling crop systems are: (1) a research tool; (2) teaching and extension - understanding the system; (3) a tool for optimal crop management. Simulation models are often coupled with expert systems.

Efforts to simulate the cotton crop system began more than 20 years ago in Arizona (Stapleton *et al.*, 1972). Since then, several cotton models have been developed in Mississippi (McKinion *et al.*, 1975), California (Gutierrez *et al.*, 1975), Texas (Jackson *et al.*, 1990) and elsewhere. The most advanced cotton model is GOSSYM (Baker *et al.*, 1983), which is presently used by cotton growers throughout the cotton belt. It is bundled with an expert system named COMAX, has a friendly graphic user interface, and is backed by a special extension team.

The use of GOSSYM in California and in other irrigated areas in the western USA indicated problems involving the response of cotton to irrigation management. It has been realized that many substantial changes would be needed before this model will be able to simulate effectively soil and plant processes in an irrigated semi-arid environment.

An effort has been made at the Water Management Research Laboratory to adapt and modify the model so that it may be able to simulate effectively the growth and development of cotton in response to different irrigation regimes. Many routines in GOSSYM had to be modified, especially those involving soil water transport, evapotranspiration, water stress, leaf growth, boll growth, root growth, and the response of plants to water stress. Because of the extensive changes made in GOSSYM, the new model was given a distinct name - CALGOS (for CALifornia GOSsym).

SOIL WATER TRANSPORT

The simulation of soil water and nitrate transport in GOSSYM has the following weaknesses: (1) water and nitrate distribution in the soil slab are assumed to be symmetric; (2) cell sizes can not be made non-uniform; (3) the transport of water is based on differences between the water content of adjacent cells and the hydraulic diffusivity between them, thus sometimes causing non-realistic situations at the boundary between soil layers with different hydraulic properties; (4) the procedure for solving the differential equations is explicit, thus leading to a high risk of non-convergence; and (5) high values of hydraulic conductivity (or diffusivity) are reduced to unrealistically low levels in order to minimize the risk of a non-converging solution.

The proposed routine adopted in CALGOS (Marani *et al.*,1992a) corrects these faults. It has the following main features: (1) The transport of water between cells is based on the difference between their soil water potential (matric and gravitational) and the hydraulic conductivity between them; (2) the solution of the flow equations is a combination of the explicit and implicit methods, thus producing stable and converging results under most conditions; (3) the solution for vertical flow in soil columns alternates with the solution for horizontal flow in soil layers at each time-step; (4) the functional relationships between soil water content, soil water potential and hydraulic conductivity are computed by the equations suggested by Van Genuchten (1980).

The use of drip irrigation improves water use efficiency and increases cotton yields. CALGOS is capable of simulating drip irrigation as well as sprinkler and furrow irrigation. It should be noted that furrow or drip irrigation bring about asymmetric water distribution, and therefore also asymmetric root growth.

EVAPOTRANSPIRATION

Improved simulation of water loss from the soil by evapotranspiration is crucial for getting the correct response of the plants to soil water conditions. New simulation procedures for evapotranspiration have therefore been devised.

CALGOS uses new routines for computing hourly values of air temperature, short wave radiation, wind velocity and relative humidity from the standard available daily values. Hourly net radiation is computed using the CIMIS algorithm (Dong *et al.*, 1988). These hourly data are used to compute the hourly reference evapotranspiration using the CIMIS version of the modified Penman equation.

Evaporation from the soil surface is computed separately for each soil column, and the radiation component of the Penman equation for computing potential evaporation is modified by shading by the plant canopy. Actual evaporation is further modified by the water content near the soil surface.

Transpiration by the plants is computed from the daytime sum of hourly reference evapotranspiration, multiplied by light interception of the plant canopy. Actual transpiration is further modified by the average soil water potential in the root volume. Water loss is allocated among soil compartments in proportion to the amount of available water and the amount of 'roots capable of uptake' in each compartment.

ROOT GROWTH AND ACTIVITY

A good simulation of the root system is very important for simulating the correct response of the crop to irrigation and fertilizer application. This involves root growth and distribution in the soil, responses of root growth to soil environment parameters, and to the supply of carbohydrates from the shoot, as well as the uptake of water and nitrogen by the roots. The main obstacle in devising a root simulation model is the scarcity of available root validation data (Taylor and Klepper, 1974). The root system model used in CALGOS (Marani *et al.*,1992a) is derived from the principles of RHIZOS (Bar-Yosef *et al.*, 1982), as implemented in GOSSYM and in GLYCIM, and from some principles of ROOTSIMU (Hoogenboom *et al.*, 1987).

The new root model is based on the following assumptions. Root mass in each cell is made up of three age classes. The main state variables that describe the root system are: number of soil layers with roots; first and last columns with roots in each soil layer; time from the first appearance of roots in each cell; length of the taproot and lateral roots; and for each soil compartment and each root class - mass of dry matter of root tissue, potential root growth, root growth resistance factor (0 to 1), and actual root growth.

Potential root growth in each soil compartment with roots is affected by: root weight capable of growth; soil temperature; soil mechanical resistance (a function of soil water content and bulk density); oxygen deficiency; and soil moisture. The amount of assimilated carbon allocated for root growth limits actual root growth. When the ratio of root weight capable of growth to cell volume reaches a threshold, redistribution of new growth of roots into adjacent cells begins. Geotropism, soil water matric potential and root growth resistance affect root growth into the adjacent cells.

Elongation of taproots and of lateral roots takes place irrespective of the supply of carbon to the root system. This elongation is modified by soil temperature and by soil resistance near the growing tip. The age of roots is updated in each soil cell containing roots. After a threshold age, a proportion of root tissue is transformed from each root class to the next class. Also, when root age reaches another threshold a proportion of the roots in each class dies.

LEAF WATER POTENTIAL

Leaf water potential is computed in CALGOS by a new procedure, based on some of the assumptions proposed by Meron (1984). The average soil water potential is computed in CALGOS as the average soil water potential of soil cells in the soil volume containing roots, weighted by 'root weight capable of uptake' in each cell. The maximum (predawn) leaf water potential is assumed to be linearly related to the average soil moisture potential.

The minimum (midday) leaf water potential is computed as the maximum leaf water potential minus the product of the daily maximum transpiration rate and the total resistance to water transport, which is the sum of the following components: soil resistance near the root surface; root resistance; shoot resistance; and leaf resistance. The details of this procedure have been described by Marani *et al.* (1992b).

PLANT GROWTH, PHOTOSYNTHESIS AND COTTON YIELD

Potential growth rates of leaves, stems, fruits and plant height are affected by water stress. A general water stress factor is computed as a function of the sum of the minimum and maximum leaf water potentials. The effect of water stress on stem growth is assumed to be more severe (Marani *et al.*,1992b). The effect of water stress on photosynthesis, is computed as a function of the minimum leaf water potential, based on the work of Ephrath and Marani (1992).

When the supply of carbon is less than required for potential plant growth, the cotton model activates a routine for allocating the carbon among plant organs. A condition of "carbon stress" is defined in this case. CALGOS assumes a first priority for allocating carbon to the growing fruits, and this priority is enhanced by water stress. Allocation of carbon for root growth is also enhanced by water stress.

The abscission of squares and bolls is a physiological process which has an important effect on the final cotton yield. It is mainly affected by carbon stress, and thus water stress may have an indirect effect on it. CALGOS also assumes a direct effect of severe water stress on the abscission of young bolls.

RESULTS AND CONCLUSIONS

Results of validation runs of the model for several different irrigation treatments will be presented. Figures 1 to 6 are from two extreme treatments from a 1991 drip irrigation experiment at the Westside Field Station, with cultivar 'GC510'. Treatments T1 and T6 have been irrigated with 100% and 60% of evapotranspiration, respectively. Simulation and validation data are presented for the minimum leaf water potential, plant height, and leaf area index.

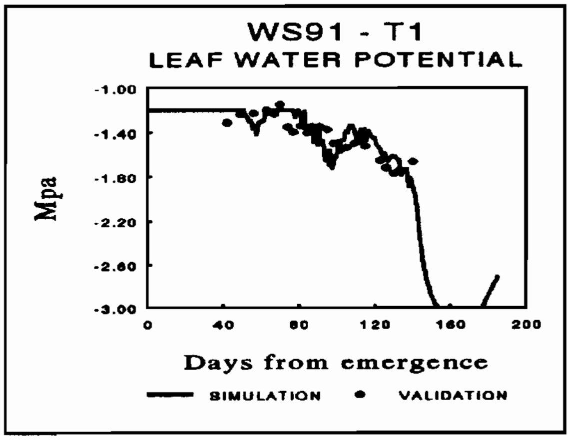


Figure 1.

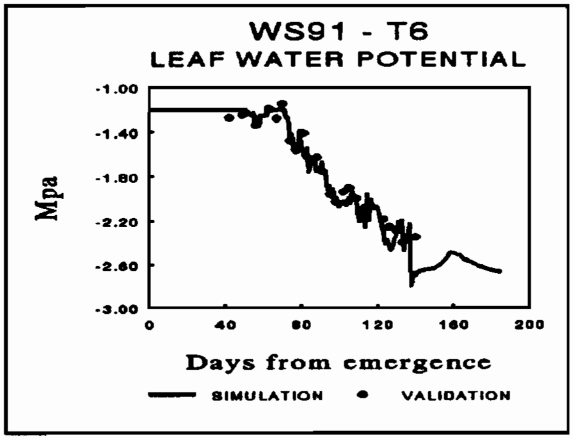
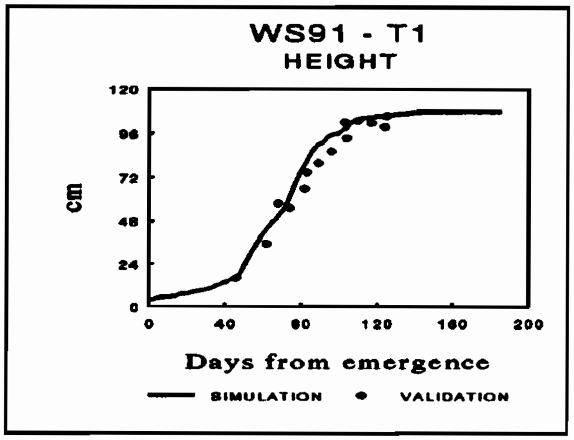


Figure 2.



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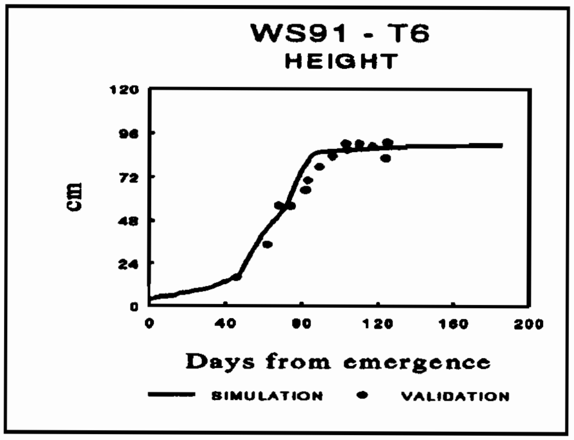

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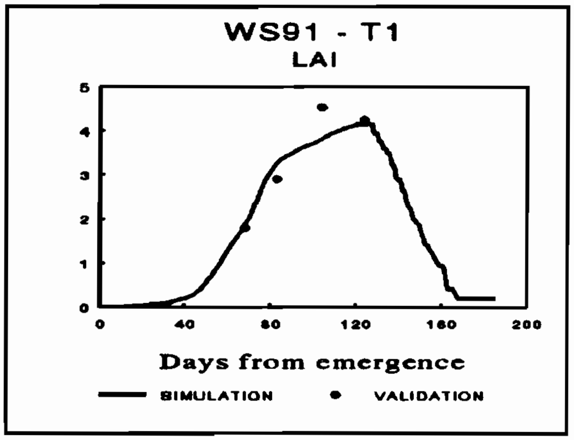

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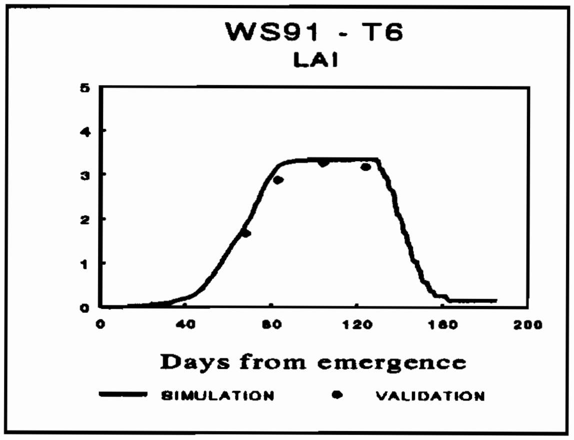

Figure 6.

These results indicate that reliable simulations of cotton growth and yield in the California environment can be obtained by running CALGOS. Sensitivity tests indicated that the response of the model to various irrigation regimes depends on using the correct assumptions for: (1) functional relationship between soil water content, potential, and hydraulic conductivity; (2) root growth model; (3) evapotranspiration; (4) moisture stress functions.

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Plant/Soil Nitrogen Dynamics in a Vegetable Crop System

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INTRODUCTION

Nitrogen (N) application to cool-season vegetables (*e.g.* lettuce, celery and cole crops) often exceeds crop demand, resulting in nitrate (NO_3^--N) losses *via* leaching and denitrification (Lorenz and Maynard, 1988; Feigin *et al.*, 1982; Lund, 1979). In California and Arizona, recommendations for lettuce range from 112-225 kg N ha^{-1}, yet an additional 25-150 kg N ha^{-1} is typically applied (USDA, 1991; Doerge *et al.*, 1991; Lund *et al.*, 1978; Raushkolb and Mikkelson, 1978; Whitaker *et al.*, 1974). Growers may over-apply fertilizer to avoid perceived risk of low yield and quality of these high cash value crops.

Management practices that result in closely matched crop root distribution and soil N availability, both spatially and temporally, can improve the efficiency of N utilization by the crop plant (van Noordwijk and de Willigen, 1986; Burns, 1980; Barley, 1970) and decrease NO_3^--N losses to the environment (Legg and Meisinger, 1982). This requires an integrated understanding of the effects of management practices on the distribution of both roots and soil N.

The purpose of this study was to monitor root distribution, plant N utilization and soil NO_3^--N loss at a commercial lettuce production field, and to evaluate factors that contributed to low N use efficiency (NUE). An on-farm site was chosen so that information was relevant to actual management practices. The site contained two soil types which became finer in texture from east-to-west across the field.

METHODS

The study site was an commercial vegetable field in the Salinas Valley on which two lettuce crops were grown from May 2-October 10, 1990. Sampling was done in two randomized blocks (30m x 50 m), one on a Mocho silt loam and the other on a Pacheco silty clay loam. Fertilizer application (8.1 and 10.3 g-N m^{-2} for the two crops) was lower than is typically used in this region (20.0 g-N m^{-2} per crop; Schulbach, 1992) or for general recommendations for lettuce (17.8 g-N m^{-2} per crop; Lorenz and Maynard, 1988). Only 0.4 g NO_3^--N m^{-2} was applied in the irrigation water. During the two crops of lettuce, 490 mm was applied from beginning to end of the crop period, and rainfall was 52 mm, so that the field received approximately half as much water as is typically applied (Schulbach, 1988; 1992). The lettuce crops were sprinkler-irrigated until thinning, then furrow-irrigated during the last month of the crop period.

Soil cores (8 cm dia.) in the beds were partitioned into 0-15, 15-45, 45-75 cm, and 75-105 cm depth increments. The furrow space was equivalent to the 0-15 cm depth, so the furrow core was divided into 15-45, 45-75, and 75-105 cm increments. After mixing soil in the field, subsamples were removed for gravimetric soil moisture, KCl-extractable inorganic N, anaerobic net mineralizable N (Waring and Bremner, 1964), and nitrification potential (Belser and Mays, 1980) following Jackson and Bloom (1990). Concentrations of NH_4^+-N and NO_3^--N were determined on a Wescan Ammonium Analyzer (Alltech Assoc., Inc., Deerfield, IL) with a reduction column for NO_3^--N (Carlson, 1986; 1978).

Organic matter, CEC, total N, bicarbonate-extractable P, particle size distribution, and soil moisture retention curves (water content at -0.03, -0.5, and -1.5 MPa on a pressure plate apparatus) were determined for each soil profile layer (n=4) using standard techniques (Klute *et al.*, 1986; Page *et al.*, 1982). Bulk density was measured on four 8 cm dia. replicate cores in both soil types. Saturated hydraulic conductivity was measured on one 8 cm dia. core per layer.

Aboveground plant samples were taken at thinning, heading and harvest, dried in a 65°C oven, and weighed. Samples were ground in a Tecator mill (Hoganas, Sweden), and total N was determined by Kjeldahl digestion. Soil samples for root length and weight distributions were taken from each plot in the silt loam soil on June 1 (pre-thinning of first crop), July 15 (harvest of first crop), September 13 (heading of second crop), and October 10 (harvest of second crop). On June 1, blocks of soil (8.5 cm by 8.5 cm to a depth of 30 cm) were removed from a trench. For the other three sampling dates, cores were taken over a single plant (taproot zone), midway between the two rows of plants on the bed (mid-bed zone), and in the center of the furrow. Cores were 8 cm dia., with the exception of the bed and furrow cores on September 13, which were taken with a 4.25 cm dia. Giddings hydraulic soil corer (Fort Collins, Colorado). Roots were removed from a 500 g subsample of soil, but the core containing the taproot was not subsampled.

Roots were washed from each sample using a Gillison's hydropneumatic root washer (Benzonia, Michigan). Root length was determined on a root scanner (Hawker de Haviland, Victoria, Australia), then roots were dried, weighed, and ground for Kjeldahl digestion. Root distribution ($m\ m^{-2}$ and $g\ m^{-2}$) in the soil profile was extrapolated from sampled cores, using relationships determined from measurements of root length density and dry weight taken across the bed and furrows (Jackson and Stivers, in press).

Statistical comparisons made within each sampling area with GLM procedures of SAS (Freund *et al.*, 1986). Comparisons between the silty clay loam and the silt loam soils used t-tests. Significant results are reported in the text when $P \leq 0.05$.

The EPIC model (Sharpley and Williams, 1990) was used for simulation of soil N processes. Model parameters were calibrated to site-specific conditions after Warden *et al.* (1992a). The trigger for onset of denitrification was changed from the default water-filled porosity of 0.9 to 0.69 based on model sensitivity analysis, and evidence that dentrification occurs at water-filled porosities of 0.6 to 0.7 (Linn and Doran, 1984).

RESULTS

Soil Properties

The silty clay loam had higher clay content, lower sand content, higher moisture retention, and higher cation exchange capacity than the silt loam (data not shown). Organic C and N were also greater. Bulk density decreased below an apparent plowpan at 15-45 cm depth in both soils. Saturated hydraulic conductivity decreased with depth, particularly in the silt loam, which showed pronounced restriction of water flow below 15 cm depth.

Soil N Availability

Nitrate in the soil profile (0-105 cm depth) declined through both crop periods (Figure 1). The largest decreases occurred during the period of furrow irrigation in the last half of each crop period. At crop harvest (July and October), NO_3^--N was significantly lower than earlier in the crop cycle on both silty clay loam and silt loam soils. In the three weeks between crops, NO_3^--N in the soil profile increased by approximately 5 g-N m^{-2}. There was less NO_3^--N in the soil profile (0-105 cm) during the second crop period than during the first crop. In both soil types, approximately 1 g NH_4^+-N m^{-2} (0-105 cm) was present throughout the summer (data not shown).

The silty clay loam generally contained less NO_3^--N in the profile (0-105 cm) than the silt loam (Figure 1). Differences were significant, however, on only two dates. Concentrations of NO_3^--N in the top layer of soil (0-15 cm depth) were generally lower in the silty clay loam than in the silt loam on all sampling dates, but significant differences occurred on only one date. At the middle depths (15-45 cm and 45-75 cm), NO_3^--N concentrations were similar in the two soil types. The silt loam soil had generally higher NO_3^--N concentrations at the lowest depth (75-105 cm), but differences between the soil types were significant on only three of the sampling dates.

Soil moisture in the two lower depths of the silt loam soil (45-75 cm and 75-105 cm), exceeded 21 and 28 percent, respectively, on all sampling dates following planting of lettuce (data not shown). Soil water potential was thus greater than -0.03 MPa. In the silty clay loam soil, water potential in the lower depths reached -0.03 MPa in samples taken on the July, August and September sampling dates. Significantly lower water potential in the deepest layers of the silty clay loam was found on approximately half of the summer sampling dates.

In the upper layer of soil, soil moisture typically corresponded to water potentials of approximately -0.1 to -0.3 MPa in the silt loam, and was significantly higher than in the silty clay loam (-0.2 to -0.8 MPa) on most sampling dates.

Net mineralizable N was 1-3 μg NH_4^+-N g^{-1} soil during both crops of lettuce in the top layer of soil (Figure 2). It was <1.0 g NH_4^+-N m^{-2} (0-105 cm) in both soil types throughout the spring and summer (data not shown), and no significant differences were observed between the two soil types. Increases occurred in both soil types following incorporation of residues from the first lettuce crop.

Nitrification potential, measured by chlorate inhibition in the presence of excess NH_4^+, remained high throughout the summer (Figure 2). It increased following fertilization in June. Soil type had no significant effect on nitrification potential, but values were often numerically higher in the silty clay loam.

Crop N Utilization

Dry weight and N accumulation in the two crops of lettuce showed slow early season growth followed by rapid growth toward the end of the crop period (Table 1). Only 2 and 4 percent, respectively, of aboveground plant dry weight and N had accumulated at thinning, halfway through the crop period. Data from the second crop showed that >70 percent of dry weight and N accumulated in the three weeks before harvest.

Total N in above- and belowground plant material at harvest of the two crops of lettuce was 9.3 (first crop) and 7.7 (second crop) g-N m^{-2} on the silt loam soil (Table 1; roots not sampled on the silty clay loam). This approximately equals the amount of fertilizer N applied to each crop of lettuce (8.1 and 10.3 g-N m^{-2}, respectively). Lettuce on the silty clay loam produced less aboveground N and dry weight than lettuce on the silt loam at the second harvest, but differences were only significant at the second harvest.

Root allocation averaged 12 percent of total plant dry weight on the two harvest dates on the silt loam (Table 1). Roots were mainly confined to the top half m of soil, and most of the roots (>40% of root dry weight and 20% of the root length) were in the top 0-15 cm of soil of the beds at harvest (Figure 3). Significant differences in root dry weight were observed between the top and lower depths of bed samples. Root length density in the furrows was similar to corresponding layers in the beds.

Soil and Crop N Fates

An estimate of total available N for the site can be made by summing fertilizer inputs (18.3 g-N m^{-2}), atmospheric deposition (approximately 0.3 g-N m^{-2}; Holton *et al.*, 1991), irrigation water input (0.4 g-N m^{-2}), and soil inorganic N (27.5 and 25.8 g-N m^{-2} for the silty clay loam and silt loam soils on March 22, respectively). If net mineralizable N is used to represent the potential release of inorganic N that could occur during the crop period, then 3.5 and 4.8 g-N m^{-2} were released in the silty clay loam and silt loam soils, respectively, based on six sampling dates from March through September.

Plant N uptake, assuming uptake as NO_3^--N, could account for 17.0 g-N m^{-2} in the silt loam, and approximately 13.1 g-N m^{-2} in the silty clay loam (Table 1). From late March until harvest of the second crop, at least 28.2 and 28.5 g-N m^{-2} were lost from the top meter of the silt loam and silty clay loam soils, respectively. By difference, soil losses were at least 11.0 and 15.0 g-N m^{-2} from the two soil types, respectively.

Leaching losses below the main rooting zone during the crop period were approximated by summing incremental NO_3^--N losses from the 45-105 cm zones, where low microbial activity and soil carbon presumably limit denitrification. Summed losses of NO_3^--N were 10.8 g-N m^{-2} for the silt loam and 7.5 g-N m^{-2} for the silty clay loam. These values do not consider plant N uptake, which could account for about 1.0 g-N m^{-2} if root N uptake was proportional to root length distribution in this soil zone. Losses of NO_3-N^- in the top layer of the silty clay loam soil could be explained by denitrification. Although lower soil water potential occurred in this soil, higher water-filled pore space and greater soil carbon would be expected to result in higher denitrification rates (Linn and Doran, 1984).

The EPIC model simulations were run for the cropped period using actual irrigation and fertilizer amounts, and measured values of soil NO_3^- and water content on March 22. Soil NO_3^--N at last harvest fell within 10-30% of actual measurements, indicating fairly representative results by the model. The Mocho silt loam had higher crop N uptake and lower NO_3^--N loss by denitrification and leaching than the silty clay loam. A restrictive layer at 15-75 cm depth in the silt loam appears to have slowed percolation rates, explaining higher soil NO_3^--N in the rooting zone and accumulation of NO_3^--N at 75-105 cm depth. The model predicted higher mineralization of fresh organic and humus N in the silty clay loam soil based on higher organic N and C. Measurements of net mineralizable N did not reflect this difference, although nitrification potential tended to be higher than in the silty clay loam. Availability of inorganic N was consequently higher than in the silt loam, but more NO_3^--N was susceptible to loss due, as expected, to greater denitrification in the finer textured soil, but also to less restriction of water flow and NO_3^--N movement by lower compaction in subsurface layers. Rates of consolidation can be slower in finer textured soils that have higher porosity and greater total compressibility (Hillel, 1982).

DISCUSSION

Crop uptake of N approximately equaled fertilizer input in this on-farm study conducted in a lettuce field using lower than average amounts of fertilizer and water. Mass balance calculations and EPIC model simulations, however, suggested that substantial NO_3^--N was lost from the root zone by leaching and denitrification. Computer simulations indicated that higher N mineralization, greater water-filled porosity, and less compaction in the silty clay loam resulted in greater NO_3^--N loss by leaching and denitrification than in the silt loam.

The lettuce crops had low NUE, despite lower than average fertilizer and water application rates, because of high residual N at the start of the cropping period. Aboveground material was only 31 and 23 percent of available N (see above) on the silt loam and silty clay loam soils, respectively. If NUE is calculated as amount of N in plant tops divided by fertilizer applied, the two lettuce crops of the silt loam had 105 and 66 percent NUE, and this decreased to 76 and 55 percent NUE on the silty clay loam.

Losses of NO_3^--N were most pronounced after furrow irrigation began following thinning, so that inorganic N concentrations were low when plant had maximum N demand. Furrow irrigations used proper management, *e.g.* short durations, short advance times, and short run lengths, yet NO_3^--N losses were substantial. It is clearly difficult to maintain a adequate supply of water to this shallow-rooted crop *via* furrow irrigation without exceeding the storage capacity of the root zone. Water management strongly affects N availablity and NO_3^--N leaching, but the results of this study also suggest that more attention should be given to understanding soil microbial/plant N dynamics in developing 'best management practices' for irrigated vegetable production.

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Figure 1. Soil NO_3^- in four soil layers in the silt loam and silty clay loam soil types (n=4).

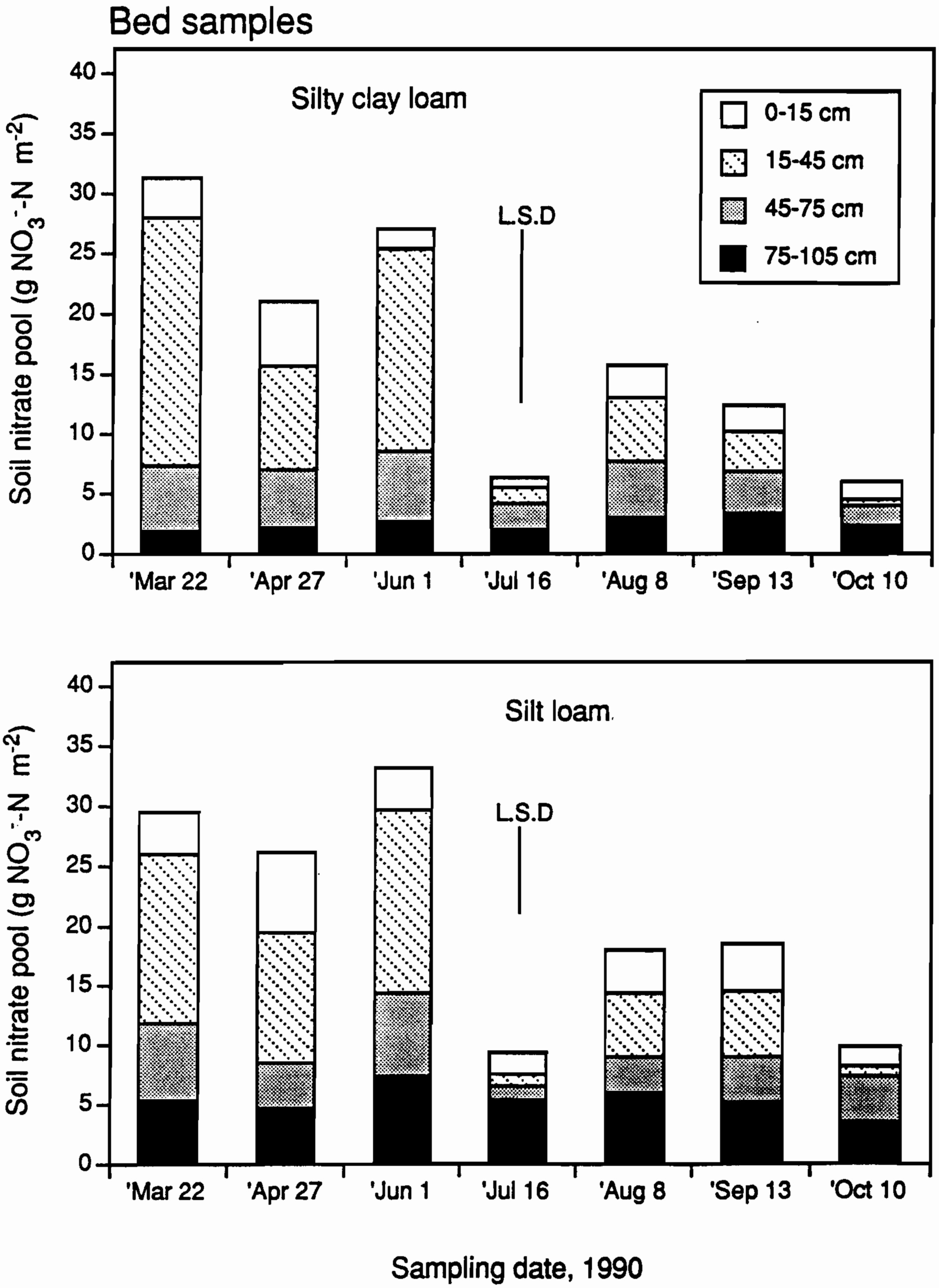
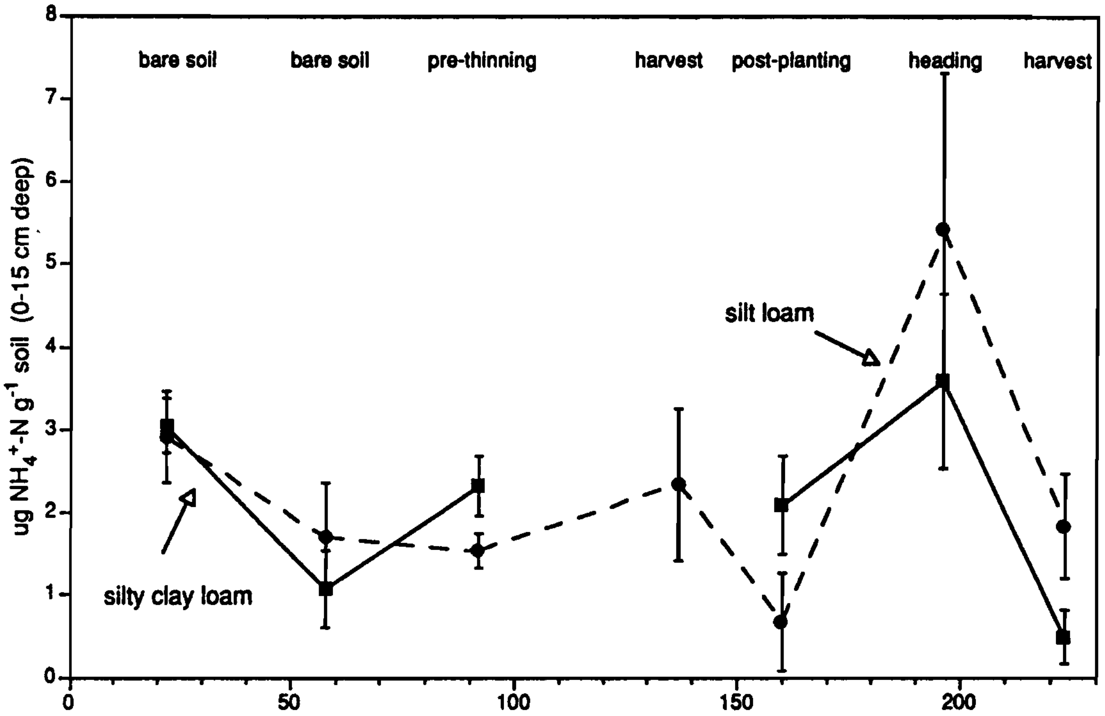


Figure 2. Net mineralizable N as determined by anaerobic incubation and nitrification potential as determined by the chlorate inhibition method. Data are for the 0-15 cm layer (n=4). R=rainfall, I=irrigation, F=fertilization, t=tillage, H=harvest.

Mineralizable N at 0-15 cm depth



Nitrification potential (0-15 cm depth)

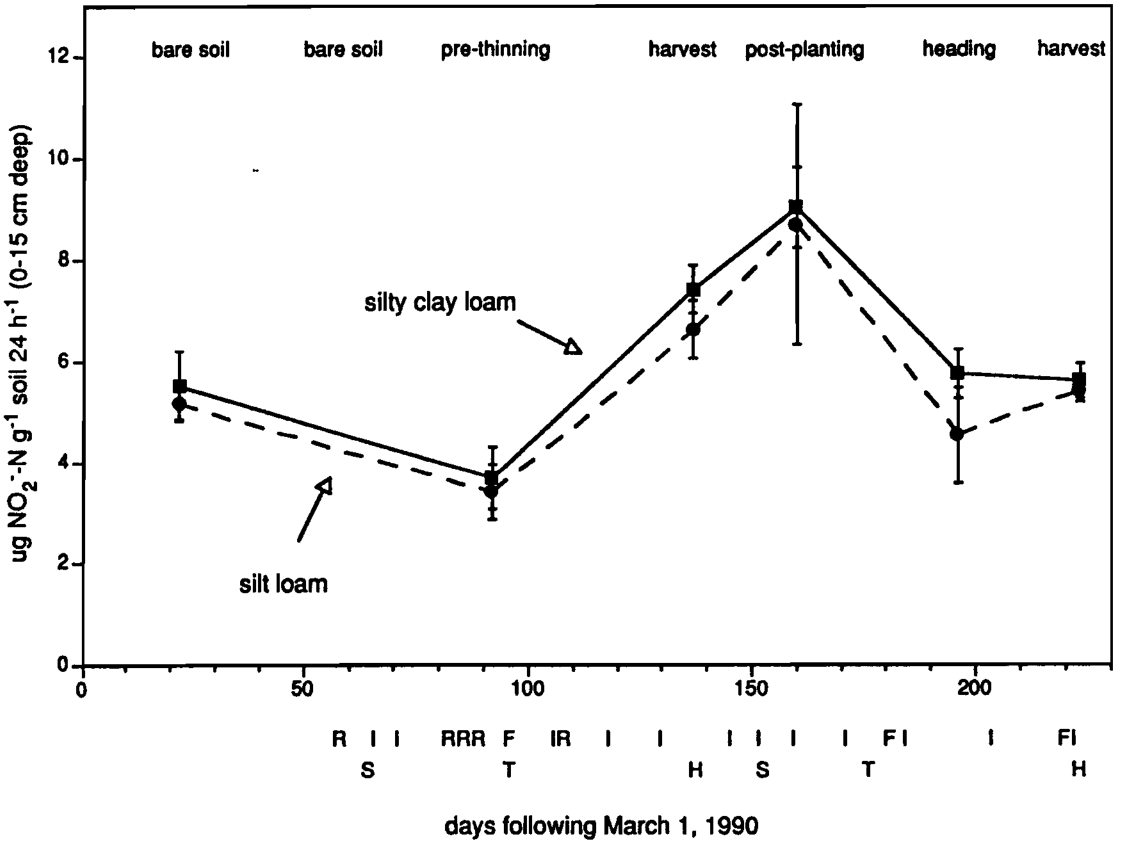


Figure 3. Root length and biomass distribution on October 10 at harvest of the second lettuce crop based on extrapolation from sampled cores in the bed and furrow zones (n=4).

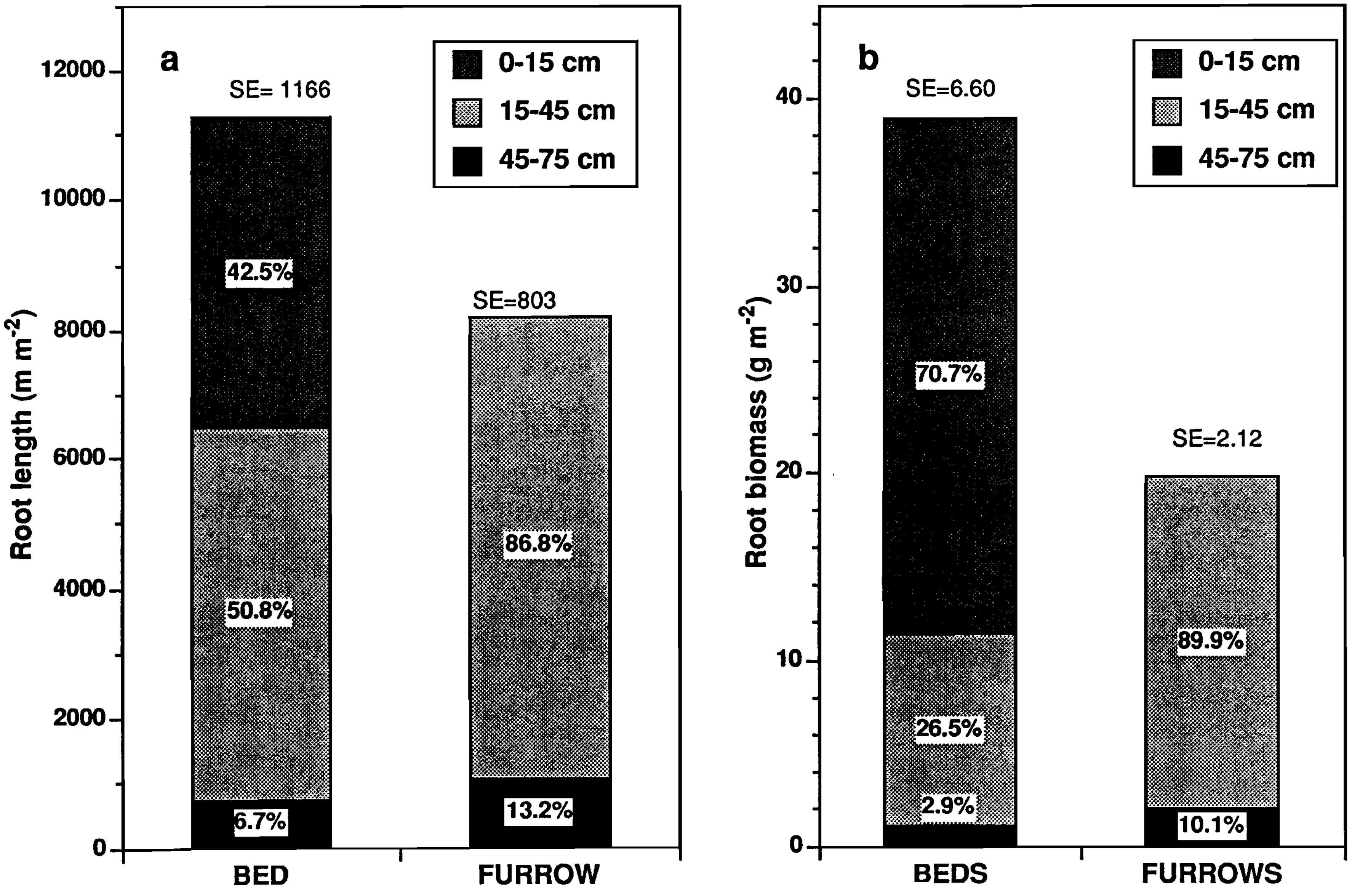


Table 1. Shoot and estimated root dry weights and N accumulation of lettuce during two summer crops. Data are means ± SE (n=4). Root measurements were only made on the silt loam soil type. Estimates of root dry weight and N content were determined by extrapolation from sampled cores.

Date	Shoot dry weight (g dw m^{-2})		Shoot nitrogen (g-N m^{-2})		Estimated root dry weight (0-75 cm depth) (g dw m^{-2})	Estimated root nitrogen (0-75 cm depth) (g-N m^{-2})	Estimated total dry weight (g dw m^{-2})	Estimated total nitrogen (g-N m^{-2})
	silty clay loam	silt loam	silty clay loam	silt loam	silt loam	silt loam	silt loam	silt loam
	mean ± SE	mean ± SE	mean ± SE	mean ± SE	mean ± SE	mean ± SE	mean ± SE	mean ± SE
June 1 (thinning)	5.3 ± 1.0	6.4 ± 1.5	0.23 ± 0.04	0.26 ± 0.06	0.63 ± 0.13	0.02 ± 0.003	7.1 ± 1.5	0.27 ± 0.06
July 16 (harvest)	259.1 ± 42.0	321.8 ± 54.6	6.17 ± 1.28	8.51 ± 2.02	45.90 ± 2.76	1.00 ± 0.07	360.4 ± 57.2	9.33 ± 2.07
Sept. 13 (heading)	48.6 ± 2.0	39.4 ± 6.0	1.78 ± 0.09	1.54 ± 0.23	20.35 ± 1.29	0.59 ± 0.04	59.7 ± 6.4	2.13 ± 0.24
Oct. 10 (harvest)	239.7 ± 19.0	261.5 ± 25.5	5.62 ± 0.02	6.76 ± 0.41	34.11 ± 4.85	0.94 ± 0.14	295.6 ± 26.4	7.71 ± 0.48

Table 2. Estimated values of soil N transformations and N fates by EPIC model simulations and by mass balance analysis for the cropped period (March 22 to October 10, 1990). Values show g-N m^{-2} for 0-105 cm depth.

	Pacheco silty clay loam		Mocho silt loam	
Output Variable	EPIC	Mass Balance	EPIC	Mass Balance
	g-N m^{-2}			
Final NO_3^--N in soil profile	15.8	13.1	18.7	17.0
Fresh organic N mineralization	12.5	—	10.2	—
Humus N mineralized	7.3	—	4.8	—
Average ammonium in soil profile	0.2	1.0	0.2	1.0
Ammonium volatilization	0.1	—	0.2	—
Nitrification	17.0	—	16.9	—
Denitrification	5.3	7.9	0.8	0.4
NO_3^--N leached	20.9	7.5	16.8	10.8
Crop N uptake	17.2	13.1	19.9	17.0

THE ROOT SOIL INTERFACE

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Much of what we know about managing soil nutrients and plant response has been derived from analysis of bulk soil. While this has proven to be a useful technique, the plant root derives its nutrients from a soil zone surrounding the root which may not be representative of bulk soil. All soil-derived plant nutrients and toxicants must pass through the rhizosphere which is soil in close proximity to the root. This soil is influenced by the root, associated microbes, microfauna and mesofauna and the variety of exudates contributed by the roots and microbes. Thus, terrestrial productivity is closely tied to processes which occur in the rhizosphere.

Root exudates and the roots themselves contribute a substantial amount of carbon to the soil. Estimates of annual fine root biomass from several ecosystems vary from 11 Mg ha^{-1} to about 0.6 Mg ha^{-1} (Fogel, 1985). Fluxes of water, oxygen, and nutrients converge at the root, while root exudates and carbon dioxide emanate from the root. These processes result in steep gradients near the root and zones of accumulation or depletion. The size of depletion zones is variable among plants, nutrients and soil type. Zones of depletion or accumulation should definite the rhizosphere; however, this definition is complicated by the fact that the mobility of these components varies and the extent of the root influence may be extensive if the mycelia of fungal symbionts are considered.

In recent years, a number of studies which have demonstrated that rhizosphere properties, process and reactions are not equivalent to those of the bulk soil. For example, rhizosphere pH may differ by as much as two pH units in relation to nitrogen source (Rollwagen and Zasoski, 1988). Differences in pH along the root and radially away from the root have been found (Häussling et al.,1985).

Research on rhizosphere processes and the expression of these process is currently limited by available techniques. Since the rhizosphere has traditionally been defined as a zone of about 2mm in thickness surrounding plant roots, it is easy to understand why techniques are a limitation. Within this zone there are strong gradients in a number of properties and processes including pH, microbial populations, organic exudates from the root including reductants and chelates. Thus, measurements of rhizosphere properties must have a spatial resolution less than 1 mm. In order to fully understand the rhizosphere processes, solution and solid phase composition as well as the complement of biological components must be known. A number of techniques which have been used to analyze or visualize properties and gradients in the solid phase. These include autoradiographs showing depletion or accumulations following radioisotope additions. Applications of liquid and solid agar containing pH or redox indicators to the interface have been tried. Slicing small radial increments of soil surrounding the root is another technique which is available. These techniques have shown that near the root P and K are depleted, while Ca often accumulates (Nye and Tinker,1977; Kuchenbuck and Jungk, 1982; Barber, 1974). These generalities are not always found. Potassium K accumulated while Ca was depleted in the rhizosphere of Douglas-fir seedlings grown in forest floor material (Zasoski and Claassen, unpublished). In another study with conifers, Ca concentrations did not change radially away from the root as Al levels increases as distance from the root cortex increased (Smith and Pooley, 1989). It is expected that the properties of the rhizosphere will be unique to a soil plant system.

The rhizosphere volume or soil volume occupied by the soil within 2 mm of the root can vary widely in a soil profile. The type of plant, the root distribution, the soil conditions which affect root growth and microbial populations will determine the extent of the root volume. In some instances where the root density is large, the 2 mm zone surrounding the root will occupy nearly all of the available soil volume. In other systems, the rooting density is such that a much smaller volume of the soil can be considered rhizosphere.

Feedback in the system has been demonstrated. Roots which are deficient in nutrients can modify proton excretion, the production of reductants, and excretion of phytosiderophores (Blaylock and James, 1992; Welch et al., 1992). Soil fertility will affect root growth as will soil density. Plant varieties may respond differentially to soil conditions such as acidity (Foy, 1974). These factors affect the rhizosphere and the availability of nutrients.

Much research remains to be accomplished to develop techniques which can probe the rhizosphere at the required spatial resolution. Elucidating the interactions among components of the root soil interface is critical since processes at the root soil interface control plant productivity. Understanding the rhizosphere will allow for intelligent management of the bulk soil properties which are more easily accessible.

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ENZYMATIC MINERALIZATION OF SOIL ORGANIC PHOSPHORUS

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A better understanding of organic-inorganic phosphorus transformations is needed to improve management of phosphorus fertilization of cultivated soils. This study was conducted to determine if the mineralization of organic phosphorus compounds in a soil could be induced enzymatically and observed using ^{31} Phosphorus Nuclear magnetic Resonance Spectroscopy (^{31} P NMR). Samples of an Osorno series (Typic Dystrandept) soil were sterilized using gamma radiation, then incubated with alkaline phosphatase, acid phosphatase, phosphodiesterase, and phytase. Soil extracts were prepared using 1.0 *M* KOH, then treated with Chelex-100 to remove interfering paramagnetics. ^{31} P NMR analysis of untreated and treated soil extracts showed a decrease in phytic acid and a corresponding increase in orthophosphate for the phytase-treated sample. Results indicate soil organic P is mineralized enzymatically and that the NMR technique is useful for studying mineralization in soils having sufficiently high levels of organic P.

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INFLUENCE OF PLANT AVAILABLE WATER ON CONIFER SEEDLING REGENERATION IN VOLCANIC SOILS OF NORTHERN CALIFORNIA

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Soil water is a limiting factor for seedling regeneration in volcanic soils of the xeric moisture regime in Northern California. Water retention is high due to the physio-chemical properties of the poorly-crystalline materials dominating the colloidal fraction. This study was conducted to determine the relationship between water holding capacity and seedling regeneration in the Shasta-Trinity National Forest. Samples from the rooting zone (upper 50 cm) of five volcanic soils were used to measure water retention between 0.1 and 15 bars. Soil moisture release curves showed that the greatest amount of water was held between 0.3 and 7 bars and that 15 bar water contents were approximately 20%. Water available to plants between 0.3 and 15 bars ranged from 4-21% with a mean value of 12%, which corresponds to an average of 5.2 cm of water within the rooting zone. Field evidence indicates that mature conifers in this climatic zone may extract water held at tensions up to 30 bars.

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Simplified and Rapid Analysis of ^{15}N and ^{13}C for Tracer Experiments

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The development of carbon-nitrogen analyzers interfaced to isotope mass spectrometers has resulted in rapid automated analysis of samples for ^{15}N and ^{13}C. Finely ground solid samples of 5-7 mg plant material or 30-50 mg soil can be analyzed at a rate of 60-100 per day at a cost of $6-$9 each, with no other chemical preparation. Typical results for plant material are 0.3676±0.0002 atom % ^{15}N, and for soils 0.3707±0.0012. Typical results for ^{13}C in plant material are -23.61±0.11 delta units.

Soil KCl extracts can be prepared by diffusing NH_3 onto a piece of paper which is then combusted in the analyzer, results compare well with those by conventional distillation.

N_2O, N_2 CH_4 and CO_2 can all be measured with precision suitable for tracer work by interfacing a conventional gas chromatograph to the isotope ratio mass spectrometer.

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GEOCHEMICAL PROCESSES AFFECTING THE SOLUBILITY OF SELENIUM AND ARSENIC IN GROUND WATER, TULARE BASIN, CALIFORNIA

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The southeastern margin of the Tulare Lake bed is affected by saline, shallow ground water containing high concentrations of Se and As. Specific conductance values of sediment porewater are as high as 60 dS/m at the three sites studied. Concentrations of selenium [>80% as Se(VI)] reach a maximum of about 400 μg/L and are correlated with specific conductance ($r^2 > 0.8$) for the upper part of the salinity profile at two of the sites. Concentrations of As are as high as 3,500 μg/L and are not related to specific conductance ($r^2 < 0.1$). Oxygen and hydrogen stable-isotope data indicate that evaporation of shallow ground water has contributed to high salinity and Se in the ground water. Reducing conditions, as indicated by increases in Mn concentrations, appear to be causing reduction of Se(VI) to less soluble Se species. Distributions of As(V) and As(III) species qualitatively agree with Pt-electrode Eh measurements. Comparisons of Pt-electrode Eh measurements and Eh values calculated from several measured redox couples show differences of several hundred mV for each well sample, indicating redox disequilibrium and the need to measure redox sensitive species. The solubility and distribution of As species appear to be related to the complex depositional environment and redox conditions in the study area.

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EVALUATION OF ALTERNATIVE METHODS OF POTASSIUM APPLICATION

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Potassium deficiency has traditionally been corrected in almond orchards with a mass dose application of potassium sulfate (2000 lbs/acre) once every four years placed in a band on each side of every tree row. This field study was conducted to determine if the expense of maintaining potassium at adequate levels could be sustained annually rather than requiring a large capital outlay every few years.

An annual every other middle potassium band application at a rate of 12.5 pounds of potassium sulfate per tree space was compared to a standard mass dose application of two 12.5 pound bands per tree in each row applied once every four years using a randomized complete block design with eight, five tree replicates. Leaf potassium levels of the every other middle potassium treatment were compared to levels found in trees receiving the standard treatment. Movement of potassium into the soil profile of a Vina Clay loam was quantified in 1991 with soil analysis.

Statistical analysis of leaf potassium levels has shown no significant differences between the standard mass dose potassium application and the every other middle treatment. Soil analysis of the profile below the standard mass dose shows elevated potassium in the top 36 inches of the soil profile in a narrow zone. The every other middle treatment that received four annual applications of potassium at the same rate per band as the standard mass dose had higher potassium levels in the top 18 inches of the soil profile in a broader zone.

Results suggest that applying potassium sulfate annually in every other orchard middle can maintain potassium leaf levels as well as the standard mass dose once every four years. Each annual band should be placed in the same location so that it adds to previous applications.

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DESIGN OF A ROTATING MULTI-STATION PESTICIDE AND SAMPLING MAST

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A multi-station pesticide sampling mast has been designed that keeps the face of the sample collector pointing into the wind; minimizing turbulent dispersion effects caused by the air stream passing around the mast. The system uses a hollow mast, wind vane and off-site vacuum source. The flow rates and heights of individual samplers can be adjusted independently. The vacuum source and mast support structure is below the ground surface reducing interference with the air flow near the soil surface and facilitating easy installation and removal. A schematic drawing showing design parameters and materials is presented. Wind vector diagrams are presented for field pesticide experiments during winter and summer periods. These diagrams demonstrate the importance of positioning the sample collector into the wind even when a prominent wind direction is present.

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A SPECIAL INVESTIGATION OF SOILS FOUND IN YOSEMITE VALLEY, YOSEMITE NATIONAL PARK

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Yosemite Valley has had intensifying human impact in campgrounds located in sensitive areas along the Merced River. Because of this impact, the soils and the Merced River are degrading. This study examined the present condition of the soils found on heavily used campgrounds, a low use campground, and undisturbed sites. The soil status of five oak restoration sites was examined. Mixed conifers are encroaching into areas of California black oak, which is the native tree and is what the Park Service wants to restore. Results showed high bulk densities on the heavily used campsites versus the low use site and the control sites. Saturated hydraulic conductivity values are lower on the heavily used campsites than in the low use site and control sites. The laboratory data showed soils in all sites having adequate fertility with compaction as the limiting factor in the heavily used areas. This study will serve as an important and useful tool aiding in soil management decisions which will directly affect the preservation of soils, water, vegetation, and habitat found in Yosemite Valley.

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FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)

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The Fertilizer Research and Education Program (FREP) of the California Department of Food and Agriculture (CDFA) is helping improve farming practices while reducing agriculture's contribution to the nitrate problem in California. FREP was created to advance the environmentally safe and agronomically sound use and handling of fertilizer materials.

In 1988, the Director of CDFA appointed a Nitrate Working Group to study the nitrate problem relating to agriculture in California. Scientists from the University of California, state agencies and industry participated. The Nitrate Working Group's recommendations became the mission of CDFA's Nitrate Management Program, which later developed into the Fertilizer Research and Education Program (FREP). The Nitrate Working group recommended that CDFA identify and prioritize the most nitrate-sensitive groundwater areas in California and work with public agencies, growers and industry to develop, demonstrate and promote the most effective ways to reduce nitrate contamination from agriculture.

Nitrate sensitive areas include the Central Coast Valleys where a large percentage of the states' vegetables are grown; including lettuce, broccoli, cauliflower, celery and strawberries. The east side of the San Joaquin Valley, where fruit trees are grown, is also of concern. This area is dominated by shallow, unconfined aquifers and sandy soils which allow for rapid percolation of nitrate.

The Grants Program

FREP manages a competitive grants program which supports research and education projects. The program currently funds seventeen projects. Research projects include nitrate reduction strategies in almonds, vegetables, citrus, grapes, peaches, and cotton. Education projects include development of curricula for California's schoolchildren, demonstration of latest composting technologies, production of two videos on Best Management Practices and efforts targeted at small and ethnic minority farmers to increase adoption of improved fertilizer practices. Staff assist in transferring the information generated by these projects to growers and interested parties.

Information Development, Outreach & Public Service Activities

FREP is developing an information system to store, process and produce resource materials and publications. FREP staff participate and develop workshops, conferences and meetings to serve the needs of growers, agricultural supply and service organizations, public agencies, and other clientele groups.

FREP makes available on request, technical and popular press articles on water, crop and soil management topics. Information on sources of funding, technical expertise and regulatory and legislative trends is also available from FREP.

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DRIP IRRIGATION SCHEDULING FOR FRESH MARKET TOMATO PRODUCTION

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Drip irrigation scheduling techniques for fresh market tomato production were compared in three consecutive seasons (1989-1991) in the southern coastal environment of Irvine, California. Three techniques were compared: 1) reference evapotranspiration (ETo, corrected Penman) x programmed crop coefficients (Kc), ranging from 0.2 (crop establishment) to 1.1 (full canopy development); 2) ETo x Kc, based on % canopy cover as estimated by average canopy width per row; and 3) irrigation at 20% available soil moisture depletion (SMD) at 30 cm, with recharge limited to a maximum of 0.8x cumulative ETo since the previous irrigation. The use of programmed crop coefficients and Kc values based on % canopy cover gave equivalent yields and fruit size distribution in all years; there was no difference in crop response between daily irrigation and irrigation three times a week. Both scheduling techniques maintained soil water content in the top 45 cm near field capacity throughout the growing season. The use of Kc based on % cover required less total irrigation in all seasons, averaging 78% of seasonal ETo vs. 88% with programmed coefficients. Irrigation at 20% SMD required an average of only 66% of seasonal ETo; marketable yield was equivalent with the other scheduling techniques in 1989 and 1991 but showed a modest yield reduction in 1990.

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DYNAMICS OF WATERSHED STREAM CHEMISTRY IN RELATION TO STREAMFLOW VOLUME IN A CALIFORNIA OAK WOODLAND-GRASS ECOSYSTEM

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The dynamics of biological, hydrological, and geochemical processes alter the chemical composition of rainfall as solutions pass through the ecosystem. This study examines fluctuations in stream water chemistry in an oak woodland-grass ecosystem as a function of stream discharge to elucidate processes regulating stream water chemistry. Stream water samples were collected at base flow and during high flow events and analyzed for suspended sediment, pH, alkalinity, and major cation and anion concentrations. Stream water show large increases in Ca, Mg, Cl, Si, alkalinity and pH compared to rainfall chemistry. The mean yearly Ca concentrations increased from 33 μM in rain to 1200 μM in stream waters, with an average pH increase of 2 units. Most cations and anions showed major decreases as discharge increases; however, NO_3 and SO_4 concentrations showed an increase at high flow during storm events, which reveals the possible lateral flow of soil solutions above a well developed argillic horizon. Ecosystem processes show a great neutralization capacity and a bicarbonate controlled system regulated by biotic CO_2 and silicate hydrolysis.

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TRANSPORT OF VOLATILE ORGANIC CHEMICALS IN UNSATURATED SOILS: MODEL DEVELOPMENT AND SOIL COLUMN STUDIES

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A transport model is developed that incorporates the effects of biodegradation and structural voids on the diffusion of volatile organic chemicals through unsaturated soil.

The degradation rate constant is a direct assessment of the persistence, and hence the fate, of organic compounds in the environment. Unfortunately, measurements of the rate constant vary enormously between field and laboratory data because many factors (e. g., concentration, temperature, water content, microbial population) influence degradation processes significantly. This complex dependence together with the lack of basic understanding of the transformation kinetics of organic chemicals in soil have made the rate constant very difficult to assess. Our model allows the degradation rate constant to be defined continuously as a function of time. Column studies under both sterilized and nonsterilized conditions are conducted to test the performance of the model by comparing model simulations with data obtained from the experiments.

The effect of preferential flow channels (e.g. worm holes) is incorporated into the model under different assumptions made on mass transfer between soil and void regions. Results from column experiments of both homogeneous soil and soil with voids are used to test these assumptions.

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A FIELD EVALUATION COMPARING TDR AND SOLUTION SAMPLERS IN ESTIMATING SOLUTE TRANSPORT PROPERTIES

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Obtaining solute transport properties in the field is often a laborious and expensive process. Time Domain Refectometry (TDR) appears to be an inexpensive and nondestructive alternative to traditional techniques. Solute transport properties were estimated from both TDR and solution sampler measurements in field and laboratory experiments with Yolo silt loam. Twenty four field sites had extensive instrumentation including 12 solution samplers and 12 sets of TDR rods each. The sites were ponded so steady state could be attained. Travel times to the 30 cm depth for pulses of chloride from both methods were calculated and compared. Also, disturbed cores were run in the laboratory under similar conditions as the field. Breakthrough curves were monitored using both TDR and effluent discharge, and the results were compared. Given specific parameters such as constant surface flux and steadystate conditions, TDR methodology compared favorably as a method for monitoring solute movement and measuring solute transport properties within the upper soil profile.

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INCREASED MINERALIZATION OF PERSISTENT PESTICIDES AFTER SOIL TREATMENT WITH *IN SITU* GENERATED OXIDATIVE RADICALS

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Bioremediation of chlorinated aromatics has had little success due to the biotoxicity and refractile nature of these compounds. Experiments were initiated to determine if *in situ* generation of oxidative radicals (OH) by reaction of Fenton's reagent (Fe^{+2}, 60 m<u>M</u>; H_2O_2, 5%) in contaminated soil would be compatible with bioremediation techniques. Plate counts (nutrient agar) showed little effect on soil bacteria numbers after a 1-h treatment with Fenton's reagent but fungal counts (Martin's medium) were reduced by 50%. In soil-free systems, ion chromatography showed a 100 % dechlorination of p-chlorophenoxyacetic acid (CPA) after treatment with Fenton's reagent for 24 h. HPLC-UV analyses found that parent concentrations of 2,4-D and 2,4,5-T were reduced 72 and 86%, respectively, after treatment with Fenton's reagent for 6 h. In soil, the combination of Fenton's reagent and bioremediation increased the dechlorination of 2,4,5-T up to 16X compared with no Fenton's addition during a 2-week incubation.

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COVER CROPS FOR SALINE SOILS

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Sustainable alternatives for saline drainage water management in areas such as California's San Joaquin Valley are needed. Previous work has demonstrated the short-term potential for reuse of saline drainage water for irrigation in this area. Results from various longer-term studies however, indicate that soil structural problems may occur which can greatly reduce stand establishment and crop yields in periodically salinized soils. To prevent these problems, we are evaluating the effectiveness of winter cover crop incorporation and gypsum applications relative to conventional fallows, for improving/maintaining soil physical properties and crop productivity in cyclically salinized soils. Six winter cover crop/fallow treatments have been imposed uon a rotation of tomatoes, tomatoes and cotton as summer crops. By monitoring water use, relevant soil physical and chemical properties as well as crop performance during the course of this 3-year rotation study, we are assessing the potential benefits and constraints of using winter cover crops in drainage water reuse systems. Initial results show improved emergence of tomato seedlings following incorporation of vetch, a winter annual legume. In a companion field screening trial of 120 prospective winter annuals, Hordeum vulgare, Hedysarum coronarium, Vicia dasycarpa, Brassica juncea, Brassica carinata, and Trifolium alexandrinum were leading biomass producers under moderate soil salinities.

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EFFECTS OF ION PAIRING WITH Ca AND Mg ON SELENATE UPTAKE BY PLANTS

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The influence of aqueous speciation on plant availability of metals is well established, but studies of speciation effects on ligand bioavailability are few. In saline soils, soluble Ca and Mg are often high enough to significantly alter the speciation of many oxyanions, including SeO_4. We grew alfalfa and tall wheatgrass in nutrient solutions containing 4 to 15 μM total SeO_4. Within each experiment, one series of solutions contained no added salt (variable free SeO_4^{2-} activity), while another included just enough $CaCl_2$ or $MgCl_2$ to maintain constant computed $\{SeO_4^{2-}\}$ values across the same range in total SeO_4. Shoot Se concentrations (and computed uptake parameters) were principally a function of the free ion activity, and were largely indifferent to the presence of $CaSeO_4^0$ or $MgSeO_4^0$. Difficulties encountered in this assessment included a surprising degree of sensitivity to choice of formation constants, and the need to tightly control the activity of free SO_4^{2-}, which competitively inhibits selenate uptake.

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VOLATILE ORGANIC VAPOR DIFFUSION AND ADSORPTION IN SOILS

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Knowledge of the relationship between D_P/D_0 and the volumetric air content ϵ is important when modelling gaseous movement of volatile organic compounds (VOCs) in soil. The effective diffusion (i.e. diffusion and retardation) of TCE, toluene and freon were measured in a two-chamber diffusion apparatus. The experiments were conducted on packed soil cores over a range of water contents. Vapor retardation factors were calculated from soil parameters and equilibrium partitioning coefficients. The partitioning coefficients were measured in batch experiments. It was found, that for water contents higher than 4 molecular layer surface coverage of water, solid/vapor partitioning coefficients, K_D' are consistent with values predicted by Henry's Law constants and solid/aqueous partitioning coefficients, K_D. For less than 4 molecular layers of water, sorption increase by orders of magnitude. The vapor retardation factors along with the measured effective diffusion allowed a calculation of diffusion coefficients (D_P) for the investigated species, by using the analytical solution to diffusion in a two-chamber apparatus. Values of D_P divided by the diffusion coefficient in free air D_0 were generally higher than values predicted by the Millington-Quirk equation, and lower than values predicted by Penman equation. Compared to the relatively non-reactive tracer freon, D_p/D_0 values for TCE and toluene agreed very well for higher water contents. However, values obtained for air-dry soil were underpredicted.

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IRRIGATION REGIME AND BARK STRENGTH IN ALMONDS

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Almond trees can be damaged by mechanical shakers when the shaker causes a separation of the bark from the wood. Many growers believe that the adhesion between bark and wood (bark strength) is increased by water stress. Our hypothesis was that water stress could lead to a reduction in cambial activity (as measured by growth rate), a reduced cambial zone thickness, and a possible increase in bark strength. Preliminary work indicated that the force of adhesion between wood and bark could be measured in two to three year old almond branches, and was increased by application of ethiphon. Among our objectives in this study was to describe the seasonal pattern in cambial strength in almond, determine the relation between branch and trunk cambial strength, and evaluate the relation of irrigation regime to bark strength and bark damage.

Trunk and branch cambial strength exhibited variation during the season, but did not always show parallel variation. During most of the season, trunk cambial strength was much less than branch cambial strength. Anatomical studies also indicated that the structure of branch and trunk cambial zones were different. These findings indicated that branch cambial strength may only be useful as a relative index of trunk cambial strength, and hence further studies concentrated on trunk measurements. Two irrigation regimes (1 week cutoff [wet] vs 3-5 weeks cutoff [dry] prior to harvest) and three experimental treatments (control, ethiphon spray directly on the tree trunk, and antitranspirant spray to the leaves) were applied to Nonpareil and Carmel trees at the West Side Field Station. Confirming earlier experimental results, no increase in cambial strength was found to be associated with water stress. There was however, a significant increase in trunk cambial strength for the ethiphon treatment, particularly in the dry treatment, and a nonsignificant reduction in cambial strength for the antitranspirant treatment compared to the control. Both carmel and nonpareil varieties gave similar results. As occurred in the previous irrigation experiments performed in Kings Co. however, we were unable to experimentally cause any significant barking injury. In the present study, a range of shaker pressures (250 psi - 2,000 psi) were tried, together with shaking long enough to cause removal of green leaves. It is surprising that significant barking injury has been difficult to achieve experimentally. In order to determine whether ethiphon will have practical benefits for reducing barking injury, it will be necessary to identify an experimental site or shaking equipment in which barking is more prevalent.

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MODELING ASSESSMENT OF NITROGEN AND IRRIGATION BEST MANAGEMENT PRACTICES FOR LETTUCE AND DAIRY PRODUCTION SYSTEMS

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Nitrate pollution of groundwaters and surface waters is a growing problem in California. A 1988 State Water Resources Control Board (SWRCB) survey of 38,000 wells found 9% exceeded the maximum concentration limit of 10 ppm NO_3-N, an increase of about 3 times in the last 30 years. Over half the nitrate contamination originates from agricultural non-point source (NPS) pollution. Best management practices (BMP) have been suggested as a means of minimizing agricultural NPS pollution, while maintaining economic viability for the grower. The Salinas Valley experiences large-scale NO_3 contamination of groundwater because of input-intensive vegetable production systems. Crisphead lettuce is the major crop grown in this region, accounting for about half of total US production. Dairy production in the San Joaquin Valley is regulated by the SWRCB and by County ordinance because of high nitrate pollution potential of these systems on indigenous sandy soils. This study used agronomic and economic modeling of nitrate leached, yield, and profit as a function of crop, soil, climate, irrigation, fertilization, and other management inputs to assess BMPs. Economically optimal irrigation and N fertilization inputs were obtained for a number of management scenarios, including non-uniform irrigation application. Irrigation volume, timing, and distribution uniformity were most important, and the amount and timing of fertilizer nitrogen application were the next most important variables to manage for cost-effective control of agricultural NPS nitrate pollution. Most nitrate leaching was associated with irrigation rather than rain.

Simulation of double-cropped lettuce showed:

- For the same total water applied, six irrigations per crop increased profits by more than 70% over four irrigations per crop at a nitrate leaching constraint of 60 kg NO_3-N/ha/yr, which coincided with the economic optima for each irrigation treatment.
- maximum profits were obtained with no fall pre-irrigation and half the usual spring pre-irrigation using an irrigation target of 50% of the field watered to evapotranspiration plus a 15% leaching fraction (ET+LF) at an irrigation system distribution uniformity of 0.84.
- Economic optimum were at about 50% the standard 450 mm irrigation water applied per crop and 67% the 200 kg /ha fertilizer N applied per crop. Use of these BMPs would reduce nitrate leaching by about 50 % and increase profits by about 20 %.
- The nature of the irrigation water input-N fertilizer input-profit relationship suggests that perceived risk of substantial yield and profit losses associated with under-fertilization and under-watering provides the only logical rationale for grower over-application of these inputs.

Simulation of dairy waste management with a corn silage-oat rotation showed:

- Supplemental N fertilization resulted in less profit and more nitrate leached relative to manure N only.
- When inorganic N is applied to the crop in addition to manure N, the economically optimal rates of N and irrigation water inputs are lower than those of standard practices. When only manures were applied, a greater animal density could be supported with commensurately more profit and less nitrate leached.
- Nitrate leaching increased rapidly with both increased animal density and amount of irrigation water. The lower irrigation rates (270-810 mm yr^{-1}) were the best management practices, giving relative profits from 93 to 100% of maximum at only 2-19% relative maximum nitrate leaching. Animal densities were between 20-50 animal units per hectare.

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Optimization of Fertilizer N Usage in Almond Orchards

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Our objectives are to develop fertilizer management guidelines to maintain almond productivity while reducing the leaching of fertilizer N below the root zone in almond orchards growing in coarse-textured soils; 2) relate nitrate leaching in mature almond orchards growing in "Nitrate Sensitive Areas" to leaf N concentration, tree yield and the rate of fertilizer N applied; 3) evaluate the need for annual applications of fertilizer N in mature almond orchards; 4) assess the relationship between differential fertilizer N application rates and the percentage recovery of isotopically labeled fertilizer N by mature almond trees; and 5) reassess the validity of the currently accepted N critical values for almonds.

This project is proceeding in 3 stages: a) determination of baseline measurements, b) establishment of differential tree N and soil nitrate status (based on differential rates of applied fertilizer N, and c) application of labeled fertilizer N; determinations of nitrate leaching, yield, and tree recovery of the labeled fertilizer N applied.

Baseline (pretreatment) leaf N conc., yield, and soil nitrate levels were determined in 2 high yielding Stanislaus County orchards in 1990. All these parameters were high including leaf N concentrations between 2.6-2.7%. As a result of the nitrate concentration in the irrigation water about 72 lbs N and 98 lbs N were applied in the two orchards in the irrigation water per acre per year. Differential rates of fertilizer N were applied during 1991 and 1992. Treatments include 0, 125, 250 and 500 lbs N/acre/year applied as a 1/3 (April), 2/3 (October) split application which represents typical grower practice.

Leaf N concentrations have been declining for the last 2 years, but despite the lack of applied fertilizer N, even the nonfertilized trees have not yet become N-deficient. Apparently, sufficient N is supplied in the irrigation water and remains in the soil profile to maintain tree growth and productivity without supplemental fertilization.

Evidence for overfertilization includes the following: a) leaf N concentrations greater than 2.5%, b) high levels of residual nitrate in the soil and c) lack of tree response to applied fertilizer N.

Annual fertilization is not necessarily required to maintain productivity if non-fertilizer sources of N (e.g., residual soil nitrate and nitrate in irrigation water) supply significant amounts of N to the trees.

Annual leaf analysis appears to be an essential component of efficient fertilization management. Additional studies are needed, however, to assess the relationship between leaf N concentration and economic risk.

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NITROGEN UPTAKE AND SEEDLING RESPONSE TO STRONGLY ACIDIFIED SOIL IN DRIP IRRIGATED ALMONDS

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Soil from drip basins which had been fertilized with $(NH_4)_2SO_4$ for 3 years developed a pH of 4.8 in water and 3.9 in $CaCl_2$. This soil was mixed with $Ca(OH)_2$ to establish treatments with pH levels of 3.9, 5.8 and 6.5. Lovell peach seedlings were planted in these treatments and amended with either ammonium or nitrate (200 mg/kg as a split application). A nitrification inhibitor (NSERVE) was added to all treatments. Height measurements were made after 10 weeks of growth. Ammonium-treated seedlings grew poorly relative to the nitrate treatment and the unfertilized control especially without added lime. Lime is a benefit to seedling growth. Both nitrogen source and lime treatment were very highly significant. A second phase of the project is concerned with root and nitrogen distribution in plots pretreated with ammonium sulfate or calcium for two years. These pretreatments established differences in drip basin soil pH. During 1991 these pretreatments were fertilized with ^{15}N-depleted ammonium sulfate to establish uptake efficiencies. In January 1992 three of these 11-year old trees from each pretreatment were extracted from the soil and the quantity of coarse and fine roots per tree was determined. Fine roots were sampled by coring and the analyses are currently in progress. The majority of the biomass is associated with the tree stem and branches, which averaged 120 kg per tree. The roots greater than 6 mm in diameter accounted for 16% of the total measured weight but contained 36% of the nitrogen in these components. This reflects the fact that the woody tissue such as stem and branch wood is generally low in nitrogen. Average above ground weight plus the coarse and medium roots was 153 kg per tree. This extrapolates to 73.4 Mg of dry matter per hectare. About 163 kg of N per hectare are need to construct the above ground tree structures plus the coarse and medium roots in this orchard. Additional N is cycled into the foliage and fine roots. This additional N is retained in the orchard, while some N is removed in the crop. We are in the process of determining the amounts of N in these additional components. The goal of this exercise is to develop a budget for nitrogen contained in the soil and trees as a guide to nitrogen needs of the orchard.

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