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CALIFORNIA PLANT
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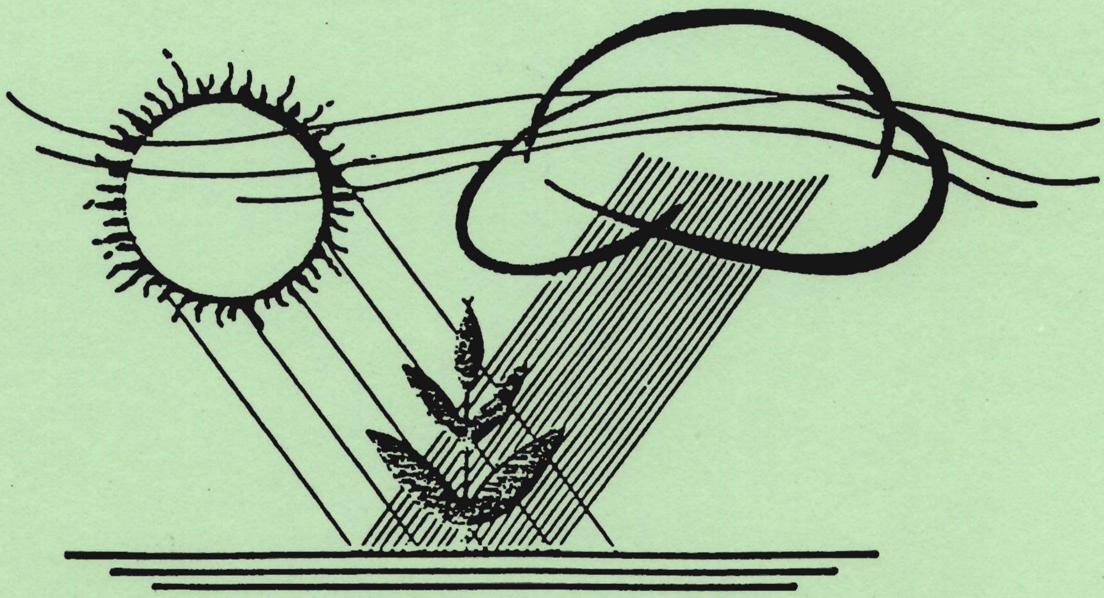
Information to Application:

Closing the Gap



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California Chapter
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February 1-2, 1989
Red Lion Inn
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Proceedings

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Assessing Existing Information
on Low-Input Agriculture for California

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Assessing the existing information is the first step in any research activity. This step is particularly important in a subject like low-input or sustainable agriculture which encompasses a variety of topics and practices, both old and new. The two-year-old University of California Sustainable Agriculture Research and Education Program is using both state-of-the-art and traditional means to help the research and extension system pull together the existing information on these topics, in order to provide better information to the state's growers and consumers and identify research needs.

Background of the Program

In 1986, the California Legislature passed the Sustainable Agriculture Research and Education Act, which officially asked the University of California to develop a research and extension program to improve the ability of California agriculture to produce food and fiber in ways that are both economically and environmentally sound. The Program has three main responsibilities: the administration of competitive research grants, the development and dissemination of new and existing scientifically-based information, and the coordination of long-term farmland research. This paper addresses the second area of responsibility.

Characteristics of the Information System

The purpose of the information system is two-fold: make the best existing information more readily available, and identify the areas of needed research. We have a strong commitment to working with the UC research and extension system in compiling this information, as well as with researchers and educators outside the UC system, such as other educational institutions, non-profit organizations, independent consultants, and farmers themselves. We are asking groups of these experts to form review groups to work with us to organize information for their production system, or region, or topic.

The way in which the information is disseminated to farmers or other end users is up to the review groups: traditional forms such as conferences and publications, or computerized forms such as databases or expert systems, may be most appropriate for a given subject and audience. While we are not requiring or even stressing computerized end products at this point, we are managing the information in the form of a computerized database.

The term database really means organized information. Database organization is required just to manage the identification and review of the huge amount of information related to the sustainability of California agriculture in an orderly way. Sometimes people think of a database as a table of numbers, but "how-to" descriptions can be organized as a database, too. A well-indexed book is not very different conceptually from a computer database of text and images. One of the advantages of a consistent database is that it provides a common index to more information than will fit in one book.

The most important job for researchers and educators is to compile the information on sustainable practices that will form the pages of a book, the screens of a computer product, or the handouts at a workshop or conference: the same information can be made available in each of these forms, if it is organized properly. The integration of the database and desktop publishing system that we have devised allows us to provide printed products today, yet have the same information ready for computerized products in the future. None of these products will replace the most important part of information dissemination, which is of course the farm advisor, consultant, farmer or other person who interprets the information and adapts it to a particular operation.

Besides providing better access to what we already know about the sustainability of farming practices in California, the organized structure of a database can help identify what we don't know. The structure can be thought of as a set of compartments, and we want to identify the relatively empty ones. Most researchers and educators certainly know where the "holes" are in their own systems or subject areas, but without a consistent structure it is very difficult to look across disciplines, production systems and regions and compare the depth of the "holes." The advisory committees who make recommendations to the Program on the funding of competitive grants, and others making research decisions, need this organized information.

Specific Information Activities Currently Underway

One source of material for the information system is the research projects funded by our competitive grants program. A description of the 29 projects funded in the last two years is available for free. All of the projects will be useful, but several are specifically designed to compile existing information: Two researchers at UC Davis are compiling information on non-pesticide controls for vertebrate pests such as pocket gophers, ground squirrels, voles, rabbits and deer. A California organic growers' organization is putting its information on member practices into a database in order to summarize their practices and concerns. Chinese pest management practices that may be applicable to California are being compiled by Chinese scholars a California pest management firm. We are working with these researchers to incorporate the results of their work into our information system.

We are also working with groups of researchers, farm advisors, growers, consultants and other experts inside and outside the UC system to pull together the existing information, crop by crop and topic by topic. In several cases we are sponsoring conferences and workshops, since it makes sense to pull together information for immediate use rather than just to feed a database for future use. We have co-sponsored a number of general-purpose conferences in the past, and have recently tried focussing on specific production systems in one-day conferences on citrus (at UC Riverside) and grapes (in Visalia). University Extension and Cooperative Extension are cosponsors of these efforts. Information presented at these conferences will be re-worked for the database and future conferences, through consultation with conference speakers and other advisors.

In two other cases, we have researcher/writers working with advisory groups to prepare information for future use. We are just completing six months of work on almonds, emphasizing floor management and pest control issues. A concentration on soil management issues in tomato-based rotations is currently underway.

While most of these activities are commodity-specific, the program has a Soils Advisory Group which will take this information provide overview across the different production systems. We also have a cover crop group that is reviewing information for a database of cover crop/green manure/living mulch characteristics. This information will be useful in practically every region and production system in the state.

It's clear that our information advisory groups have, so far, emphasized trees and vines somewhat more than agronomic crops. We are very eager to hear from individuals or groups who would like to work with us on other topics or systems.

SUSTAINABLE COMMERCIAL VEGETABLE PRODUCTION WITH MINIMAL USE OF SYNTHETIC FERTILIZERS AND PESTICIDES

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The largest organic grower organization in California is the California Certified Organic Farmers (CCOF), which began in 1974. The group estimated that, in 1988, about $100 million of total product will be sold by 382 growers. Historically, most of the grower members were small, but recently larger growers are participating in the program. Total acreage in the CCOF program has grown from 9,700 acres in 1986 to 25,640 acres in 1988, with a growing number of inquiries from large growers interested in enrolling in the program. One of the reasons for this growth can be explained by the fact that prior to 1988, most of the organic products grown were not sold as organic, but were sold in the conventional marketplace. With the recent interest by large-volume supermarket chains, more and more product is being sold as organic or as pesticide-free. The major growth-limiting factor for this marketing trend is the lack of a consistent and reliable supply of organic products, mostly produce.

Out of the 382 growers enrolled in CCOF in 1988, 200 are vegetable producers. This represents, by their own estimates, only 40% of the growers in the state who grow organically. Most of these CCOF members are smaller growers who farm under 200 acres. Only 20 vegetable growers enrolled in CCOF have greater than 200 acres in production. Accurate figures are impossible to find. While numbers of growers, and their acreage are reliable figures for those enrolled in the program, the extent to which organic farmers exist overall in California escapes a detailed accounting. In addition, growers are reluctant to report accurate income figures voluntarily.

Complicating matters further, there are several different grower groups that have different standards for participation in their programs. Although CCOF represents the largest group of organic vegetable producers and uses a well-developed certification-inspection program to verify the organic status of growers, other organizations are emerging as well. The Organic Crop Improvement Association (OCIA) has its own certification program with slightly more strict criteria than CCOF for what constitutes organic status. OCIA is presently certifying Mexican, Central American, and Caribbean vegetable growers in addition to its large

Midwestern and Canadian growers who produce grains, beans, and other crops. CCOF refuses to inspect and certify growers outside of California.

The Nutri-Clean Program, out of the San Francisco Bay area, has emerged as a significant player in bringing pesticide-free product to supermarket chains in large volumes. Its program, while not a grower group, involves farm inspections to some extent, but more strongly relies on pesticide residue analysis to certify product. Large supermarket chains are promoting these products as specialty items in full-page color newspaper advertisements. Admidst substantial controversy in agricultural circles, this program is experiencing rapid growth with supermarkets experiencing some of the most successful produce advertising campaigns ever.

Recently, a new grower group, called California Clean Ag, is organizing with a definition of product that allows for the judicious use of certain synthetic inputs determined to be less threatening to human health and to the environment than other synthetic inputs. This group may be most useful to growers who wish to make a transition from chemically-intensive methods towards those resembling organic methods.

The Organic Market News and Information Service in Davis, California (OMNIS) started in 1985 and publishes weekly market data on California organically grown produce. This subscriber newsletter is enabling distributors to keep better track of supplies, prices, and other trends to manage their trade better. OMNIS is continually upgrading its service as the database grows. The report tends to confirm that prices organic growers receive tend to be somewhat higher than conventional prices, but this is not always the case, especially when supply and demand are in balance. The price advantages for organic produce disappear at times when supply is adequate to meet demand.

LOW INPUT GRAPE PRODUCTION

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Low input farming and sustainable agriculture are catchy new phrases but are essentially the same as integrated pest management (IPM). The University of California introduced the concept of IPM to grape growers in the 1970s and today it's widely practiced. The objective is to maximize production and farm profitability while minimizing the use of pesticides. Low input farming, IPM, etc., are a systems approach that integrate pest management with viticulture, floor management, nutrition and irrigation.

Table, raisin, and wine grape growers are continually striving to improve the economic viability of their farms. Cutting costs, increasing production and quality, and finding market advantages are all part of the business. Some raisin and table grape growers in the San Joaquin Valley have received top dollar by farming and marketing their grapes as "organically grown." Chemicals they use are limited to those listed by the state code passed in 1979 for "organically grown produce."

The following is a discussion of SJV grape production with low input farming emphasizing floor management, pest control, and use of pesticides including those listed under the state code for organically grown produce.

Leafhoppers - The Biggest Hurtle

The grape leafhopper and variegated leafhopper are the most serious pests of grapes in the San Joaquin Valley. Excessive leaf damage caused by these insects delays fruit maturation or reduces yields. Table grape growers are concerned with fruit spotting from leafhopper excrement and must keep the insect populations lower than with raisin or wine grapes. High leafhopper populations can exacerbate working conditions for field workers.

Treating with insecticides for leafhoppers often disrupts the biological control of secondary pests. Population levels of spider mites, mealybug and OLR for example, are often dramatically increased in some growing districts following an insecticide treatment for leafhoppers. These secondary pests may then require an additional treatment or treatments leading to a treadmill of pesticide dependency. To get off the treadmill and reestablish biological balance can take years of intense management, while a cold turkey approach may result in short term economic loss.

When treatment is unavoidable because the crop is seriously threatened by leafhopper damage, the pesticide chosen for control and time of application is critical to minimize disruption of other pests. Based on years of observation and research, we have an improved understanding of the disruptive potential of pesticides commonly used on grapes. For example, in some grape growing areas carbaryl (Sevin) is very disruptive to spider mites along with moderately disruptive methomyl (Lannate, Nudrin), dimethoate, and naled (Dibrom). Other insecticides including endosulfan (Thiodan), propargite (Omite), ethion, parathion, bacillus thuringiensis, cryolyte, sulfur and bayleton are only minimally disruptive.

The biggest hurtle for the low input grape grower is to get through the growing season without using a pesticide for leafhopper control. One must take advantage of vineyard floor and canopy management systems along with full utilization of resident leafhopper parasites, all of which are helpful in maintaining leafhopper populations below damaging levels. Additionally, leafhoppers must be monitored carefully in order to make accurate management decisions. In years when populations increase to levels nearly causing yield or quality reductions, low input growers often allow population to climb beyond the comfort zone. Only experience will give those growers confidence in making treatment decisions that will be cost effective.

"Organically Grown" Grapes

California Certified Organic Farmers (CCOF) was formed in 1974 to create uniform standards for organic food production and establish a verification program. CCOF guidelines for allowable pesticide materials are based on the provisions of the state code passed in 1979 that gives a legal definition of the term "organically grown." Useful materials falling within these guidelines that can be used in grape production include compost, dolomite, gypsum, limestone, mined potassium sulfate, micronutrient sprays, sulfur, gibberellic acid, bacillus thuringiensis (B.T.), dormant oil, fatty acid soaps, mined cryolite, and botanical pyrethrums.

Insecticides for leafhoppers on the CCOF organic list include botanical pyrethrums and fatty acid soaps. These materials give only fair to poor control. Conventional insecticides give adequate control, however leafhoppers are rapidly developing resistance. To control leafhoppers, pesticides should be applied as late in the season as possible, second brood or later, and only when absolutely necessary to minimize disruption and slow the resistance process. (Late season spraying is difficult with many materials because of reentry considerations and spotting of table grape fruit.)

Raisin and wine grape growers, with good vineyard management, can usually get through the season without treating leafhoppers. Although, with the presence of variegated leafhopper, more leaf damage is occurring late in the season and complaints by pickers are more common. Also, early-season table grape varieties (Flame Seedless, Perlette, Cardinal, Exotic) can usually get through the season without a leafhopper treatment. Late harvested Thompson Seedless, Calmerias, Ruby Seedless, Ribiers, and Emperors take the full force of hoppers and it's much more difficult to avoid chemical control. However, it is possible as demonstrated by a few growers who are successfully growing these varieties without treating for leafhoppers.

Sulfur is routinely applied to foliage each year to control powdery mildew, the most important economic disease of grapes. Skeletonizer, omnivorous leafroller, and grape leaffolder are controlled yearly with an application of kryolyte in May or several applications of bacillus thuringensis.

Leaves are removed from around bunches in June with some table varieties (Flame Seedless, Ribier, Exotic, Ruby Seedless) to improve ventilation and reduce bunch rot. This practice also removes many first brood leafhopper nymphs. The amount and timing of crop adjustment and bunch thinning are critical in managing bunch rot of some table grape varieties.

Vineyard Floor Management

Vineyard floor management has demonstrable affects on pest populations. Cover crops often act as an insectary for and increase the numbers of spiders and other predators and parasites; thus, vineyards generally have fewer leafhoppers and spider mites. The rate of water infiltration improves on most soils when cover crops are consistently grown. In addition, the use of cover crops, manure, and compost can improve soil fertility along with vineyard productivity and health. However, cover crops require additional management skills, labor, and irrigation to be of maximum benefit.

Seeding cover crops in the fall is an old, established practice in San Joaquin Valley vineyards. Cereals such as barley and rye or combinations of a cereal and a legume are most commonly grown.

Compost, manure, or nitrogen fertilizer is often applied to stimulate cover crop growth and to ultimately make nitrogen available to the vines upon decomposition. However, growers should avoid legumes and additional applications of nitrogen fertilizer when high levels of nitrogen in irrigation water, soil, and plant tissue exist.

Some growers use reseeding winter annual cover crops (legumes and grasses). These are initially planted in the fall but allowed to mature in the spring to produce seed for subsequent self seeding the following fall. Close mowing is practiced from mid-March to mid-April to help protect vines from frost. After the danger of frost is over the cover is allowed to grow and mature before final mowing or disking.

Summer cover crops are common in table grape and wine grape vineyards. Summer-annual grasses, such as watergrass and crabgrass, are allowed to develop in May, mowed as needed in the summer, and then disked in the fall.

Vine rows are strip tilled using specially designed plows, harrows, or blades. Row cultivation to control winter weeds is practiced in late winter after vine pruning and tying, usually in February or March. The few remaining weeds are hand hoed. After frost danger has passed (mid-April) the soil is thrown back to the vine row reestablishing the berm. This process controls newly emerging summer annuals. By the end of May, the vine's canopy shades the berm thus inhibiting further weed development. Perennial weeds are hand-shoveled or cultivated. Bermuda grass can be a formidable problem, but should be controlled especially in areas prone to Pierce's disease.

Row plowing can damage stakes and sometimes vines and is labor intensive. However, advantages of this system include reducing overwintering populations of leafhopper and other insects and diseases. In the spring, deep irrigations are made easier using the uncompacted furrow down the vine row. Managing the middles, between vine rows is accomplished by mowing when sod or grass cultures are used, or cultivated with standard disks and harrows.

Summary

The UC Grape Pest Management Manual is a valuable reference to low input farmers and conventional farmers alike. The manual is a compendium of research and experience that began in the late 1950s when UC personnel and industry began intensive studies to lay the groundwork for integrating chemical, cultural and biological controls into a practical pest management program. Information is provided on insect identification, life cycles, population dynamics and damage thresholds.

Current University research in grape pest management emphasizes the cultural and biological control of leafhoppers. The most important natural enemy of the grape leafhopper is a tiny wasp, Anagrus epos, that parasitizes leafhopper eggs. Biotypes of this parasite have been found in Mexico (home of the variegated leafhopper) and other areas. These biotypes give more effective parasitism of variegated leafhopper and are being mass reared and released in San Joaquin Valley vineyards.

Information is being developed on ways to encourage Anagrus activity through use of refuges (prunes, almonds, riparian areas). Managing leafhopper populations through canopy manipulation and vineyard floor management are also areas of high priority research.

Finally, more information is needed on the relationship of the farming system to pest and disease pressure within the vineyard. Changing or rearranging one component of the system effects the whole system. Through continued and improved IPM practices growers can gradually change to a low input managed vineyard. There is a fine balance between successful and unsuccessful low input farming. Good management by well informed growers is the difference.

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IS INTENSIVE GRAZING MANAGEMENT LOW INPUT OR HIGH INPUT AGRICULTURE?

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Introduction

Traditional methods of pasture production are high input with limited returns from these inputs. Common production practices include:

Seeding to improve production and quality
Fertilization to increase production
Dragging to spread manure
Spraying to kill weeds
Mowing to remove unused rank forage and weeds

After several years of declining productivity due to increasing clumpiness, increasing weeds and loss of legumes pastures are renovated and we begin a new production cycle. Because of these high agricultural inputs and the poor return on investment, pasture improvements and especially irrigated pasture improvement, is often considered to be uneconomical.

Our biggest problem in grass farming has been that we have been attempting to grow more grass rather than attempting to more efficiently harvest what we have already grown. It is on this one key missing piece of the puzzle that all of our pasture economics have foundered. We have a crop that will grow for free. We've got a harvesting machine that runs on sunlight and water, but we allow our harvester to wander about randomly harvesting what it pleases and wasting the rest.

The forage lost to inefficient harvesting and wastage due to trampling and fouling turns a crop with a relatively low input:production ratio into a crop requiring high inputs. Pasture subdivision with permanent and portable electric fences and implementation of controlled grazing allows the manager to use the grazing animal to manage the pastures. Concentration of stock for short periods of time results in uniform utilization, reducing the need for mowing to remove rank forage and weeds. Concentrated grazing in small areas (e.g. 35 stocker calves per acre for one day) concentrates the deposition of urine and manure on a new area each day and animal trampling begins to break down the manure reducing the need to drag pastures. More importantly nutrients are kept on the pasture instead of accumulating under a favorite shade tree or next to the water trough. Murphy (1987) states that livestock camps can have soil N levels as high as 1500 lbs per acre without controlled grazing. If we can keep the nutrients on the pastures we can reduce fertilizer inputs. Thus we can see that controlled grazing systems can turn grass production into an enterprise requiring lower inputs while increasing production.

Controlled Grazing Systems

The fundamentals of controlled grazing were described by Voisin (1959) and amplified by researchers in New Zealand (Nicol 1987) and the United States (Savory and Parsons 1980, Smith et al. 1986, and Murphy 1987. Voisin's rotation principles are based on two simple rules: a) rest periods should vary with pasture growth rate and b) individual paddocks should be grazed for no longer than six days. During periods of slow pasture growth rests are long (60 - 90 days) and during periods of rapid growth rests are shorter (20 to 30 days). Inexpensive New Zealand fencing techniques allow the controlled grazing manager to subdivide and conduct a planned but flexible pasture rotation. As part of the fencing and rotation plan the manager can limit the use of critical areas to meet environmental quality objectives such as erosion control, agroforestry and reforestation, wildlife habitat enhancement, and riparian area improvement. Controlled grazing also facilitates the management of pasture legumes and development of complementary forages to fill gaps in the forage system.

Nicol (1987) reviews the state of the art of pasture production and utilization practices in New Zealand. Barrow (1987) reviews nutrient cycling in pasture systems. These publications and the results of studies in California and Oregon (Peterson 1951; Sharrow 1979; George, O'Connell and Knight 1986) and the western U.S. (Tiedeman 1986) indicate that controlled grazing can have the following benefits:

Increased carrying capacity
Increased productivity per acre
Improved animal performance
Reduced winter feeding
Increased legume density and cover
Improved nutrient cycling and fertilizer efficiency
Reduction in weed populations
Improved management planning
Improved predator control
Protection of critical areas

Increased gross income, reduced variable costs, reduced overhead costs, reduced energy inputs and improved efficiency are associated with each of these benefits.

Comparisons of rotational and continuous grazing on California annual rangeland seemed to show that rotation offered no advantages over continuous grazing (Heady 1961) based on a trial at Hopland Field Station on three paddocks with one rotation cycle per growing season. Unfortunately, these results contributed to an attitude among researchers and extension staff that pasture rotation does not pay on annual rangelands, and no further trials were conducted until a few innovative ranchers implemented cell grazing after attending Alan Savory's Holistic Resource Management School (Savory and Parsons 1980).

In 1967 Hull et al. showed that rotational grazing at heavy stocking rates on California irrigated pasture produced more beef (lbs/a) than continuous grazing. However, Hull et al. (1971) showed that continuous grazing resulted in higher beef production (average daily gains and lbs/a) than continuous grazing. However these studies were inconclusive because they used too little subdivision, rotations were too rigid, and stock densities were insufficient. One study of controlled grazing almost passed unnoticed. Petersen (1951) had earlier offered a glimpse of controlled grazing's future when he documented improved utilization of pastures that were daily ration grazed by dairy cows.

Because controlled grazing can have multiple pervasive effects on the ranch system, its full influence can not be determined from short term studies involving single factor contrasts (Sheath and Bryant 1984). Instead its effect on several components of the whole ranch system must be determined. Because it is impractical to replicate entire ranches, case study and on-farm monitoring approaches must be taken. To document the several changes due to controlled grazing systems (CGS), stock flows, forage flows, calendars of operations, gross income and variable cost inputs are used to conduct an analysis of the livestock-pasture enterprise. Gross margins (Gross income - variable costs) are used as a diagnostic tool to determine changes in enterprise profitability. Following are some examples of changes that influence ranch operations and profitability.

Preliminary Ranch Monitoring Results

Fencing Costs: Permanent electric fencing is becoming popular because it requires fewer posts, less wire, and less installation labor, it is easier to maintain, and it reduces predation. Portable electric fencing increases land use flexibility. Table 1 compares material costs of traditional fencing and high tensile fencing using a wagon wheel cell (Figure 1) and supplemental fencing to subdivide existing pastures (Figure 2). Permanent and portable electric fencing makes pasture subdivision easy and inexpensive.

Table 1. Material costs of electric fencing for two grazing cells and estimated cost if traditional barbed wire were used.

Grazing Cell	Area (acres)	Distance (miles)	Cost ($/mi)	Cost ($/a)
	Single strand electric high tensile wire			
Heavey	1060	12.5	400	4.72
Alfalfa	1110	9	400	3.24
	4-strand barbed wire			
Heavey	1060	12.5	2000	23.58
Alfalfa	1110	9	2000	16.22

Figure 1. Wagon wheel pasture cell configuration with stockwater at the center.

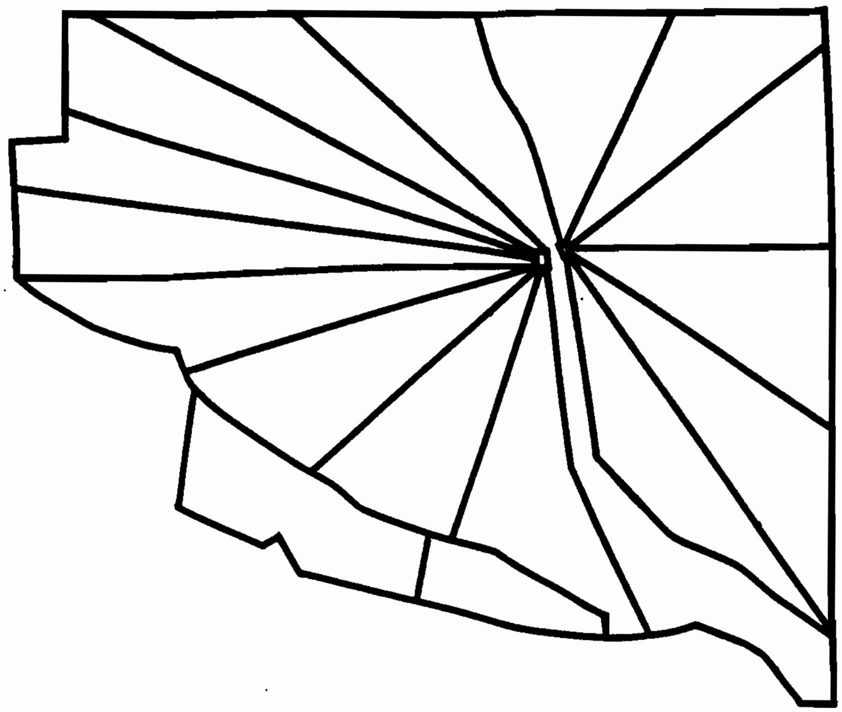
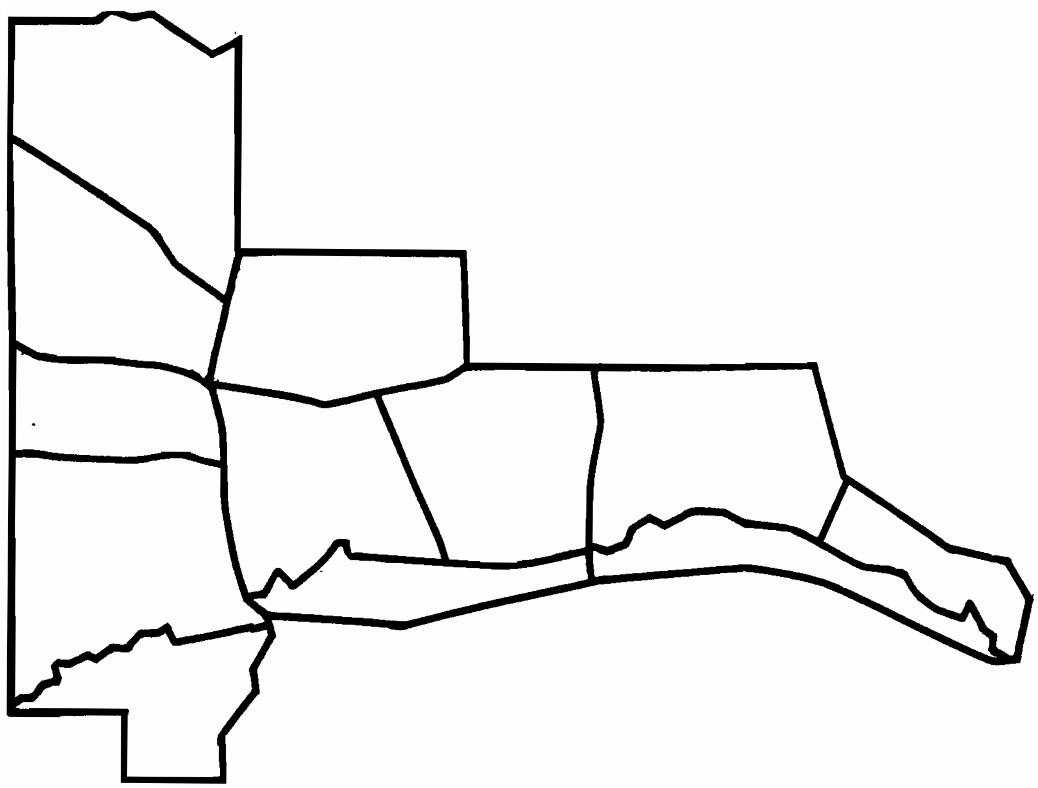


Figure 2. Pasture cell developed from existing fencing.



Increased production: Livestock production (lbs/a) can be increased in two basic ways: 1) increase animal performance, 2) increase carrying capacity. Table 2 shows the increases in production that have been documented on seven farms and ranches in northern California following implementation of a CGS. Table 3. compares pasture subdivision costs and production changes on rangelands with those of traditional range improvements.

Table 2. Estimated material costs for fence and water development, and production improvements for annual range and irrigated pasture determined from ranch records.

Pasture Type	Costs ($) Fence	Water	Total	Total Amortized*	Livestock Production (lbs/a) Before CGS	After CGS	Difference	Stock Type
Annual Range	5	0	5	.92	25	48	23	Calves
Annual Range	5	0	5	.92	50	75	25	Stocker
Irrigated Pasture	30	15	45	8.28	600	1000	400	Stocker
Irrigated Pasture	30	20	50	9.20	400	1000	600	Bulls
Irrigated Meadow	10	0	10	1.84	140	200	60	Calves
Irrigated Pasture	25	0	25	4.60	150	225	75	Calves
Irrigated Pasture	20	5	25	4.60	400	800	400	Lambs

*Costs amortized over 10 years @ 13%.

Table 3. Comparison of pasture subdivision to other common range improvements using conservative estimates of improvement life, costs and production increases.

Practice	Life (yrs)	Cost ($)	Amortized Cost ($/a/yr)	Production Increase (%)	Return (lbs/a)
None	--	--	--	--	50
Subdivision	10	10	1.84	30 - 100	75
Legume Seeding	20	50	7.12	50 - 100	75
Nitrogen Fertilization	2	25	14.99	50 - 100	75

Secondary Benefits: One of the early uses of controlled gazing in New Zealand was to reduce winter feeding. One California ranch we are monitoring has reduced winter hay feeding of stocker cattle to zero. Most have witnessed increased vigor and density of pasture legumes. Another has reduced the number of bulls required in his cow herd due to the concentration of stock.

Weed Control: Pasture weeds are the number one complaint of many pasture owners. Several ranchers have witnessed decreases in pasture weeds following implementation of controlled grazing. Unfortunately we have not documented these apparent declines in sour dock, foxtail and even thistles but we have documented a decline in medusahead (*Taeniatherum asperum*) on annual range two years after implementation of controlled grazing (Table 4). Medusahead declined from 45 percent of the species composition to ten percent and the heavy litter associated with medusahead patches was reduced.

Protection of Critical Areas: The livestock industry is increasingly perceived by environmentalists as using grazing practices that reduce wildlife habitat, degrade riparian areas and accelerate erosion. Controlled grazing systems provide tremendous livestock control which when properly planned and applied can reduce or mitigate environmental concerns associated with livestock grazing. Erosion from grazing is largely the result of poor livestock distribution resulting in overgrazing and poor vegetative cover in some areas while other less accessible areas remain ungrazed. Controlled grazing allows the manager to achieve proper livestock distribution resulting in much improved soil cover.

Controlled grazing systems have been used to limit livestock access to riparian areas allowing natural vegetation to stabilize stream banks. Wildlife habitat has been improved leaving selected pastures out of the rotation, allowing grass to provide cover and seed for food. These improvements are the result of management planning that targeted special management to meet wildlife habitat goals.

Table 4. Change in species composition (%) from 1984 to 1986 for four transects in medusahead infestations and one transect in a small ungrazed exclosure.

Composition	Medusahead 1984	Medusahead 1986		Exclosure 1984	Exclosure 1986
Bare Ground	1	8		0	0
Litter	16	25		16	18
Medusahead	45	10	**	08	10
Soft Chess	17	23		16	
Wild Oats	4	0		34	22
Annual Ryegrass	2	5			
Annual Fescue	1	2			
Ripgut Brome	0	0		22	44
Annual Legumes	4	4			
Filaree	10	13			
Other Forbs	2	6	*	4	6
Sample size (n)	4	4		1	1

* (p<0.05)
** (p<0.01)

Reduced Predation: One sheep ranch in Solano county, several in Mendocino County and one in Humboldt county have reduced coyote predation using electric fencing. Table 5 shows sufficient decline in lamb losses following addition of three offset electrified wires to an existing fence to pay for the fence in one year. Another sheep producer uses a Great Pyrennes guard dog to supplement the electric fences. The concentration of the sheep that occurs in a controlled grazing system prevents the dog and sheep from being separated and thus less effective.

Table 5. Sheep (no.) and financial ($) losses due to coyote predation before and after installation of electric fencing in 1985 (Pratt 1987).

	1984-85	1985-86	1986-87
Ewes*	50	0	0
Lambs**	200	40	0
Estimated Cost	($15,050)	($2,660)	($0)

*$35.00 each
**Avg. 95 lbs. @ $0.70/lb.

Conclusion

Controlled grazing facilitates the efficient use of land, labor and capital resulting in lower input costs and higher production per unit of input. It puts the **man** back in **man**agement, and improved management can reduce environmental conflicts associated with livestock grazing. However controlled grazing will not work everywhere. Some grazing lands will always be managed extensively. Of all the benefits associated with CGS a comment from one rancher stands out above all the others. When asked to describe some of the benefits in addition to increases in productivity he said, " **My son decided to continue ranching.**"

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LOW-INPUT STRATEGIES FOR INSECT PEST MANAGEMENT

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The concept of low-input or sustainable agriculture has recently gained substantial popularity. Among the primary considerations in this approach are economic, environmental, and sociological issues. In the area of insect pest control, the low-input philosophy generally suggests a "least is best" policy for use of pesticides. This approach is entriely consistent with the broad concept of integrated pest management (IPM), perhaps best defined as the evaluation and consolidation of all available techniques into a unified program to manage pest populations so that economic damage is avoided and adverse effects on the environment minimized (1).

In this paper I have chosen to describe various low-input IPM strategies for **grape** production systems. This choice was made not only to reflect the economic priority of this commodity (nearly a billion dollars annually in California), but also to complement information from another grape paper in this session.

Monitoring Population Levels

Modern pest management cannot operate without accurate estimates of pest and natural enemy population densities, or without reliable assessments of plant damage and its effect on yield (2). Intelligent decision-making in IPM thus generally necessitates some effort in determining the population levels of important arthropods by means of appropriate sampling techniques.

The following examples illustrate various methods for monitoring important grape pests which have been developed to optimally approach the elusive dual goals of speed and accuracy.

Spider mites (primarily Pacific spider mite Tetranychus pacificus and Willamette spider mite Eotetranychus willamettei) have been serious pests of Central Valley grapes for several decades (3). Due to small body size and the high mite density required to cause economic loss, conventional mite counting methods are relatively cumbersome and time-consuming. Thus, IPM decision-makers have tended to rely on a conservative approach to managing mites, with a greater number of sprays being applied on a prophylactic basis (4).

Presence-absence sampling does not require that mites are counted, but instead makes use of a biological relationship enabling mite density to be estimated by recording only whether each sampled leaf is infested with mites (4). Having determined the percentage of leaves infested, the IPM decision-maker has indirectly derived an estimate of mite density (supported by extensive background research to establish the mite density / infestation relationship), and can thus reliably make a treatment decision without having directly counted spider mites.

Presence-absence sampling was first introduced to California agriculture for sampling spider mites in cotton in 1983. Since then, research programs in almonds and citrus have resulted in development of presence-absence sampling plans for spider mites on these crops, as well as for two aphid species on Brussels sprouts (4). During 1988, the presence-absence sampling program in grapes was validated in five Central Valley vineyards (Bill Barnett, pers. commun.). Currently the program is quite labor-intensive, requiring careful examination of 45 leaves (three each from 15 different grapevines) regardless of mite density. In the future, the program may become sequentialized so that very low and very high spider mite densities can be reliably detected in a minimum number of samples.

The western grapeleaf skeletonizer (WGLS) Harrisina brillians is a serious defoliating pest of vineyards and backyard grapevines throughout much of central and southern California (3). After defoliating vines, larvae often feed on fruit clusters, leading to severe bunch rot problems. Also, larger larvae possess urticating (stinging) hairs which cause skin welts on field workers contacting them. The present monitoring method for WGLS adults is to count the number of moths observed flying between two stakes, 25 feet apart, between two vine rows in one minute (3). This "stake count" technique was compared to sticky traps baited with the synthetic analog of the female WGLS sex pheromone (sec-butyl-(z)-7-tetradecenoate) to determine WGLS daily flight activity and trap attractiveness (5).

A total of nearly 35,000 WGLS moths were recorded during field studies conducted at CSU Fresno in 1986 and 1987. Results clearly indicated that females normally emit sex pheromone from sunrise to around 1000 hr, the time when males are dramatically more likely than females to be flying (30:1), and when pheromone trap catches occur almost exclusively. After mid-morning, female WGLS are by far the prevalent fliers (seeking oviposition sites), and males are generally unattracted to pheromone traps. Thus, IPM decision-makers could combine both methods into an integrated approach: a) pheromone traps to detect initial presence of WGLS moths, and b) stake counts conducted at strategically chosen times of day to pinpoint specific areas of moth activity and to help gauge potential severity of WGLS larval infesatations (6).

Biological Control

First reported from the Central Valley in 1980, the variegated leafhopper (VLH) *Erythroneura variabilis* has developed into a serious pest of raisin, wine, and table grapes. VLH can reach tremendous densities late in the season, causing fruit spotting on table grapes, threatening long-term reduction in yields due to defoliation, and causing a nuisance to pickers at harvest (7). As of spring 1988, VLH had been found as far north in the Central Valley as Lodi, CA (8).

VLH is a more serious pest of grapes than the closely-related grape leafhopper (GLH) *E. elegantula*, at least partially due to differences in egg-laying behavior. VLH eggs, deeply buried within the leaf tissue, are less likely to be detected by the mymarid wasp parasitoid *Anagrus epos* than are GLH eggs, which stand out as blisters on the leaf surface (7).

Researchers Ted Wilson (UC Davis) and Dan Gonzalez (UC Riverside) have developed a classical biological control research program against VLH which has led to the discovery of several new parasitoids and biotypes of *Anagrus*. Among the most promising *Anagrus* biotypes are those from Coachella CA, Grand Junction CO, and Hermosillo MX, all of which achieve a higher seasonal level of parasitism on VLH than does the native biotype (8,9,10).

Another valuable approach to reducing VLH pest pressure is to grow French prune trees near the vineyard. The critical link is that Anagrus wasps need an alternate leafhopper egg host during the winter when VLH and GLH are quiescent adults, and eggs of the often abundant prune leafhopper appear to fill this essential role very well (11). However, interested growers should note that to be effective in this capacity, the prune trees must be grown in a block (approx. 1 A per 40 A vineyard) rather than in a single row. Also, standard cultural practices for the prune block must be followed to prevent outbreaks of such insect pests as mealy plum aphid and San Jose scale. High numbers of these pests can lead to drastically reduced numbers of the prune leafhopper alternate host, which is counterproductive to Anagrus enhancement (Don Flaherty, pers. commun.).

During the past several years, Vern Stern (UC Riverside) has demonstrated that larvae of the western grapeleaf skeletonizer (WGLS) are attacked by an extremely virulent granulosis virus (GV). This native virus occurs naturally in vineyards in Mexico, Arizona, and parts of California. Stern's program to rapidly increase the spread of WGLS GV has met with formidable roadblocks from the U.S. Environmental Protection Agency, which ironically views even this classical biological control agent as an "unregistered pesticide." Previous work clearly indicates that insect granulosis viruses are highly specific, affecting only a single host species or a few species within a genus (12).

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TRANSITIONS TOWARD A LOW-INPUT AGRICULTURE

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I am the owner-operator of a mid-sized family farm in Pleasant Grove, CA. We farm 1400 acres, of which 600 is owned, to rice, corn, popcorn, wheat, oats, vetch, and almonds. In 1985, we farmed 45 acres in an organic production system. Presently, about 60% of the 1400 is in organic production, the remainder of which is in varying degrees of what is refered to as low-input, or sustainable.

The driving forces behind our transition were many, but probably the greatest was the frustration associated with conventional farming practices. In continuous cropping, we saw increasing weed and other pest problems which required more purchased inputs. The increased expenditure required increased production to achieve the same return. More often than not, some extraneous factor such as weather appeared and production was not as high as hoped for.

Often, the high-priced inputs we had to purchase were not working to our satisfaction. My experience with rice herbicides and strip spraying in almonds is that we were quickly selecting for weeds which were not controlled by the herbicide. Another effective herbicide, if available, was usually more expensive and often did not perform well either.

Looking ahead, we saw developments which would make the conventional production of the commodities that we were growing less viable. One development was the pressure to reduce farm subsidies in light of the federal deficit. Another was the increasing environmental problems and regulations associated with agricultural chemicals. Lastly, the hungry world scenario, which has been touted by many for years, in which the U.S. farmer would export rice, wheat and corn, at high volume and high price, was not visible on the horizon.

Given these circumstances, our own profitability and survivability required the developement of a different production strategy. My definition of sustainable, regenerative, or low- input agriculture is a cropping system whereby an agricultural resouce, mainly soil, is not depleted, but actually improved through cropping, while maintaining adequate production levels.

Our strategies for a low-input, sustainable cropping system are:

1) Rotation with a legume. In our organic rice production system, rice is alternated with purple vetch. The vetch is sown in the fall after rice harvest, without burning of stubble. The standing rice stubble provides a

structure for the viny vetch to grow up on. The seed is harvested in the summer. Harvest losses usually provide enough volunteer seed for a full stand to incorporate the following spring for the rice crop. Under this system, I harvested 8100 lbs of dry rice per acre from 95 acres in 1987 and 7000 lbs per acre from 145 acres in 1988. There were no added fertilizers or chemicals used in this system.

2) Incorporation of all crop residues. In addition to all cover crops, rice, corn and wheat stubbles are incorporated to build soil organic matter and improve long term fertility.

3) Creation of an ecological balance: A general rule that I use is that the promotion of a diverse ecosystem will prevent any single damaging organism from becoming numerous enough to cause economically significant crop damage. We have 75 acres of almonds which I am interested in devising a low-input system of production. For the last few years, no herbicides have been used, and natural ground covers have been allowed to grow. In 1988, little or no twig borer shoot strikes were observed and there was insignificant crop damage, while no sprays were used. Apparently, we have provided an environment for a controlling predator.

If the above successes are so easily attainable, why does conventional agricultural thought have problems with sustainable agriculture and why has it not been promoted?

1) Sustainable agriculture often uses organic farming practices. Organic farming has long been thought to have been practiced only by people in their backyards and was thought not applicable to production agriculture.

2) High-input agriculture can be marketed and the entire agri-chemical industry was built around it. In contrast, an agriculture which relies mostly on its on-farm resources gives less opportunity for an outside industry.

3) Departmentalization and specialization of agricultural science promotes research which only relates to the particular discipline of the researcher. In addition, since multi-disciplinary and multi-variable research is more difficult, efficacy testing of a pesticide, for example, is more prevalent than analysis of predator/prey relationships.

4) There is a bias toward new technology. The assumption is that newer or more complicated technology is inherently more valuable regardless of questionable efficacy, economics, or appropriateness. There are solutions based on "old" technologies, such as cover cropping or crop rotation, that may be totally appropriate

and cost effective in many situations, but they lack the glamour of the latest technological breakthroughs, such as those associated with biotechnology.

5) There is a bias toward solutions which involve more control or power over natural systems. It is satisfying for us to feel smart and adept at manipulating our environment to meet our needs. Related to this concept is that the production of food requires action, not inaction and that nature is adversarial.

The majority of agricultural research has been directed toward increasing yields, with little analysis of either the direct cost of the required inputs or the indirect costs, such as environmental problems. Unless there is an ever expanding market for this increased abundance, the net result has been a lower price for farmers and a higher cost of production which has offset any gains made in yield.

Agricultural research in this single-minded vacuum where increasing yields are emphasized, neglects a whole range of effects, from disruption of established producers or producing areas, to structural changes in the entire industry.

A viable, sustainable agricultural system requires that we work in concert with the natural system. The total biological environment is the product of millions of years of evolution. It is a system composed of interactions between plants, soil, competing plants, pests and predators. There are mechanisms within this system that make land more fertile and abundant. Production systems which are very different from the natural system will require the most energy to maintain. Regardless of whether we use the most benign biotechnical breakthrough or a chemical pesticide, the less the production system mimics the natural system, the more energy or costs will be required to maintain the system. Often, an input which is very disrupting, will have other effects which will require additional inputs. For example, worm sprays in almond production will often reduce predator mite populations, such that a miticide is needed. A recent study found that certain herbicides stimulate nematode development. How many other similar situations are occurring, but are unknown?

Biotechnology is believed to be the next wave in agricultural progress, the solution to a polluting, chemical agriculture. Surely, there will be some useful tools devised that will be more environmentally sensitive, but what will be the cost? Given the expense of development and the nature of industry, I expect these tools to priced at what the market will bear, which will be equal to or greater than the cost of the replaced chemical inputs. As a solution, biotechnology still neglects the problem of grower reliance on off-farm resources and purchased inputs.

Sustainable, low-input agricultural systems that are productive, resource conserving, environmentally benign, and profitable, can and will be devised. However, the needed changes in the agricultural industry require relevant information and techniques. The scientific community must overcomes its biases and other impediments, so that wholistic, systems-oriented research appropriate to our time can be undertaken.

REGULATION OF PESTICIDES TO PREVENT GROUND WATER CONTAMINATION IN CALIFORNIA

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Competitive production of food and fiber requires the efficient growing, harvesting, handling or processing, storing, shipping and marketing of agricultural crops. One of the key elements in this process is the protection of the crop, both before and after harvest, from damage by pests, such as insects, mites, fungal and bacterial diseases, and vertebrate pests. Along with appropriate use of plant varieties, cultural practices, and post harvest handling techniques, successful crop protection often involves the use of pesticides.

In California, the Department of Food and Agriculture (CDFA) is responsible for regulating the registration, sale, handling, and use of pesticides under provisions of Division 6 (Pest Control Operations) and Chapters 1 - 3.5 of Division 7 (Agricultural Chemicals) of the Food and Agricultural Code (FAC). The purpose of this part of the FAC is given in Section 11501 as follows: (1) provide for the proper, safe and efficient use of pesticides for production of food and fiber and for protection of the public health and safety; (2) protect the environment from environmentally harmful pesticides by prohibiting, regulating, or controlling uses of such pesticides; (3) assure the agricultural and pest control workers of safe working conditions where pesticides are present; (4) permit agricultural control by competent and responsible licensees and permittees under strict control of the director and commissioners; (5) assure the users that economic poisons are properly labeled and are appropriate for the use designated by the label; and (6) to encourage the development and implementation of pest management systems, stressing application of biological and cultural pest control techniques with selective pesticides when necessary to achieve acceptable levels of control with the least possible harm to nontarget organisms and the environment. Thus, the CDFA is charged with registering pesticides for use in California, and protecting agricultural and pest control workers, public health and safety, and the environment from the potential adverse effects of such use.

Traditionally, environmental protection efforts have been focused on monitoring residues in surface water, air, soil, and in fish and wildlife. It was generally assumed that pesticide movement to ground water would be prevented by such factors as dilution, low water solubility, high vapor pressure, binding to soil particles and rapid degradation in soil relative to downward movement. Although these factors and others appear to prevent movement of most pesticides to ground water, the detection of DBCP residues in California ground water in 1979, and of other pesticides since then, show that under certain conditions pesticides can leach to ground water.

In response to reports of pesticide residues in ground water, the Legislature passed the Pesticide Contamination Prevention Act (PCPA) which was signed into law in 1985. Although a complex law, the PCPA has three basic objectives: (1) identify and begin monitoring soil and ground water for pesticides identified as "suspected leachers"; (2) evaluate and mitigate the effects of those pesticides found in ground water and soil under certain conditions (known leachers); (3) establish a statewide database that includes the location of wells sampled for pesticides, a list of the pesticides sampled for, and a list of the pesticides found in well water.

Suspected leachers are pesticide active ingredients that have not been detected in ground water due to legal agricultural use but that have environmental fate characteristics similar to active ingredients that have been detected due to such use. Suspected leachers are identified by comparing certain environmental fate data, required to be submitted by registrants, to specific numerical values (SNVs) for this data that the CDFA sets to distinguish leaching pesticides from non-leaching pesticides. Suspected leachers are those pesticides with characteristics that exceed these SNVs and which are applied to the soil or the application of which is followed by irrigation as specified in the law. Suspected leachers are identified to focus CDFA monitoring efforts on those pesticides most likely to move to ground water.

Known leachers are pesticides that have been found in ground water or soil under certain conditions due to the agricultural use of the pesticide. Once a pesticide is detected in ground water, the detection is first verified by taking a second discrete sample from the well within 30 days, and by confirming the residue either by a second analytical method or second laboratory. This procedure reduces the risk of false positives due to contamination during sample collection, preparation or analysis, or due to chemist error or analytical interference by the presence of other compounds. Next, the Department determines whether or not the contamination resulted from legal agricultural use. If a point source, illegal use, or non-agricultural use of a pesticide is a likely source of the residue, then the detection is not due to agricultural use and would not be reviewed under provisions of the PCPA. Such detections would be referred to other CDFA branches or the State Water Resources Control Board for evaluation. If the residue is determined to result from agricultural use, the Director may either: (1) immediately suspend use of the pesticide if the residues are detected at levels that pose a serious health threat, or (2) in the absence of a serious health threat, notify all registrants of such pesticides who may then request a hearing before an interagency subcommittee to present a report regarding the detection as specified in the PCPA. The subcommittee may make one of three specified recommendations to the Director regarding continued use.

The Director then evaluates this subcommittee recommendation, issues a final decision and adopts regulations to implement that decision. As of December, 1988, six pesticides have been detected in California ground water and determined to be due to legal agricultural use: atrazine, simazine, bromacil, diuron, prometon, and aldicarb. These pesticides will thus be designated as "known leachers." For the first five of these pesticides, the Director has made finding 2, as specified in the PCPA, that "the agricultural use of the economic poison can be modified so that there is a high probability that the economic poison would not pollute the groundwaters of the state." A hearing has been scheduled to review the aldicarb detection in April, 1989.

To modify use of known leachers, the Director has proposed regulations that would: (1) establish Pesticide Management Zones (PMZs) which are one square mile sections of land, corresponding to the township, range, and sections established in the Public Land Survey, which have been demonstrated to be sensitive to leaching of pesticides through soil from legal agricultural use; (2) declare known leachers registered for agricultural and certain other uses as restricted use materials, but require permits for such uses, when allowed by the Director's final decision, only in PMZs; (3) require that no permit for use of a known leacher in a PMZ shall be issued unless the applicant for a permit submits a written recommendation of a licensed pest control adviser who has completed the ground water protection training program approved by CDFA; (4) require all dealers of known leachers designated as restricted materials to obtain a signed statement from purchasers regarding whether or not the material will be used in a PMZ.

In addition, regulations have been proposed to require reporting of use and sales of both known leachers and suspected leachers that are registered for agricultural and certain other uses.

These regulations establish the basic structure for regulating pesticides to prevent ground water contamination. As each known leacher is evaluated, pesticide-specific use requirements will also be established in regulation. For example, the first set of regulations, expected to be adopted in early 1989, implement the Director's decision to prohibit agricultural and certain other uses of atrazine in PMZs where atrazine has been found in ground water. Future regulations will implement the Director's decision to prohibit rights-of-way uses of simazine in PMZs, prohibit non-crop uses of diuron and bromacil in PMZs, and to prohibit agricultural and certain other uses of prometon in PMZs.

The first ground water protection training programs for pest control advisers who wish to recommend the use of known leachers in PMZs will be given in Butte, Tulare, and Orange Counties in February, 1989.

<u>The statewide database</u> of wells tested for pesticide residues is summarized in the annual report <u>Sampling for Pesticide Residues in California Well Water</u> issued in December. This report is a compilation of the results of various studies and monitoring activities that were reported to the CDFA by federal, state, and local agencies. Because of the nature of the data submitted, it is inappropriate to use the data to draw general conclusions about the overall

impact of pesticide use on California ground water. Nevertheless, this data can be used to display the geographic distribution of well sampling and of pesticide contamination in wells sampled, identify areas potentially sensitive to pesticide leaching, and design studies for future sampling.

The PCPA focuses on identifying and monitoring for suspected leachers and preventing further ground water contamination by the agricultural use of known leachers. However, it does not address factors affecting pesticide leaching, how such factors can be used to establish use practices that prevent contamination, and the potential significance of wellheads as a source of contamination. This information is being developed as part of CDFA's larger Ground Water Protection Program which includes all the activities the Department conducts to: (1) implement the PCPA; (2) identify factors affecting pesticide movement to ground water; (3) establish use practices to prevent contamination of ground water; (4) develop a wellhead protection program and (5) incorporate ground water protection information into continuing education programs for pest control advisers and users.

Thus, the regulation of pesticides to prevent ground water contamination in California is a cooperative effort that includes legislation that expresses the public interest and is the basis for appropriate funding, regulations that implement the legislation, monitoring that characterizes progress, research that increases understanding, and education that translates ground water protection information to pesticide users.

PREDICTION OF THE MOVEMENT OF PESTICIDES FROM SOIL TO GROUND WATER

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Introduction

Because of comprehensive ground water monitoring programs throughout the United States, increased attention has been focused on the potential of pesticides to leach below agricultural fields into public water supplies lying below the soil surface. Several states such as California have enacted legislation to identify compounds with enhanced potential to leach to groundwater, using chemical fate properties submitted by registrants at the time of application. There is promise that other states and perhaps even the federal government will develop similar procedures.

Because of the absence of comprehensive data sets describing the movement of chemicals from the soil surface to ground water, it is expected that some type of model will be employed, at least in an advisory capacity, in deciding which chemicals pose a potential ground water pollution risk. This talk will discuss the role that models might play in this context.

Simulation Models versus Screening Models

There are two distinct types of models which may be used in the evaluation process for determining the movement of chemicals from soil to ground water. The first type, the simulation model, is a quantitative mathematical representation of the transport and transformation process using differential transport and reaction process descriptions to predict the concentration of chemicals as a function of space and time between the surface and ground water. Simulation models are hampered in two respects from performing this role. There is substantial data uncertainty associated with the calibration of such models, since they require detailed knowledge of the soil, transport and reaction coefficients for both water and chemicals. At the field scale, such coefficients will differ substantially over space and time and cannot be provided for a given location without a prohibitive amount of prior experimentation. Model coefficients for such coefficients are limited in that they do not generally apply to a specific location. In addition, there is substantial process uncertainty associated with the representation of specific reactions and characteristics of the transport of chemicals, including: rate limited exchange of solute between solution and stationary adsorption sites, dispersion of solute about its center of mass location, and biological or chemical breakdown of the compound. As a result of these uncertainties, knowledgeable researchers have realized that simulation models are unsuited for the two primary objectives that they would be expected to fulfill in estimating the chemical movement and reaction process. They cannot predict maximum concentrations that arrive in ground water and they cannot predict the earliest arrival times.

For this reason, screening models have emerged as an alternative philosophy for estimating groundwater contamination. Contrary to the primary role of a simulation model, a screening model operates not on site-specific conditions but on standard scenarios representing a range of soil and environmental properties. Their primary purpose is to evaluate the relative performance of large numbers of chemicals for the specific purpose of identifying those compounds which have an extreme potential for movement relative to others. They play a second fundamental role in that they can be used to evaluate new compounds and place them into behavior groups that are similar to compounds for which a substantial amount of experimental information is known. In respect to the regulation of chemicals, screening models could play an important role in sorting compounds initially and identifying those compounds for which further experimentation or detailed characterization should be undertaken.

Illustration of Screening Model

To illustrate the role of screening models, this talk will describe existing and new screening models in the context of their role in identifying relative ground water pollution potential risk. The screening models employed in this context will cover three different types of situation: the first, in which compounds experience neither climatic nor soil variability and are screened entirely on the basis of their relative mobility and reactivity as they move downward from the soil surface to ground water. The second and third types of screening models will operate under scenarios in which climatic and soil variability are represented stochastically to illustrate ranges of uncertainty in performance of models under variable soil and environmental conditions. The models will evaluate pollution potential under these scenarios and the role of uncertainty will be addressed specifically.

PATHOGENS IN GROUND WATER FOLLOWING LAND APPLICATION OF MUNICIPAL SLUDGE

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Introduction

Almost 7 million metric tons (dry weight) of municipal sludge was produced in the U.S. in 1982; this amount is expected to nearly double to 12 million metric tons (dry weight) by the year 2000 (U.S.EPA, 1986). It has been estimated that 42% of the total is applied to land or distributed and marketed. By the year 2000, it is expected that 5 million metric tons (dry weight) will be applied to land on an annual basis.

When applying municipal sludge to land for use as a fertilizer, consideration must also be given to the potential for adverse environmental or animal and human health effects. In addition to nitrogen, sludge also contains heavy metals and pathogenic microorganisms. The focus of this paper will be on the potential for adverse effects from microorganisms present in municipal sludge.

Characteristics of microorganisms

Bacteria are microscopic organisms, ranging from approximately 0.2 to 10 um in length. They are distributed ubiquitously in nature and have a wide variety of nutritional requirements. Many types of harmless bacteria colonize the human intestinal tract and are routinely shed in the feces. One group of intestinal bacteria, the coliform bacteria, has historically been used as an indication that an environment has been contaminated by human sewage. In addition, pathogenic (disease-causing) bacteria, such as *Salmonella* and *Shigella*, are present in the feces of infected individuals. Thus, a wide variety of bacteria is present in domestic sewage.

Viruses are obligate intracellular parasites, that is, they cannot replicate (increase in number) outside of a host organism. They are very small, ranging in size from approximately 20 to 200 nm. Viruses that replicate in the intestinal tract of man are referred to as enteric viruses. These viruses are shed in the fecal material of individuals who are infected either purposely (i.e., by vaccination) or inadvertently by consumption of contaminated food or water, swimming in contaminated water, or person-to-person contact with an infected individual. Unlike bacteria, viruses are not normally present in the feces of humans. More than 100 different types of enteric viruses may be excreted in human feces; the concentration of viruses may be as high as 10^{10} per gram of feces. Thus, viruses are also present in domestic sewage.

A third group of microorganisms of concern in domestic sewage is the parasites. In general, parasite cysts (the resting stage of the organism which is found in sewage) are larger than bacteria, although they can range in size from 2 um to over 60 um. Parasites are present in the feces of infected persons; however, they may also be excreted by healthy carriers. Cysts are similar to viruses in that they do not reproduce in the environment, but are capable of surviving in the soil for months or even years, depending on environmental conditions.

Waterborne disease

Ground water supplies over 100 million Americans with their drinking water; in rural areas, there is an even greater reliance on ground water as it comprises up to 95% of the water used (Bitton and Gerba, 1984). It has been assumed traditionally that ground water is safe for consumption without treatment because the soil acts as a filter to remove contaminants. As a result, private wells generally do not receive treatment (DiNovo and Jaffe, 1984), nor do a large number of public water supply systems (U.S.P.H.S., 1965). However, the use of contaminated, untreated or inadequately treated ground water has been the major cause of waterborne disease outbreaks in this country since 1920 (Craun, 1986a,b).

When considering outbreaks that have occurred due to the consumption of contaminated, untreated or inadequately treated ground water, from 1971 to 1982, the most commonly identified causative agents were Shigellae and hepatitis A virus (Table 1)(Craun, 1985). In almost two-thirds of the outbreaks, no causative agent could be identified, and the illness was listed simply as gastroenteritis of unknown etiology. However, more recent results suggest that the majority of these outbreaks were caused by enteric viruses and parasites such as Giardia.

Table 1. Causative Agents of Waterborne Disease in Untreated or Inadequately Treated Ground Water Systems, 1971-1982.

Disease	No. outbreaks	% of total
Gastroenteritis, unknown cause	132	64.7
Bacterial diseases	30	14.8
Viral diseases	23	11.2
Chemical poisoning	12	5.9
Parasitic diseases	7	3.4
TOTALS	204	100

Sources of Microorganisms

Microorganisms may be introduced into the subsurface environment in a variety of ways. Goyal et al. (1984) isolated viruses from the ground water beneath cropland being irrigated with sewage effluent. Viruses have been detected in the ground water at several sites practicing land treatment of wastewater; these cases were reviewed by Keswick and Gerba (1980). The burial of disposable diapers in sanitary landfills is a means by which pathogenic microorganisms in untreated human waste may be introduced into the subsurface. Vaughn et al. (1978) detected viruses as far as 408 m downgradient of a landfill site in New York. Land application of treated sewage effluent for the purpose of ground-water recharge has also resulted in the introduction of viruses to the underlying ground water (Vaughn and Landry; 1977, 1978). Septic tanks are a major source of pathogens to the subsurface, as they dispose of over one trillion gallons of waste to the subsurface every year (OTA, 1984). The role of septic tanks in causing waterborne disease has been reviewed recently (Yates, 1985).

Municipal sludge and ground-water contamination

There are several factors which will determine the potential for ground-water contamination by microorganisms at a sludge application site. The first of these is the concentrations and types of microorganisms present in the sludge. As stated previously, domestic sewage may contain many types of disease causing microorganisms. Treatment of the sewage removes some of these organisms, but many microorganisms are resistant to various sewage treatment processes, and the extent of removal will depend on the type of treatment and the particular microorganism. Table 2 presents concentrations of microorganisms which have been found in digested sludge.

Table 2. Concentrations of Microorganisms in Digested Sludges
(Adapted from U.S.EPA, 1988)

Organism	Type of Stabilization: Anaerobic (No. per g dry weight)	Aerobic
Enteroviruses	0.2-210	0-260
Rotaviruses	14-485	ND*
Salmonella	$3-10^3$	3
Total coliforms	10^2-10^6	10^5-10^6
Fecal coliforms	10^2-10^6	10^5-10^6
Shigella sp.	20	ND
Yersinia enterocolitica	10^5	ND
Ascaris	4**	
Trichuris	1.3**	
Toxocara	0.4**	

* ND = no data
** Average of all types of digested sludge, percent viable

The potential for ground-water contamination is also affected by the method of sludge application. If the sludge is applied to the surface, the probability that some of the microorganisms will be inactivated is greater than if it is ploughed into the soil, due to exposure to the sun, high temperatures, etc.

Other factors that influence microorganism movement in the soil are the type of microorganism, the soil type, and environmental conditions. For example, most microorganisms will persist for longer periods of time in cooler temperatures than warm ones. The rate and amount of water applied to the soil surface will also affect the extent of microbial movement: the more water applied, and the greater the rate of application, the more extensive the movement. Soils with a coarser texture generally will permit more movement of microorganisms. The clay content of the soil is important in that many microorganisms adsorb onto these charged particles, and thus are restricted in their movement.

Several studies conducted in the late 1970's suggested that viruses are tightly bound to sewage solids and are not easily released into the soil (U.S.EPA, 1988). A review of these studies showed that they were conducted under conditions where virus movement would be expected to be limited. In a more recent study, viruses were detected in a 3-m-deep well at a site where anaerobically digested sludge was applied to a sandy soil 11 weeks after sludge application.

Conclusions

Land application of municipal sludge is becoming a more common practice as alternatives are sought for the disposal of the ever-increasing amounts of sludge produced in this country. There are potential environmental and human health hazards associated with this activity due to the presence of microorganisms and other contaminants in the sludge. These hazards can be minimized by using stabilized sludge, choosing a site which is not conducive to extensive movement of microorganisms, and managing the site in such a way that the soil's capacity to handle the microbial load is not overcome.

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MUNICIPAL AND INDUSTRIAL GROUNDWATER PROBLEMS

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A recent report (Anon., 1986) states that approximately 40% of the State's population uses groundwater as the source of its domestic supply, and 93% of the small water systems uses groundwater to supply approximately 5% of the State's population. Groundwater is critical to the economic vitality of California. However, today we find that the San Joaquin Valley's groundwater has been subjected to the introduction of a number of contaminants with the chief among these being pesticides (with DBCP being the principal pesticide contaminant), nitrates, and salts. A possible major problem which has not yet been fully evaluated is the presence of naturally occurring radium and uranium in groundwater.

Nitrates

Nitrate is the stable chemical species resulting from the nitrification of more complex organic-nitrogen and ammonia forms, and the forms are normally converted to the nitrate ion when they are introduced into natural water and wastewater. Common sources for organic-nitrogen and ammonia forms are septic tanks, domestic and industrial wastewater, fertilizers and pesticides, dumps and landfills, dairies and animal feed lots, and decomposing plant and animal tissue (Hurlburt, 1988). In the agricultural setting, high concentrations of nitrates in the groundwater are normally associated with animal waste materials and fertilizer application (Canter, et. al, 1987). From a study conducted in Nebraska by Spalding and Kitchen (1988), results from vadose zone sampling beneath nitrogen fertilized and irrigated farmland was obtained which showed that application rates of 200 pounds of nitrogen per acre-year caused nitrate to accumulate in vadose zone pore water in high enough concentrations to potentially contaminate the underlying groundwater.

Schmidt (1972) evaluated the occurrence of nitrate in groundwater in the Fresno-Clovis area. He found an inverse relationship between aquifer transmissibility and nitrate concentration. At the extreme conditions, the inverse relationship was apparently due to the retardation of the percolation of high nitrate waters provided by soils having a high clay content, and the aerobic conditions which prevail in areas having extensive cobble zones in the subsurface. In certain areas without known sources of nitrate (e.g., Fresno downtown area), a high nitrate concentration in the groundwater was attributed to the migration of nitrate-bearing waters from areas with known sources of nitrate. Because of the large number of factors which affect the nitrate concentration in a groundwater, no clear-cut and universal cause and effect relationships were discernible from the results presented.

Salts

The problem of salt accumulation in irrigated soils, particularly in arid areas, continues to exist in many regions of the world including the San Joaquin Valley. When the source of water is irrigation water which normally has an appreciable total dissolved solids concentration, very large amounts of salt may be deposited into the root zone where it remains until it is flushed downward by the application of more irrigation water than is required to simply satisfy storage, evaporation and plant moisture requirements.

An alternative to the movement of salt downward to the groundwater is the installation of shallow collector drains (8 to 10 feet deep) to intercept salt laden percolating water and to conduct it to another site for final disposal. If irrigated agriculture is continue in the San Joaquin Valley together with the use of measures which protect the groundwater from increasing dissolved solids, particularly on the west side of the Valley, the construction of drains must continue together with the development of safe and economic measures for the final disposal of the drain waters.

Radionuclides

The U.S. Environmental Protection Agency is now in the process of reviewing and establishing standards for the radioactivity from naturally occurring radionuclides in drinking water supplies including radium-226, radium-228, natural uranium (U-231 + U-235 + U-238), radon-22, and gross alpha particle, gross beta, and photon activities. Interim regulations are expected to be announced mid-1989.

Data from the U.S. Environmental Protection Agency's National Inorganics and Radionuclides Survey was reported by Longtin (1988). One thousand random samples were collected from community water supplies throughout the United States, and a summary for selected radionuclides shows widespread occurrence of radium-226, radium-228, and uranium in drinking water.

Radon gas, a radioactive, odorless, colorless, noble, and chemical inert gas, is dissolved in groundwater. It enters homes and other buildings with the water, and when the water is used the radon is degassed and enters the room air. Therefore, the route of entry to the human body is either by ingestion or by inhalation of the radium

(Hall et al., 1987). Radon is removed relatively easy from water by air stripping, and it is also readily adsorbed to granular activated carbon (Dixon and Lee, 1987).

Pesticides and Other Organic Contaminants

A study conducted during the summer of 1982 and reported by the California Department of Food and Agriculture (1983), stated that large quantities of pesticides, carbofuran, DBCP, EDB, and simazine had been used in four major agricultural areas corresponding to four ground water basins: the Upper Santa Ana, Santa Maria, Salinas, and San Joaquin. Certain of the pesticides were found in the underlying aquifers.

Reacting to evidence of possible widespread organic pollution of California's groundwater, the California legislature responded in 1983 with a bill, Assembly Bill 1803, which required the implementation of a program for detecting and monitoring organic chemical contaminants in public drinking water supplies. The data collected (Anon., 1986) as a result of this program are from larger utilities which are defined as those serving over 200 connections. Twenty-four of California's 64 counties had one or more wells contaminated with one or more of the organics reported as part of the study. A total of 2,944 wells were sampled with one or more organic contaminants found in 538 (18.3%) of the wells. The 538 wells were distributed among 184 of the 807 water systems in the study, and the sample results from 165 of the wells exceeded an action level. The four most commonly detected organics were perchloroethylene, trichloroethylene, DBCP, and chloroform. These data show that only 13 of California's 64 counties had more than 10% of their wells contaminated with the most contaminated wells being in Fresno County which had 99 of 231 test wells (42.9%) being found positive, and Los Angeles County which had 221 of 536 (41.2%) of the tested wells being found positive.

The contamination of groundwater in the San Joaquin Valley by trichloroethylene and other solvents, while not as prevalent as in Silicon Valley and parts of southern California, has generally been associated with electronics manufacturing, metal cleaning activities, solvent recovery operations, and landfills. Groundwater contamination by phenols is primarily incidental to the petroleum industry though pentachlorophenol contamination of the groundwater has resulted from the chemical treatment of wood poles by an electric utility.

Groundwater Quality Management

Groundwater quality management is inextricably intertwined with the overall management of groundwater. Decisions which regulate groundwater recharge and withdrawal, and land use over the aquifer, also have considerable impact upon the resulting quality of the groundwater. Consequently, all decisions regarding groundwater should also include an evaluation of possible impacts to groundwater quality and the resulting consequences.

Thus, a requirement for effective groundwater management is an institutional setting which, at a minimum, permits the efficient management of groundwater basins as complete entities by individual groundwater management units. The management unit must have the authority to collect fees or revenues, and it must have the requisite policing powers to enforce water management policy.

A functional requirement for effective groundwater management is a well-designed monitoring network for the collection of the data needed to describe the groundwater setting. These data can be optimally managed and applied to information transfer and decision making functions by utilizing geographical information system technology and current statistical software designed for data base management.

Conclusion

While the chemical contamination of the San Joaquin Valley's waters which has resulted due to industrial activities is a serious matter, the problem is not widespread. Effective groundwater management within the San Joaquin Valley can prevent significant further deterioration of the groundwater quality; however, effective groundwater management is lacking today in the San Joaquin Valley.

Effective groundwater management requires an institutional setting which is conducive to the management of a total water basin as one entity; an efficient water management organization which has the requisite authority for raising funds and carrying out policing actions; and, a comprehensive and fully integrated environmental data collection and management system.

Further deterioration of the groundwater due to the application of fertilizers and pesticides can be minimized by the adoption of improved agricultural practices. However, a full-scale program of draining irrigated lands must be instituted and a satisfactory solution found for the disposal of the drain water.

Radionuclides in groundwater will become a greater issue in the future with the promulgation of federal regulations scheduled for mid-1989.

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Sampling the Vadose

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All segments of California's rural and urban economy, including agriculture, industry and individuals that use chemicals for any purpose, are subject to strict enforcement of legislation and regulations pertaining to the use and disposal of toxic compounds. The Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) makes, the already strict California regulations, even more restrictive in the disposal and use of potentially toxic compounds to prevent them from entering the ground water of the state. The implementation of this Act requires "best management" practices be used by all users and dischargers of toxic materials in the state. Included in this implementation are vadose zone monitoring requirements supplementing those already existing as mandated by the Resources Conservation and Recovery Act (RCRA).

The intention of the monitoring is to detect potential toxic's before they reach the ground water. Sampling of percolating solutions in the unsaturated zone (vadose) below the biologically active (root or soil) zone, then, becomes of critical importance in the implementation of this legislation. The design, operation and maintenance of these monitoring systems requires a working knowledge of the physics of unsaturated water flow and the limitations of the sampling techniques that are available.

WATER IN SOIL

Every one involved in the monitoring of toxic's in the unsaturated zones (soil or the vadose) should view the classic film produced by Dr. Walter H. Gardner of Washington State University[1], may be even more than once. The free energy of surface applied water is rapidly dissipated in the soil. Except in the coarsest sands, most water movement ion the soil is by unsaturated flow. This means that the largest pores are not filled with water, table 1, and the flow is mainly a result of surface attraction of the water to soil particles. The water and its dissolved solutes moves mainly in response to capillary forces and only slightly in response to gravity in most soils, figure 1[2]. Water flow is from wetter to drier soils, that is from soils that have larger pores filled to soil with smaller pores filled with water. As in saturated flow, the rate of movement is proportional to the square of the diameter of the pore that is conducting the water. When any soil layer with a different pore size distribution is encountered there is an interruption in the flow.

Obviously, when a layer of finer textured material is encountered rates of movement are slowed, and, if flow from above continues, saturation of the soil above the fine layer will occur, figure 2. This is the usual case that results in saturation zones above the local ground water elevation in many locations, "perched" water tables, flowing springs, etc. What is not as obvious is that when water flowing in a soil layer with relatively fine pores encounters a layer with only large pores, saturation must also occur before the coarser textured layer can be wetted, figure 3. Gravel is placed in the bottom of the nursery container not to provide drainage, but to keep the planting mix from leaking out of the holes.

Sub soils and the vadose underlying soils that are supporting plant growth always contain some water. These zones are usually near "field capacity", the water content of a soil when drainage has "virtually" stopped, table 1. Water in soil materials that are this wet is held with sufficient force that 10 to 30 kPa, 1/3 atmosphere or bar, of pressure is required to remove the water. This results in pores on the order of 10 to 50 microns and larger containing air and not water. Where active plant roots are present water can be extracted, rapidly enough too support crop plants, from pores approaching 1 micron. Soils that fold water only in these finer pores are said to be at their "permanent wilting point", a water content that is most usually evaluated by equilibrating a soil sample with 1500 kPa, 15 atmospheres or bars, of air pressure while providing drainage of the soil solution.

When water moves from a finer textured soil layer into a damp coarser layer, movement is frequently by "spatially disturbed flow"* or fingering, figure 4*. Fingered flow produces spatially distinct and separate flow streams in the underlying layer and lateral flows near the bottom of the top, finer textured, layer.

When water flows become insignificant, relative to rates of reactions, the soil solution moves towards an equilibrium with the solid phase. Cation and anion exchange, chemical precipitation, physical adsorption and biologic alterations all change the nature and concentration of the solute carried into that soil volume. Water entering an already moistened soil replaces the soil solution that existed. Plugged flow of the soil solution occurs from that soil volume to a lower one with the reaction semi-equilibrium state occurring at each level. The net result is that percolating solutions represent the soil volume just vacated, not the conditions at the point of water input into the soil.

SAMPLING TECHNIQUES

The monitoring of unsaturated flows is difficult. Water held in fine pores will not move into larger pores until the layer becomes saturated. Changes in water volume in an unsaturated medium can be monitored through the use of the neutron probe, but under conditions frequently encountered in the field, below the active root zone these volume changes are small. In addition the volume of soil analyzed is relatively small and variable and the pore size distribution, immediately around the access tube, has been altered by the installation. The neutron probe measures only water content and provides no information of potential solutes in that water or rates of flow.

Suction lysimeters, first described by Briggs and McCall[5] in 1904, are frequently used to sample unsaturated water. These may be cup shaped, often the same material and size as a tensiometer, or flat porous plates. These porous samplers are then placed under suction, vacuum is applied, to draw water from the unsaturated soil into the device. The collected sample is removed by applying pressure and providing a flow path to the surface, figure 5, Harris and Hansen[6].

Hansen and Harris[7] state that "earlier laboratory tests showed that many variables interacted to affect the observed sampling characteristics of the porous cups." Some of the inherent limitations of the suction lysimeter are: The pollutant may interact with the porous material, ie. phosphorus adsorption on the older ceramics. The solution sampled tends to over represent the solution in the larger pores that are water filled, non-reactive ions like nitrate and chloride can appear to be at higher concentration than that of the bulk soil solution. Any moiety with a high vapor pressure may be reduced in concentration, unless precautions for trapping are taken, ie. TCE[8]. Some water is lost as vapor in the sampling, usually indicating a higher concentration of solute and the amount of that loss can not be assessed. The vacuum differential and technique (constant vs falling vacuum) and the texture and moisture status of the soil material sampled all affect the volume of soil from which the sample is extracted and therefore the precision and accuracy of the solute concentration determined.

Usual installation techniques also add to the uncertainty of results, the act of auguring a hole and insertion of the sampler alters the flow pattern in the immediate neighborhood of the sampling cup or plate (unless the later is installed as a lysimeter from below). This is true even with careful backfilling of the augured hole after installation.

Using lateral insertion of sampling cups, from the side of a dug pit, Hansen and Harris[7] could not predict soil solution nitrate concentrations within 30 percent of the collected mean. In an attempt to model water extraction by ceramic cup, van der Ploeg and Beese[10] found that "no useful relation between extracted amount of soil water and freely percolating water could be detected. And this is the most frequently used and possibly the "best available" technology in use for monitoring the movement of toxic's in the soil and vadose!

To minimize sampler data variability Hansen and Harris suggest, as interim guides, that;

"1. Select samplers with similar intake rates.
2. Use short sampling periods.
3. Use uniform sampler length.
4. Use the same initial vacuum for all samplers.
5. Do not composite samples as this may obscure biases related to sampling technique and further distort the results.
6. Check sampler bias for soils, ions, and ionic concentration that will be sampled.
7. Follow procedures that minimize nitrogen transformations, when N compounds are being measured in the soil water."

Another classic technique for monitoring is the physical sampling of the soil. With the likelihood of "fingered" flow patterns in any layered soils the number of samples required to obtain reasonable precision - to say nothing of accuracy is expensive. Since most soils are layered either as deposited, the alluvial or wind modified sediments in California's valleys, or by the development of pedogenic horizons, fingered flows are probably the usual case rather than the exception. Even careful coring and sampling can result in unusual contaminant profiles, figure 6[11].

Zero tension lysimeters have been used in the study of soil formation, nutrient flux in agricultural and natural vegetation, salt balance in irrigated soils and for evapo-transpiration studies. The "normal" zero tension lysimeter is constructed by carefully digging a pit, placing a liner and/or a weighing device (for a weighing lysimeter), and back filling with the excavated soil. The soil should be replaced at the same depth that it was excavated and re-compacted to the original bulk density. This assures that total porosity will be as close to the original soil as possible, if not reestablishing the pore size distribution or water flow characteristics of the natural soil.

Another type of zero tension lysimeter has been a trough or funnel shaped pan installed from a lateral shaft or tunnel into the base of an overlying undisturbed soil[12], figure 7. These have suffered from the randomness of the fingered flows of sub-soil water. Radulovich and Sollins[13] reported that the "failure" rate, those that captured less than 50 ml per collection period, decreased with increasing size of the lysimeter. Their largest units, 2500 cm^2, had a total failure to collect rate of only 3.3% and nearly 80% of the time collected > 500 ml of percolating solution. A major limitation of this technique is the digging of the initial pit from which the shaft is extended and maintenance of the supporting shaft after installation. There is also the potential of evaporation of soil water into the shaft and pit which are often left open for sampling after installation.

Currently an nearly linear zero tension lysimeter that can be inserted below an undisturbed soil is under development at California State University, Fresno with financial support from the Claude C. Laval, Jr. Award for Innovative Technology Development.

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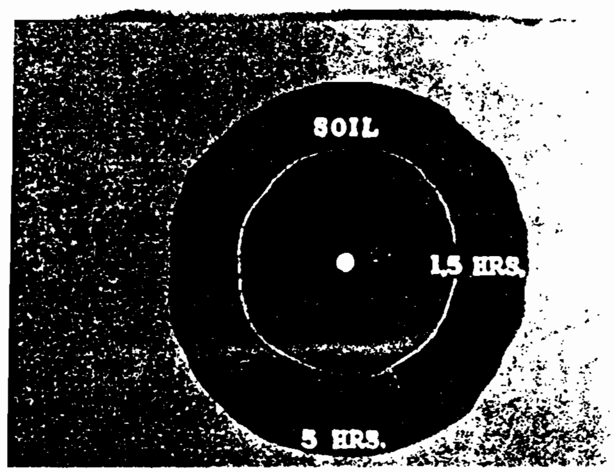
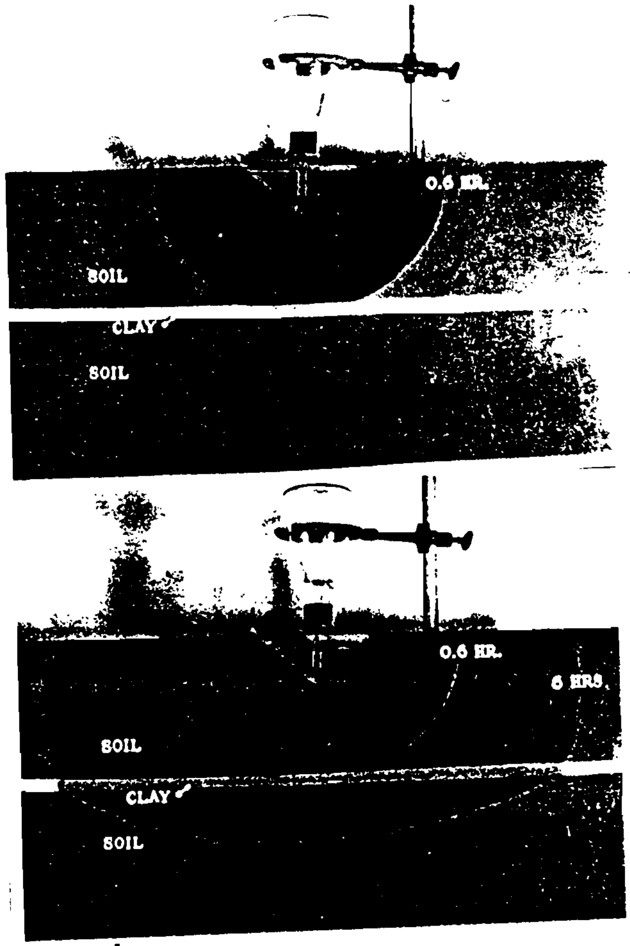


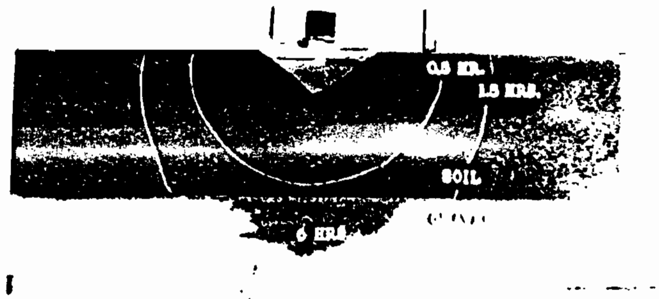
Uniform or homogeneous soils

Figure 1. Water movement in a uniformly textured soil. From Gardner.



Clay layer

Figure 2. Water movement in a soil with a finer textured sub soil layer. From Gardner



Coarse sand or gravel subsoil

Figure 3. Water movement in a soil with a coarse textured sub soil layer. From Gardner.

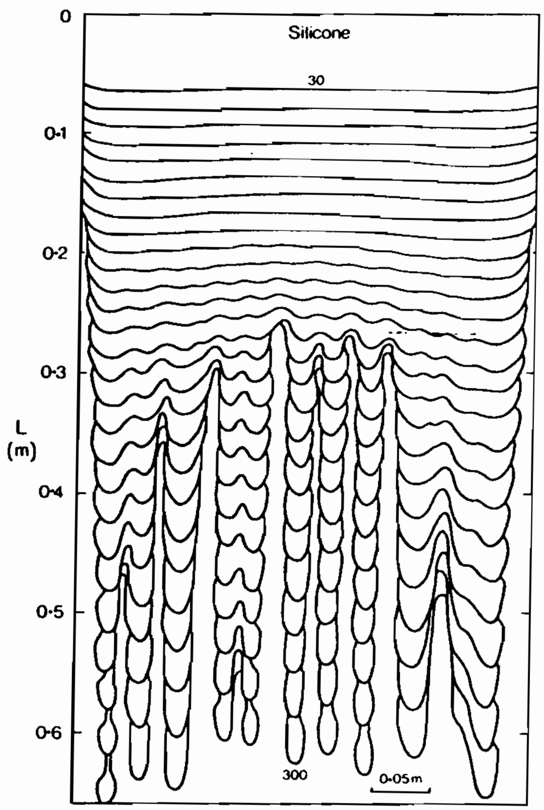


Fig. 3—Experiment 10. Tracings of the development of instability for quadratic increase in conductivity with depth. The profiles are 10 sec apart.

Figure 4. Fig. 3 from White, Colombera, and Philip. 1977

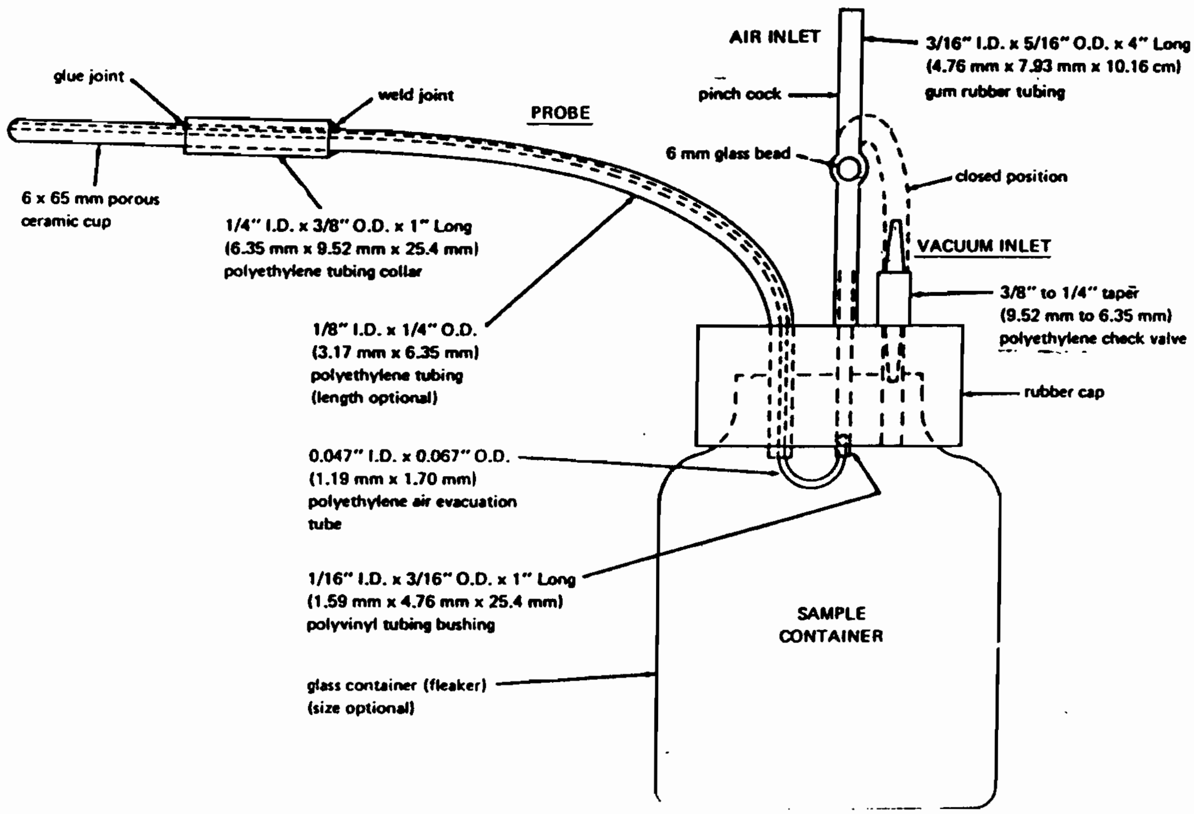


Figure 5. Atypical suction lysimeter design. From Harris and Hansen1975.

Fig. 2—(*A*) Wetting finger formed in center of plastic cylinder frozen to retain structure. (*B*) Wetting fingers broadened by diffusion in Plexiglas chamber.

Figure 4. Fig 2. from Hill and Parlange, 1972

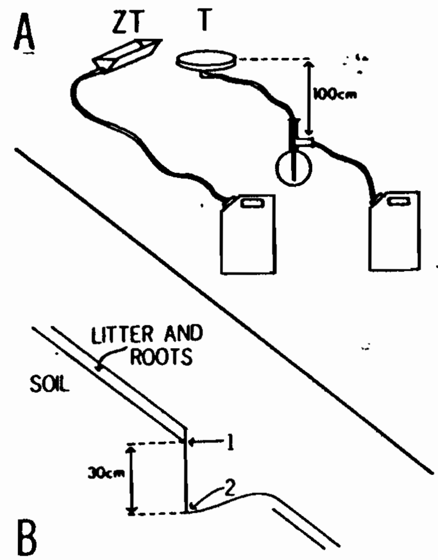


Fig. 1—Lysimeter elevations (*A*) lysimeters: zero-tension (ZT) drain by gravity, while tension (T) was fitted with 100-cm-hanging water column. Water accumulated in 20-liter carboy; and (*B*) elevations: one each ZT and T lysimeters placed at each level 1 and again at level 2. Not drawn to scale.

Figure 7. From fig. 1. Haines, Waide and Todd 1982

ORCHARD FLOOR MANAGEMENT EFFECTS ON INFILTRATION AND AGGREGATE STABILITY

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The objective of this project is to study the long-term effects of vegetative cover, gypsum, and tillage on water infiltration in an orchard soil with a history of crusting problems. The study was planned for a five-year period and is currently entering its third year. Data presented represents information gathered during the most recent growing season. The project receives funding through the 1986-91 mission of the Kearney Foundation of Soil Science; "Water Penetration Problems in Irrigated Soils."

Experimental Design

The experimental plots are located in Butte County on a portion of an Onstott prune orchard approximately one mile east of Highway 99 on Ord Ranch Road, north of the city of Gridley. The orchard was established in 1979. The soil is a Gridley loam, and irrigation is with Feather River water. The orchard is irrigated by flooding alternate north-south trending rows, waiting three days, then flooding the remaining rows, a practice which stems from the growers' fear that flooding adjacent rows simultaneously would make trees too susceptible to blow-down. The 1988 growing season is summarized in Figure 1.

Figure 1. Calendar of 1988 growing season

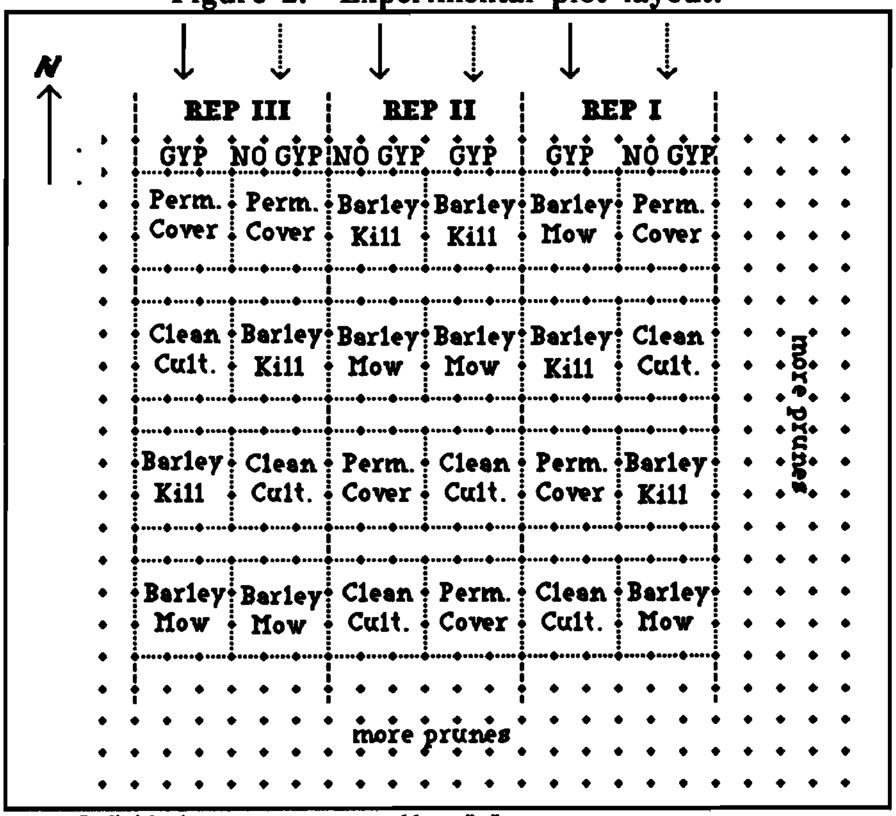
M\D	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Feb.						N																									
Mar.																									IRRIG.						
Apr.	N										N	IRRIGATION														N					
May												N		IRRIGATION												N	G				
June												IRRIGATION									N										
July	N	IRRIGATION										N										N/D					IRRIGATION				
Aug.						N									Harvest							N	IRRIGATION							N	
Sept.								N										IRRIG.													

N = neutron probe moisture measurement
G = gypsum application
D = disking

Treatments are as follows: 1) Permanent grass cover (Elka ryegrass) mowed when necessary; 2) Fall tillage followed by a planted annual grain (barley or wheat) mowed when necessary; 3) Fall tillage followed by a planted annual grain (barley or wheat) killed with herbicide in spring; and 4) Clean cultivation (standard Onstott management) which includes fall and mid-season (preharvest) disking components. One half of all plots are amended with gypsum in mid-spring at two tons per acre. Treatments are replicated three times in a split plot design, giving a total of 24 plots.

Each treatment plot consists of a 20 by 20 foot square bounded by four trees and is immediately surrounded by eight additional 20 by 20 foot treatment squares as illustrated in Figure 2. Each central square is instrumented with two neutron probe access tubes to a depth of 1.8 m. Neutron probe moisture measurements were taken from 48 tubes at four depths per tube (20, 50, 100, and 150 cm) before and after individual irrigations. Additional data collected included a late season set of double-ring infiltration tests and early and late season aggregate stability measurements.

Figure 2. Experimental plot layout.



Individual trees are represented by a "+"
Solid and dashed arrows indicate differences in irrigation day for central plot squares.

Results and Discussion

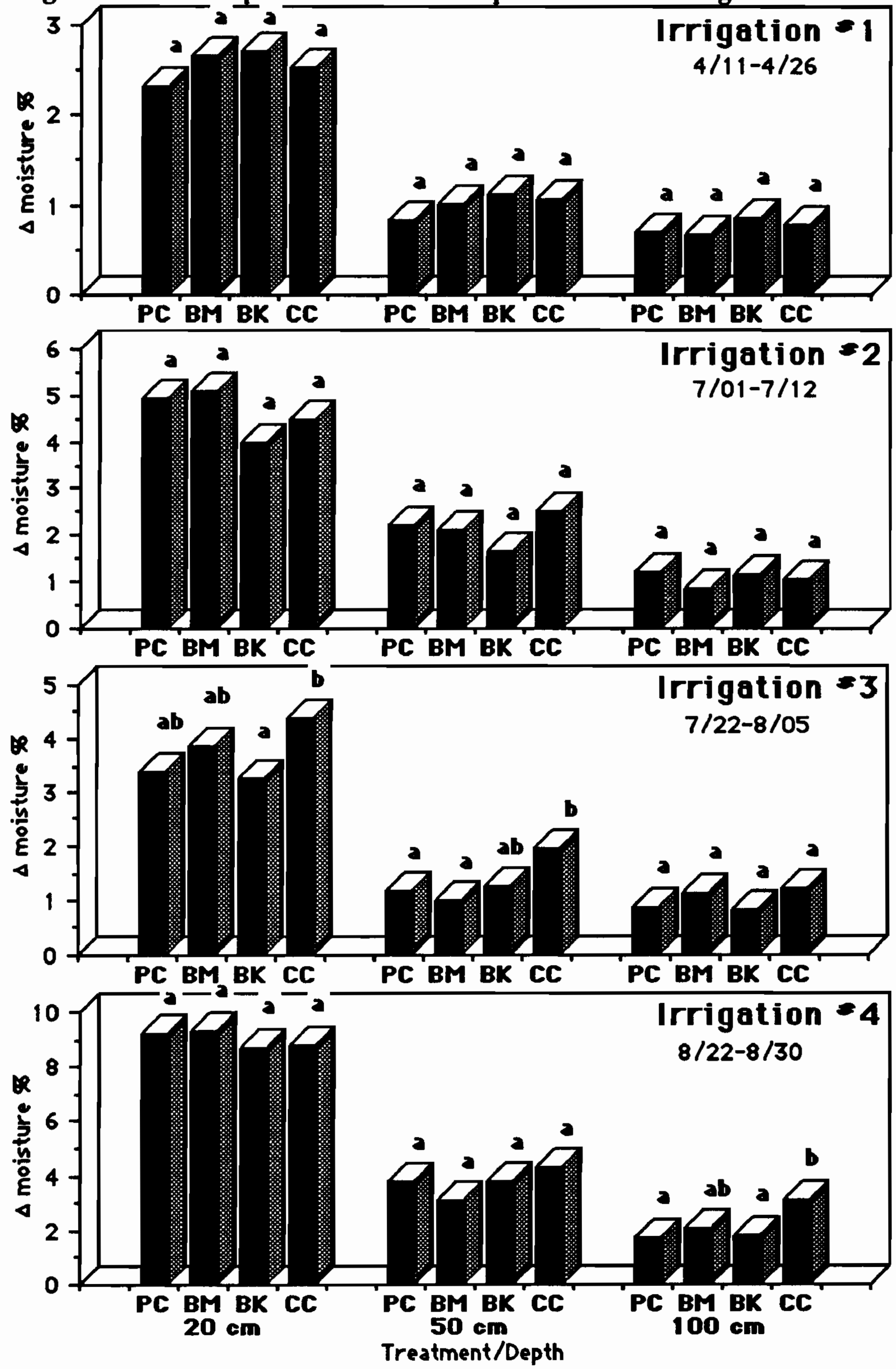
Confounding effects due (primarily) to Onstott irrigation management practices have placed limitations on the types of soil moisture comparisons which can be made thus far. Statistical analyses were only possible within and between rows irrigated simultaneously. Due to the nature of the plot layout, central plot tubes were located every third tree row, while irrigation was on an alternate row basis. As such, moisture comparisons between gypsum and non-gypsum treated plots could not be confidently made but rather only comparisons between cover treatments within rows. Also, moisture readings at the150 cm depth were discarded because of a high textural variability at this depth over the experimental area. Moisture data presented were obtained by subtracting "pre-" from "post-" irrigation neutron probe moisture measurements to give a change in soil moisture content due to the irrigation. Four such data sets are presented here. Units are in gravimetric moisture percentage.

No advantage of any vegetative cover over the clean cultivated plots was found. Prior to the midseason disking of the clean cultivated plots, no significant differences between any of the treatments appeared at any depth (Figure 3). Immediately after the disking of the clean cultivated plots on 7/22, significant differences at the .05 percent level were noted between the clean cultivated and the killed grain treatments at 20 cm, and between the clean cultivated and both permanent cover and mowed grain treatments at the 50 cm depth. Over the subsequent irrigation, significant differences between the clean cultivated and both permanent cover and killed grain treatments appeared at 100 cm (Figure 3). These significant increases in moisture change for the clean cultivated plots indicate a positive effect of the disking.

The addition of gypsum *appeared* to significantly increase infiltration over all plots for one irrigation by approximately ten percent at the 20 and 50 cm depths. The gypsum appeared to significantly increase infiltration for only one irrigation immediately following addition.

Five aggregate stability samples of the surface soil were taken diagonally across each plot early in the season following the gypsum application and again after harvest. In general, higher aggregate stability values are associated with good soil structure and hence higher intake rates (Table 1). The aggregate stabilities of the gypsum-amended mowed and killed grains were significantly higher than those of the non-amended mowed grain and clean cultivated treatments at the .05 percent level. The gypsum-amended plots showed a significantly higher aggregate stability than the non-amended plots. Comparison of cover treatments showed no significant differences. This may in part reflect the fact that for most of the season, the clean cultivated plots were not actually "clean" but rather abundantly vegetated with various weeds. This cover may have had an effect similar to that of the vegetative cover treatments.

Figure 3. Comparative table for vegetative cover treatments showing change in moisture percent at three depths for four irrigations.#*



*Means followed by the same letter are not significantly different at p = .05.
#PC = permanent cover; BM = mowed grain; BK = killed grain; CC = clean cultivated.

Table 1. Aggregate stability measurements for early season 1988.

Individual Treatment #	Mean* (%)	Cover Treatment #	Mean* (%)	Gypsum Treatment #	Mean* (%)
Gyp BK	96.2 a	BK	95.3 a	Gyp	95.5 a
Gyp BM	96.2 a	BM	95.0 a	No Gyp	94.2 b
No Gyp PC	95.0 ab	PC	94.9 a		
Gyp CC	94.9 ab	CC	94.2 a		
Gyp PC	94.7 ab				
No Gyp BK	94.4 ab				
No Gyp BM	93.8 b				
No Gyp CC	93.5 b				

*Means followed by the same letter are not significantly different at p = .05.
#PC = permanent cover; BM = mowed grain; BK = killed grain; CC = clean cultivated.

Double-ring infiltration measurements were taken after the growing season to determine final infiltration rates. One set of readings was taken per plot. Treatment means were surprisingly low (Table 2). Individual measurements indicated extremely variable conditions, as demonstrated by two- to threefold differences in infiltration over short (< 1 m), within-plot distances. This may be in part due to discontinuities in the surface crusting because of variability in surface topography, vegetation density, and traffic history, and to a plow pan observed over the entire orchard, and its variability in thickness, depth, and bulk density. No significant differences were found between any set of treatments, though observable trends were in accordance with moisture and aggregate stability data.

Table 2. Final infiltration rates (September, 1988).

Treatment #	mean* ($mm\ hr^{-1}$)	Treatment #	mean* ($mm\ hr^{-1}$)
CC	1.46 a	Gyp	1.12 a
PC	1.06 a	No Gyp	0.98 a
BM	0.99 a		
BK	0.84 a		

*Means followed by the same letter are not significantly different at p = .05.
#PC = permanent cover; BM = mowed grain; BK = killed grain; CC = clean cultivated.

Conclusions

The most important factor limiting infiltration for this orchard appears to be structural and depositional crusting formed during the off-season and during irrigation. A secondary limiting factor seems to be the plow pan, though the degree of its effects are not fully understood. Only the clean cultivated treatment showed any significant increases in moisture gains over any of the irrigations, and therefore appears to be the superior management practice here. Cultivation was the only aspect of any of the treatments which could significantly alleviate the controlling effects of the crusting by temporarily destroying it through disking. This hypothesis is supported by the double-ring infiltration data, which was collected approximately one month after the mid-season disking of the clean cultivated plots. These plots showed infiltration means 50 percent higher than the vegetative treatments, though these differences were not significant due to high variability. However, despite serving as a short-term remedy for crusting problems, disking operations further contribute to the formation of the pan.

The magnitude and duration of the forces involved in disrupting aggregates in the field are much greater than those under which aggregate stability values are determined in the lab. Despite aggregate stability means of over 90 percent for all treaments, severe crusting problems were noted in all plots. Here, values are perhaps misleadingly high, suggesting that comparison of values rather than assessment of absolute values should be the objective of such determinations. A treatment effect improvement of surface structure is indicated by trends in the aggregate stability data. The gypsum-treated plots exhibited higher aggregate stabilities than the non-treated plots. Two gypsum/vegetative cover individual treatments showed significantly higher aggregate stabilities than the "control" clean cultivated non-amended treatment. The clean cultivated treatment was the least stable amongst the cover treatments, though not significantly lower. These data confirm the hypothesis that soil structure may be improved with gypsum, and seem to indicate that organic matter may also play a positive role.

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Acknowledgements

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WATER INFILTRATION CHARACTERISTICS OF SOIL UNDER VARIOUS VEGETATION MANAGEMENT SYSTEMS USING A PORTABLE RAINFALL SIMULATOR-TYPE INFILTROMETER

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Numerous attempts have been made to develop sprinkling infiltrometers which can measure the effects of rainfall upon soil erosion and infiltration (Peterson and Bubenzer, 1986). Two basic types were developed, nozzle and drop-forming infiltrometers. The usual method of measuring infiltration is by difference between applied and runoff collection water. Most of these devices were relatively complicated and logistically difficult (Julander and Jackson, 1983), and not suitable for rapid field setup and movement. Ross and Bridge (1985) developed a portable variable rate infiltrometer for field use which addressed these deficiencies. In development of our infiltrometer, these additional criteria were considered:

1) measured area of sufficient size to satisfactorily represent the conditions being evaluated
2) user variable application rate
3) good uniformity of water application
4) portable, movable and operatable by single person
5) computer controlled operation data acquisition and storage
6) continuous operation, non-cycling
7) low energy droplets
8) 12 volt DC power supply

Portable Infiltrometer. A portable, drop-forming rainfall simulator-type infiltrometer was designed for use in measuring water infiltration characteristics of field soils. The device can be handled by a single person and is small enough to easily fit in a pickup truck. All power is supplied by a 12-volt DC lead acid battery power source. Since 120V 60Hz sinewave power is required, an invertor is used which provides frequency control of ± 0.5Hz.

The structural component is a rectangular steel frame, supported by two 25 cm diameter pneumatic wheels and two steel support legs. The wheels and legs are adjustable to provide leveling. Carried under this frame on a linear motion track is a water distribution device (rack) made of 25 mm schedule 40 PVC pipe. The rack has ten 1-meter length lines each 11.1 cm apart. Each of the lines have 50 equally spaced syringe adapters to which 0.18 to 0.38 mm inside diameter hypodermic needles can be attached. In alternate lines, the needles are staggered by 1/2 the needle spacing. In total, 500 outlets cover one square meter area. The rack is moved back and forth the distance of two line spacings (22.2 cm) to insure maximum droplet distribution uniformity. Control of this motion is by a digital linear actuator controlled by a separate logic device.

Water is pumped through a 200 mesh filter to minimize clogging which has been a problem with other similar devices of this type (Julander and Jackson, 1983). Water is pumped to the rack by a peristaltic pump which contains onboard logic to control pump speed from 60-600 rpm. The pump controller communicates with the external laptop computer through a RS232C serial interface. The pump responds to commands issued from the laptop computer to apply the desired precipitation rate. Rates are selected based on visual observations to maintain near "Incipient Ponding Conditions" for the term of the experiment.

RESULTS

Infiltrometer Evaluation

The infiltrometer was tested for uniformity of application under zero wind conditions by using a 103 mm diameter catch can placed within each of the 72 sub-zones of the application area. The infiltrometer was run at a constant rate for a fixed period of time. Application rates varied from 1.6 to 101.6 mm per hour using 0.18 inside diameter needles. Water caught in the can was measured volumetrically. Data were compared using Christiansen's Coefficient of Uniformity (CCU). At all rates, CCU values exceeded 86 percent (Table 1). The lowest values were obtained from the highest rates. The Coefficient of Variation (CV) between catch cans was less than 16.2 for all rates. The poorest CV of 14.3 and 16.2 occurred at 1.6 mm h^{-1}, respectively (Table 1). The variation at the low rates is attributed to minor unleveling of the rack. At the high rates, squirting occurred which distorted the normal gravitational dripping effect. Larger needles reduced the CV at the higher rates. Unfortunately, larger needles also increased the CV at the low rates.

Table 1. Infiltrometer performance using 0.18 cm inside diameter needles at various rates of application.

Rate (mm h^{-1})	Time (hrs)	Mean Depth of Applied Water (mm)	Coeff. of Variation (%)	Christiansen's Coeff. of Uniformity (%)
1.6	8	12.8	14.3	89
5.1	6	30.6	12.6	90
50.8	2	101.6	9.0	93
101.6	1	101.6	16.2	86

The infiltrometer was used to determine the infiltration rate curve of Hanford fine sandy loam soil (coarse, loamy, mixed non-acid thermic typic Xerorthents) near Modesto, California. The infiltrometer was allowed to operate from a beginning rate of 114 mm h^{-1} until "incipient ponding" occurred. The rate was then decreased in small decrements to maintain this condition over the term of the experiment. Data collected in each plot were fit using non-linear regression to an infiltration equation (Figure 1) proposed by Horton (1935):

$$f = f_c + (f_0 - f_c)e^{-kt}$$

where:

f = infiltration rate at some time

k = constant representing the rate of decrease in f capacity

f_c = final equilibrium or steady state rate

f_0 = initial infiltration rate

The infiltration equation is integrated to obtain accumulated infiltrated water volumes (Figure 2). Infiltration capabilities can be evaluated using various infiltration parameters including initial (maximum) rate, rate of decline, steady state rate, or accumulative infiltration after some "set time." The most beneficial parameter to orchardists and design engineers would be steady state, or the sustained infiltration rate, and accumulative infiltrated water volumes after a "set time."

Orchard Floor Vegetation Management Evaluation

A long-term (4 years) orchard floor vegetation management experiment was selected to initially evaluate the infiltrometer. This experiment includes treatments with bromegrass, Salina strawberry clover, and resident vegetation cover crops which are mechanically mowed in addition to bare soil where all vegetation is controlled year round using residual herbicides. A fifth treatment uses a postemergence herbicides at low rates throughout the season to retard vegetation growth. The herbicide is then utilized to eliminate the resident vegetation by harvest time. Water infiltration characteristics of these treatments were determined on a Hanford fine sandy loam.

Significant differences in water infiltration characteristics were found between orchard floor management systems. In general, the cover crop treatments (resident vegetation, clover and brome) were significantly higher in both infiltrated volume after 120 minutes and steady state infiltration than in the chemical mowing and residual herbicide treatments (Tables 1 and 2). A total of 33 mm of additional water volume was infiltrated over a 120 minute irrigation period in the brome versus the residual chemical treatments (Figure 2).

SUMMARY

A portable rainfall simulator-type infiltrometer has been constructed in order to measure the water infiltration characteristics of field soils. The application rate is continually variable from 1.5 to 114.3 mm h^{-1}, making it possible to determine intake characteristics measured near incipient ponding. Measurements of water infiltration characteristics of soil varying in vegetation management practices reveal significant differences exist between treatments. The "cover" management strategy enhances water infiltration over those treatments which deter vegetative growth. Bromegrass seems to offer the best water infiltration characteristics of the management systems evaluated. The portable rainfall simulator-type infiltrometer can be used for characterizing infiltration of soils under physical and chemical management regimes as well as evaluating remedial physical chemical amendments, affecting infiltration rates of field soils.

Table 2.
Infiltration Rate at 120 minutes
(mm/hour)

clover	18.8	a*
resident vegetation	14.5	ab
brome	14.5	ab
chemical mowing	10.4	bc
residual herbicide	7.6	c

Table 3.
Accumulated Infiltration After 120 minutes
(mm)

brome	65.3	a*
clover	63.2	a
resident vegetation	54.9	a
chemical mowing	39.1	b
residual herbicide	32.5	b

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

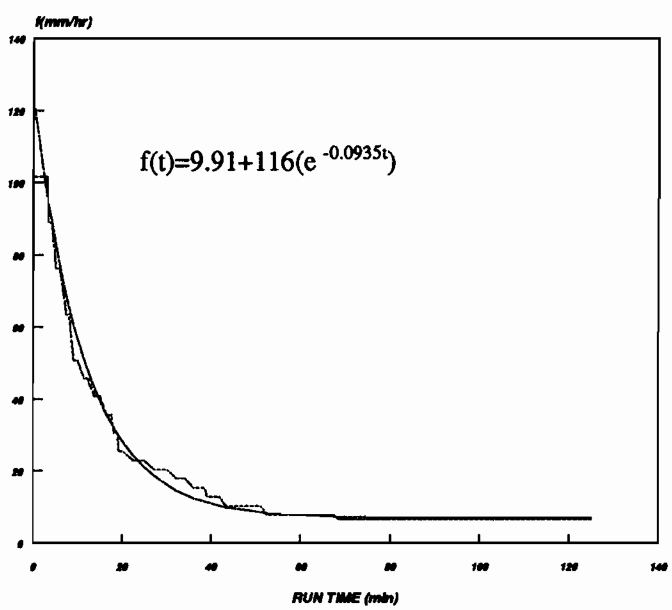

Fig. 1 . A graphical representation of the field data and calculated non-linear regression (smooth curve).

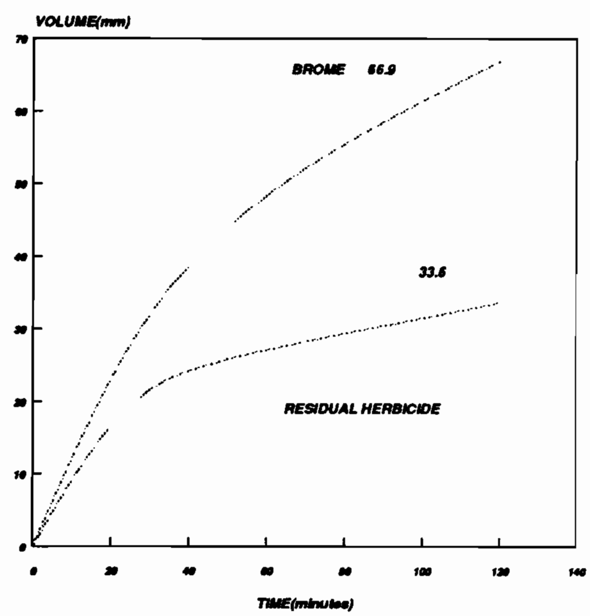

Fig. 2. Accumulated infiltrated volume (mm) for brome and residual herbicide in a 120 minute period.

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INFILTRATION MANAGEMENT UNDER LOW-VOLUME IRRIGATION

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Low-volume irrigation systems (drip, fogger, micro-sprinkler) are now commonly used in permanent crops on the east side of the southern San Joaquin Valley. Initially, it was hoped that low-volume systems would offer a solution to irrigation problems associated with soils having slow water infiltration characteristics. In fact, infiltration problems have often been worse with low volume systems.

Soils with slow infiltration do not allow enough water to penetrate into the root zone to meet the tree or vine's water requirement. With low-volume irrigation, surface puddles will extend along the entire drip hose while soil a foot beneath the surface remains dry. Under these conditions, plants can exhibit severe water stress in summer even though irrigation amounts greatly exceed evapotranspiration.

By the beginning of the irrigation season, the entire root zone is usually wetted by winter rainfall. However, by June and through the summer months only 50 percent or less of the root zone is effectively wetted by low-volume irrigations on most soil types. Less than ten percent of the soil in the root zone may be wetted when water infiltration is a problem. Water storage in such a small volume of soil amounts to only 2 to 3 days of evapotranspiration.

The average vineyard or orchard in the San Joaquin Valley (55% to 75% of the ground area shaded with the sun directly overhead) will use 4000 to 6000 gallons per acre per day during summer months. The plants water needs are met with daily irrigations using this amount; irrigation intervals with low volume systems should be no greater than 4 to 5 days during summer months to avoid water stress.

An infiltration problem is often associated with irrigation water low in salt and/or soils with inherently slow infiltration rates. Gypsum, a calcium salt, is commonly used to improve water infiltration on nonsodic soils. It is the most effective with low-salinity irrigation water (electrical conductivity [EC] <0.1 decisiemens per meter [dS/m]).

Spreading gypsum down the vine row has improved infiltration in vineyards using low salt irrigation water. The application equipment is modified to apply gypsum in a three to four foot strip down the vine row (where the drip lines and emitters are located) at a rate of approximately two tons per acre (2/3 T per vineyard acre). The gypsum is applied in late April or early May before the vine's canopy interferes with application. The gypsum usually improves infiltration for the season.

In deciduous fruit orchards, gypsum is applied earlier in February and March in order to strip apply the gypsum down the tree row without interference from foliage. In citrus, it is very difficult to spread gypsum under the permanent tree skirts where the emitters are located.

Research

The objective of our research was to increase water infiltration in a drip-irrigated, mature navel orange block at the University of California Lindcove Field Station in Tulare County. Experiments were located on two different soil types, a San Joaquin sandy loam and Vista sandy loam, both with steady-state infiltration rates of less than a tenth of an inch (.25cm) per hour. Irrigation was with canal water that had an electrical conductivity (salinity) of 0.1 dS/m. Trees were drip-irrigated every weekday to meet evapotranspiration demand.

A unique method of measuring infiltration and applying amendments was used in this research. An infiltrometer made from a 12-inch-diameter PVC pipe was placed near each dripper and driven about 3 inches into moist soil, leaving 4 inches above the surface. We placed the drip tubing so that water would be applied inside the infiltrometer. Half-inch holes drilled in the PVC pipe at the soil surface allowed surface spreading unimpeded by the infiltrometer. When measurements were made, these holes were stoppered; the water quickly filled the infiltrometer, spilling out of an outlet near the top where it was collected and measured. The infiltration rate was calculated from the difference between inflow from the dripper and outflow from the infiltrometer.

Some treatments required a continuous application of 3 milliequivalents per liter (meq/l) of calcium to irrigation water. The amendment was applied through intravenous (IV) bags and tubing, filling the bags daily and adjusting the flow rate. The discharge tube from the IV bag was attached to the discharge tubing from the dripper.

The experimental design was a randomized complete block with eight blocks. Infiltration was measured twice before applying treatments. The rings were then ranked in order of increasing infiltration rate, and divided into eight blocks of similar rates. Statistical variation showed up in blocks allowing for a more sensitive statistical comparison between treatments.

Gypsum Helps

Infiltration rates were doubled by applying gypsum to the soil surface, table 1. Gypsum was applied weekly to maintain a slight excess continually on the soil surface.

Polyacrylamide did not improve infiltration. At the onset of the experiment, a 150 ppm polyacrylamide solution was applied to treat a 2-inch soil depth.

Nonionic surfactant did not improve infiltration. The surfactant was added weekly at a rate of 1 quart per acre.

Tilling the soil in the spring did not improve infiltration during the course of the experiment. Soils were disturbed by cultivating a 2-inch depth.

Daily Application of Calcium to Water Helps

Adding calcium continuously to irrigation water doubled or tripled infiltration rates over that of untreated low-salt water, table 1 and 2. Calcium was continuously applied to irrigation water adding 3 meq/l. Calcium acetate, calcium nitrate, calcium chloride, and CAN-17 were evaluated. These materials were either applied continuously, biweekly, or as a slug; total calcium applied for the season was the same.

The continuous application of calcium was quite beneficial. However, the occasional additions of calcium nitrate or CAN-17 were not effective in maintaining infiltration rates.

There are concerns using calcium nitrate or CAN-17. Nitrogen application must not be greater than the tree or vines nutritional requirement. The effect on growth and production from applying nitrogen continuously during the growing season needs to be evaluated.

Further Study

In 1988, the experiment was moved to site having Vista sandy loam. At this location, Calcium nitrate and calcium acetate were compared applying calcium continuously at 3 meq/l. Calcium nitrate did not improve infiltration whereas calcium acetate did. It is theorized that the acetate stimulated microbiological activity affecting the surface crust. This needs further study.

A gypsum company in the San Joaquin Valley has developed an applicator that can apply gypsum to irrigation water at rates of 3 meq/l or greater, and plugging of emitters has not been a problem. To date, only a few farmers have used the procedure but they report improved infiltration rates and no emitter plugging problems. This technique is promising and may provide a solution to difficult infiltration problems and should be further evaluated.

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Table 1. 1986 Lindcove treatments and grouped average infiltration rates

Treatments	Avg infiltration rate Amendments Applied 6/11 - 8/6
	cm/hr
Calcium nitrate, undisturbed	.46 a
Gypsum, disturbed	.42 a
Gypsum, undisturbed	.37 ab
Polyacrylamide, disturbed	.29 bc
Polyacrylamide, undisturbed	.29 bc
Control, disturbed	.26 bcd
Control, undisturbed	.23 cd
Nonionic surfactant, undisturbed	.21 cd
Nonionic surfactant, disturbed	.16 d
LSD .05	.12

Table 2. 1987 Lindcove treatments and grouped average infiltration rates

Treatments	Avg infiltration rate Amendments Applied 6/24 - 8/19
	cm/hr
Calcium acetate, daily	.68 a
Calcium nitrate, daily	.52 ab
Calcium chloride, daily	.41 bc
CAN-17, daily	.40 bc
Calcium nitrate, biweekly	.35 bcd
Calcium nitrate, single application	.23 cde
Control	.22 cde
CAN-17, biweekly	.17 de
CAN-17, single application	.13 e
LSD .05	.20

EVALUATING CRUST PROPERTIES OF FIELD SOILS USING A MICROPENETROMETER

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The development of a soil crust or surface seal has been implicated as one of the major causes of poor water infiltration in California soils (Oster et al., 1984). Crusts are also detrimental in terms of seedling emergence. The strength of the crust differs between soils depending upon the physical, chemical, and mineralogical characteristics of the soil, the method of water application, and other environmental variables.

Many field soils develop a surface seal during irrigation or rain with cracks or small fractures developing within the crust as the soil dries. The size and frequency of these fractures is considered to be a major factor in the infiltration properties of field soils.

Thus, if a clear understanding of those processes resulting in poor infiltration in field soils is to be attained, the characterization of the crust and the frequency and size of crust fractures should be evaluated. This summary describes a portable micropenetrometer designed for use in measuring soil crust characteristics under field conditions.

Description of Micropenetrometer

The micropenetrometer was designed to measure soil crust strength in situ in order to delineate fractures at the crust surface and differences in strength within the very shallow soil surface of a few mm in depth. The unit is 1.62 m long, 0.61 m wide, 0.61 m high and weighs approximately 40 kg. It operates from a single 12 volt, rechargeable battery. A vertical stepper motor pushes a small, flat-tipped probe (1.6 mm diameter) into the soil at a constant penetration rate. Force measurements can be recorded every 0.1 mm of depth during penetration. A horizontal stepper motor moves the probe assembly along guide rods for taking measurements anywhere along a distance of 1 m. The small diameter of the probe also allows for spatial measurements to be taken as close as 3 mm apart.

The controller for the penetrometer is built around a laptop computer. The controller can respond to commands which cause the penetrometer probe to move horizontally or vertically and to initiate a penetration sequence. The penetration sequence causes the probe to move down until it just contacts the soil and then the controller begins sending force date to the computer over the serial line. Penetration continues until a predetermined depth is reached and the probe retracts and moves to the next spatial position. Data stored in the computer in the field can be transferred to a laboratory computer by means of an RS-232c serial interface.

Evaluation of in situ crust characteristics

Measurements were made on plots of Hanford soil at the Kearney Agricultural Center in order to evaluate if the penetrometer could detect differences in crust strength of field plots with various surface treatments. In addition, measurements were made at a field site on the Davis campus in order to determine if differences in crust characteristics could be measured for plots which had been flood and sprinkle irrigated.

For the Kearney plots, three different surface treatments had been applied one year prior to penetrometer measurements. They included the addition of gypsum, incorporation of almond hulls, addition of a PVA surface stabilizer, and a control with no additives. Sixty penetration measurements were made of the top 4 mm of soil in each treatment at a time period when the surface soil had been air dry for some time. Figure 1 gives the average maximum force for each of the treatments. These results show that the control treatment had significantly larger values of strength than all other treatments. The almond hull treatment showed significantly higher strength than the PVA treatment, but no significant differences were detected between the gypsum treatment and the almond hulls or the PVA treatments. Differences in surface condition as measured by the penetrometer were also reflected in differences in infiltration rate (Grimes, personal communication). From this field test, it appears that the micropenetrometer is capable of detecting differences in strength after one year of treatment with additives which also influence infiltration rates.

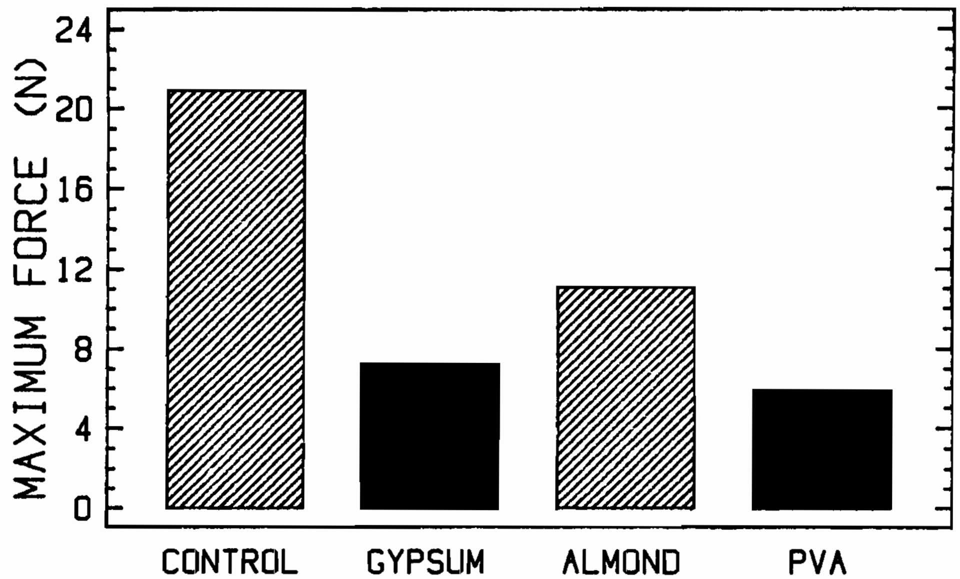

Fig. 1. The average maximum penetration force (newtons) for three soil surface treatments and the control at the Kearney Ag. Center.

Another example of the capability of the penetrometer to measure characteristics of field crusts is given by Fig. 2. These results are from an experiment where water with an EC of 2.6 dS/m was applied to Yolo soil by two different irrigation systems; flood and sprinkler. In this case, instead of making very shallow surface measurements as for the previous case, measurements were made every 0.1 mm to the 30 mm depth. Fig. 2 gives the force as a function of depth for the two different irrigation treatments. The penetration force was greater for the flood-irrigation treatment, and the force tended to remain fairly constant after the maximum force was attained at about 3-4 mm than for the sprinkled treatment. The data for the sprinkled soil also show that the soil beneath the upper few mm required less force to penetrate than that near the surface and that some force values approached zero in many places, especially between the 10-20 mm depth. Force values near zero indicate that the tip of the probe must have been in air spaces between particles or small aggregates. Thus, the soil below the upper surface (or crust) of the sprinkle-irrigated plot was less dense and contained air spaces, at least as large as 0.1 mm, than in the soil of the flood-irrigated site. Ponding of water during irrigation in the flood irrigated plot apparently caused much more settling, probably higher densities, and higher penetration resistance than in the sprinkler-irrigated soil.

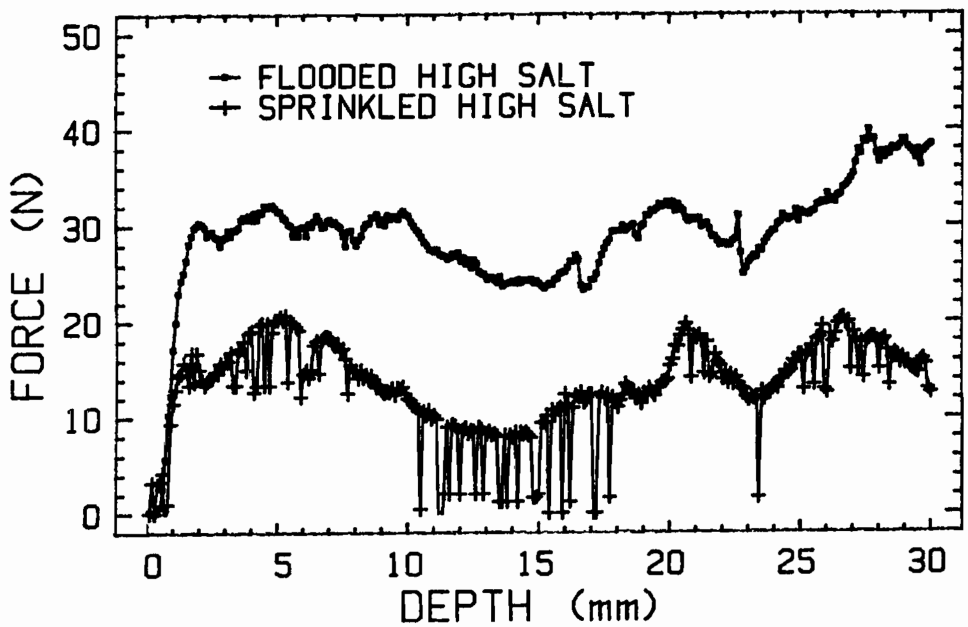

Fig. 2. Penetration force (newtons) as a function of soil depth for two representative locations in flood- and sprinkle-irrigated plots at UC Davis.

These preliminary results with the micropenetrometer indicate that the instrument is capable of detecting differences in soil strength useful in evaluating crust and surface soil characteristics in the field. The research is being extended to studies correlating physical, chemical, and mineralogical characteristics with the spatial and depth patterns of penetration force measured for various field soils.

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Acknowledgements

This research is supported by the Kearney Foundation of Soil Science. Appreciation is expressed to Don Grimes at Kearney and Jan Hopmans at Davis for providing access to their research plots.

EFFECT OF CRUST FORMATION AND POLYSACCHARIDE ON WATER INFILTRATION AND SOIL ERODIBILITY

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Runoff and water erosion are a serious problem in many places in the world with different climates and soil types (Black and Adams, 1984; Crosson and Stout, 1984, 1984).

As water wets the soil surface, cohesive forces between the soil particles are reduced and water drop impact breaks the soil aggregates (Agassi et al., 1985; Morin and Benyamini, 1977). Moreover, low electrolyte concentration in rainwater causes clay dispersion and increases aggregate breakdown at the soil surface (Shainberg and Letey, 1984). Aggregate disintegration releases small soil particulates (individual particles or small aggregates) which can be transported by runoff water and/or by the splash. This process is the initial step in erosion (Baver et al., 1972).

Simultaneously with the breakdown and dispersion of the aggregates at the soil surface by water drop impact, a thin crust layer is formed on the soil surface (Ben-Hur et al., 1985; Shainberg and Letey, 1984). Surface crusts are characterized by greater density, finer pores, and lower saturated conductivity than the underlying soil which reduces the water infiltration (Gal et al., 1984; McIntyre, 1958; Wood and Oster, 1985). On the other hand, crust formation increases the shear strength of the soil surface which could reduce soil erodibility. While much work has been carried out on the effect of rain erosivity and soil properties on soil erosion, only limited research has studied the effect of crust formation on soil erodibility.

Treatment of soils with chemical amendments may improve or maintain soil structure and aggregate stability. Polymers have been shown to be effective in increasing hydraulic conductivity and porosity (Shanmuganathan and Oades, 1982) and reducing crust formation and runoff (Ben-Hur and Letey, 1989).

The objectives of this study are two-fold. First to investigate the effects of crust formation on water infiltration and soil erodibility. Second, to test the effects of various polymers applied at low concentrations with the water on crust formation and soil erodibility.

The study was conducted on a Haplic Durixeralts soil classified as Arlington sandy loam using a rainfall simulator. Polysaccharide (derivatized guar) polymers which were cationic, anionic or nonionic with molecular weight between 0.2 to 2.0 x 10^6 were used in this study. These polymers were added to the applied distilled water (DW). The concentration of eroded material in the runoff water and the total amount of eroded material from small (240 cm^2) trays containing soil were measured as a function of applied water. The steady state infiltration rate was used to characterize the extent of crust formation.

RESULTS AND DISCUSSION

The final infiltration rate (IR), eroded material concentration (EMC), their standard deviation (SD), and the total eroded material (TEM) for the different treatments are presented in Table 1. When the impact energy of the water drops was prevented (covered soil), the crust was not formed and the final IR was high. Likewise, the EMC and the TEM values were lower than under impact conditions (uncovered soil). When the impact energy was dissipated, the aggregates destruction and the detachment processes were prevented. The low energy of the runoff water flow could not carry off the relatively large aggregates from the soil surface.

When high (HCCP) and low (LCCP) cationic polymer solutions were applied, a high final IR values were maintained. The polymers were most likely adsorbed on the particles at the soil surface and acted as a cementing material holding the primary particles together against the destructive forces of the water drops. Thus, the destruction of the surface soil structure and the crust formation diminished.

Distribution histograms of the soil fractions at the time of packing in the rainfall simulator (dry sieving), of the primary particles of the soil (suspension sieving), and of the eroded material from the uncovered soil which was subjected to first rain event of DW and 10 g m^{-3} HCCP are presented in Fig. 1. The ratio between the amount of the silt and clay particles (<0.05 mm), which acts as a cementing material, and the amount of larger material (1.0-0.05 mm) which act as a structure matrix, is high (1.5) for the DW treatment and low (0.25) for the HCCP treatment. The material with sizes >1.0 mm are not important, since they are not involved in crust formation (Gal et al., 1984). This high ratio is apparently the main factor in the formation of the crust in the DW treatment. In other words, the disintegration of the aggregates into dispersed clay particles is needed for crust formation.

The results from Fig. 1 and Table 2 suggest that there are two main processes that affect soil erodibility: 1) The breakdown of the aggregates at the soil surface to micro aggregates, thereby making the transport of this material by the runoff flow possible. 2) Dispersion of the aggregates to primary silt and clay fractions, which is needed for crust formation at the soil surface. This crust increases the resistance of the soil surface to erosion and the erodibility of the soil is decreased even though these finer particulate sizes are more easily transported by the flowing water.

The regression lines and experimental points of the EMC values as functions of the final IR are presented in Fig. 2. Each experimental point represents an average of four replicates. A significant statistical correlation ($r^2 = 0.90$) was obtained between the EMC values and final IR values. A higher final IR means lower crust formation. Consequently, there is an inverse relationship between soil erodibility and crust formation.

Ambiguity exists on the effect of crust formation on the amount of erosion under natural conditions. Data reported here indicate that crust formation decreases soil erodibility. Thus for a given amount and velocity of water flow over the land surface, crust formation should decrease the amount of erosion. However, the results also indicate that crust formation increases runoff. Increasing runoff increases the quantity of water flowing over the land surface which would potentially increase the amount of erosion. Thus the ultimate effect of crust formation on erosion would depend on several factors including the dynamics of water flow and the land area under consideration.

SUMMARY

Treatment of the water with cationic polymers decreased crust formation with increasing concentrations up to 10 g m^{-3}. The nonionic and anionic polymers used had negligible effects on crust formation as compared to the control. Inverse relationships between both the concentration of eroded material and total amount of eroded material and the steady state infiltration rate were found. Thus, crust formation was found to decrease soil erodibility. The effect of crust on the amount of erosion is ambiguous because, while crust formation decreases erodibility, it increases runoff which increases the energy for transporting sediment over an extended area.

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Table 1. Final IR, EMC, their standard deviation (SD), and TEM for the different treatments.

Treatment	Final infiltration rate		Eroded material concentration		Total eroded material
	Mean	SD	Mean	SD	Mean
	-------mm h^{-1}------		----kg m^{-3}-----		---kg ha^{-1}---
		First storm			
DW, CS†	19.0	2.8	0.15	0.04	20
DW, US†	4.0	0.3	3.5	0.9	1107
HCCP 1.0 g m^{-3}, US	4.9	0.9	4.8	1.4	1583
HCCP 2.5 g m^{-3}, US	6.0	2.3	5.7	1.2	1733
HCCP 5.0 g m^{-3}, US	10.4	2.4	10.2	1.5	2228
HCCP 7.5 g m^{-3}, US	12.4	3.3	12.7	1.0	2653
HCCP 10 g m^{-3}, US	19.0	3.0	19.5	2.0	2642
LCCP 5 g m^{-3}, US	7.4	0.9	7.3	1.1	1984
LCCP 10 g m^{-3}, US	14.2	1.9	10.0	0.9	1722
LCCP 20 g m^{-3}, US	14.5	1.2	14.5	2.8	2557
nonionic 10 g m^{-3}, US	5.2	1.0	2.3	0.9	630
nonionic 20 g m^{-3}, US	4.4	0.5	2.0	0.4	579
anionic 10 g m^{-3}, US	4.0	0.4	3.2	1.3	1012
		Second storm			
DW, US	3.2	0.6	4.3	0.2	1678
HCCP 10 g m^{-3}, US	5.1	0.8	2.0	0.9	654
		Third storm			
DW, US	2.6	0.2	4.1	0.5	1702
HCCP 10 g m^{-3}, US	3.5	0.1	1.3	0.3	520

†covered soil (CS), uncovered soil (US)

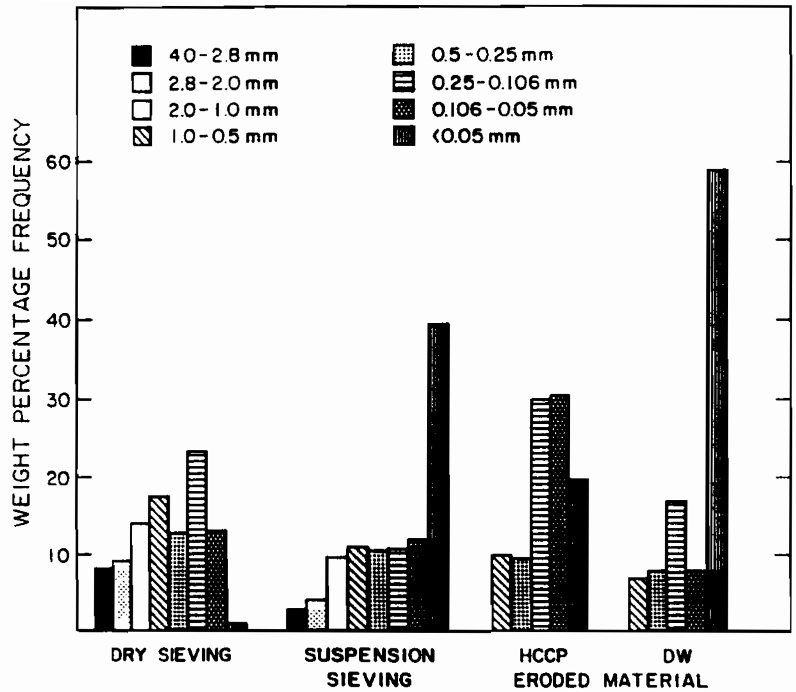

Figure 1. Distribution histograms of the material sizes for the dry soil and the eroded material and particle sizes determined by suspension sieving.

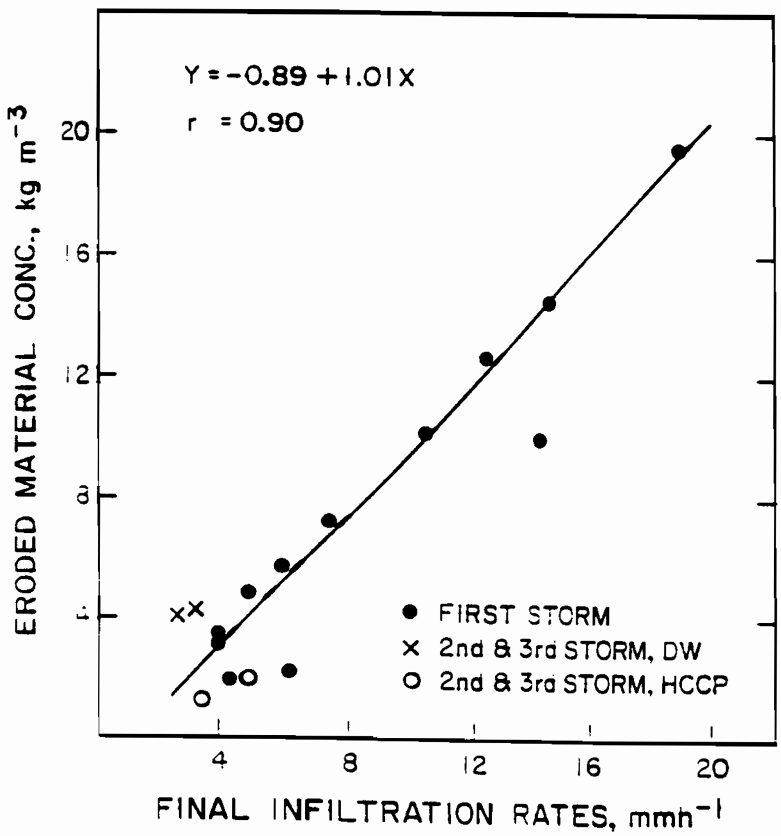

Figure 2. Regression line and experimental points of the EMC values as functions of the final IR.

ADVANCES IN THE GENETIC TRANSFORMATION OF CROP PLANTS

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Genetic engineering methods for crop plants have progressed to the point that several transgenic plant species are in field tests. Results of the past year (1988) have added rice and soybean to the list of plants which can be transformed. While complete success has not been achieved yet with other major crop species such as maize and wheat, new methods are giving renewed expectations that these barriers will also fall.

Advances in transformation technology have come in four areas. These are protoplasts, Agrobacterium, microinjection, and microprojectile bombardment. Each of these applications will be discussed in turn.

The most obvious transformation route is to remove the plant cell wall, creating a protoplast, to introduce the gene of interest, and to nurture the protoplast back into a walled cell, a callus, and, finally, a flowering plant. For most species, the first steps are routine; problems arise at the plant regeneration step. Typically, the time and manipulations required for the transformation events destroy any capacity of the cultured cells to regenerate plants. Careful optimization of the starting materials and culture conditions is essential. The payoff in the past year has been transformed rice plants (1) and transformed but sterile maize plants (2).

The most successful transformation route is mediated by Agrobacterium tumefaciens, the organism which induces crown galls by transferring a panel of genes (the T-DNA) into a plant cell. Many dicotyledonous species can now be transformed using genetically-modified Agrobacteria (3). For example, Hinchee and co-workers (4) recently reported the low frequency transformation of soybean using Agrobacterium. Unfortunately, the cereals do not appear to be susceptible to this method of transformation.

Given the significant limitations of these established transformation routes, the search is always on for simpler and/or more general methods. Microinjection has long promised to be such a tool (5). The successful transformation of oilseed rape via microinjection of individual, intact cells in multicellular tissue culture embryos (6) has generated renewed interest in this technology. Other crops, including the cereals, have similar morphogenetic structures which might be especially suited to this method.

A second purely physical method for moving DNA into intact cells was also demonstrated this year. The "biolistic" method, also called microprojectile bombardment, particle gun, ballistic transformation, or permutations thereof, was described by its inventors (7) in 1987. Dense metal particles, coated with DNA, are accelerated on a carrier towards target cells. Several cell layers can be penetrated, and a few of these cells become transformed. Klein et al. (8) reported the first use of this method, on onion epidermal cells. Christou and co-workers, using a different gun design, later extended this method to transform soybean plants (9, 10).

Plant transformation technology continues to advance at a rapid pace, in terms of new methods and of the list of species amenable to genetic engineering. The expectation is that all major crop plants will be subject to transformation within a period of years.

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MODIFICATION OF WHEAT STORAGE PROTEINS FOR IMPROVED FLOUR QUALITY

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Introduction

The wheat storage (gluten) proteins are of prime importance in determining the mixing and baking properties of wheat flour doughs and the variation in these properties among cultivars. Although we still lack a detailed understanding at the molecular level of dough properties and why they vary from cultivar to cultivar, various hypotheses have been put forward (1,2,3) to explain these properties and their variations. All would lend themselves to molecular biological approaches to genome modification when that becomes feasible for wheat and other monocots, possibly in the near future.

I plan to discuss several of these hypotheses and speculate on how genetic engineering approaches might be used to improve quality. It will often be possible to bring about the desired changes by conventional breeding approaches, and, at present, this is the only way to improve wheat. Direct modification of the genome by recombinant DNA methods might make it possible, however, to avoid the extensive, time-consuming crossing and backcrossing often necessary to introduce desired genes and remove unwanted genetic material when traditional breeding approaches are followed.

Gluten Proteins

The gluten proteins are made up of a complex mixture of protein components that are notable for high proportions of two amino acids, glutamine and proline. They can be divided into two approximately equal fractions, gliadin and glutenin. The gliadin fraction is made up of monomeric proteins, that is, they have single polypeptide chains, whereas the glutenin fraction is made up of polypeptide chains, some of which are similar to many of those found in the gliadin fraction, that are joined by intermolecular disulfide bonds into higher-level structures. These higher-level structures are actually polymers of polymers insofar as the protein subunits linked together are already polymers of amino acids. I shall call them *glutenin polymers.*

There is a range of sizes of these polymers present in a dough, extending from dimers, trimers, and so on up to very large aggregates that have molecular weights (MW's) in the millions. These polymers may be largely linear in character with each subunit participating in two intramolecular disulfide bonds that link it to two other subunits (4). There are two main types of subunits in glutenin, the high-molecular-weight glutenin subunits (HMW-GS) and the low-molecular-weight glutenin subunits (LMW-GS); these are possibly joined randomly in glutenin polymers. Good correlations have been established between certain types of HMW-GS in a cultivar [recognized by its sodium dodecylsulfate electrophoretic pattern (SDS-PAGE)] and quality (5).

It is well known that the gliadins and glutenins are cohesive, but the gliadins contribute mainly to the extensibility (ability to flow) of a dough whereas the glutenin fraction contributes mainly to the elasticity of a dough. Recent work (6) indicates that the variability observed among cultivars seems to result more from the glutenin fraction than from the gliadin fraction.

Bases for Differences among Cultivars in Mixing and Baking Quality

Some possible bases for differences among cultivars in mixing and baking quality (1) might arise from differences in: [1] the gliadin to glutenin ratio, [2] the ratio of HMW-GS to LMW-GS, [3] the MW distribution of glutenin polymers, [4] the branching of glutenin polymers, [5] the integrity and elasticity of β-spirals in HMW-GS, [6] the geometric arrangement of intermolecular disulfide bonds, and [7] the intrinsic ability of glutenin subunits to interact and aggregate through secondary bonding forces. Of course, it is likely that combinations of factors or other factors that I haven't recognized may be involved.

In this relatively short paper, I plan to discuss just the first three possible factors listed above. I shall also discuss briefly the question of improving the nutritional quality of wheat flour by increasing the lysine content of the storage proteins.

<u>The relative proportions of gliadin and glutenin</u>

Because gliadins tend to make a dough more extensible (weaker in mixing character) whereas glutenins tend to make a dough more elastic (stronger in mixing character), it has been suggested that the ratio of gliadins to glutenins is a source of differences among cultivars in the mixing and baking character.of bread wheats (6,7). Evidence for this ratio being important for durum wheat quality has been presented by Autran et al. (8).

Insertion into the wheat genome of glutenin genes, along with highly-efficient promoter sequences, should increase the strength of a weak flour by increasing the proportion of glutenin (usually this would increase loaf volume as well). It might be necessary to insert both a HMW-GS gene and a LMW-GS gene (or multiple copies of these genes) at the same time. The importance of placement in the genome in regard to genome, chromosome, and intra-chromosome location in determining gene expression is not yet determined. However, because of the large proportion of non-coding DNA in plant genomes and the diverse locations of gluten protein gene clusters that are known to be expressed in the wheat genome, the insertion location may not be of major importance for obtaining expression of the inserted genes as long as the necessary promoter sequences are present. Introduction of a gliadin gene or cluster of gliadin genes, again perhaps with highly efficient promoter sequences, into the wheat genome in an additive fashion might be effective in reducing the strength of a too-strong flour.

The Ratio of HMW-GS to LMW-GS in Glutenin

Because HMW-GS are known to correlate with good and poor quality and because Lawrence et al. (9) have suggested that greater proportions of HMW-GS in a wheat cultivar might increase mixing strength and loaf volume, insertion of a particular HMW-GS gene, one known to correlate with good quality, into the wheat genome of a weak mixing character wheat cultivar with poor loaf volume should result in improved quality. If this addition resulted in a character that was too strong and too elastic, it might be possible to decrease the efficiency of the promoter or select for a transformant with decreased promoter activity. Alternatively it might be possible to insert a LMW-GS gene or a gliadin gene simultaneously with the HMW-glutenin subunit gene in order to decrease strength and elasticity.

MW Distribution of Glutenin Polymers

Glutenin polymers range in MW's from about 80,000 (LMW-GS dimers) through very large size aggregates incorporating twenty or thirty subunits and having MW's in the millions. The MW distribution of these polymers in a wheat cultivar might play an important role in determining the viscoelasticity of doughs prepared from flour of that cultivar. In polymeric systems, a shift in the MW distribution toward higher MW's usually results in greater viscosity and greater elasticity. A strong mixing cultivar with good loaf volume might have a MW distribution shifted toward the high end as compared to a cultivar with weak mixing character and poor loaf volume. It seems likely that certain gliadin-like protein genes that have undergone mutations resulting in an odd number of cysteine residues are capable of terminating the growth of glutenin polymer chains during synthesis (10). This is a consequence of having only a single cysteine available for intermolecular disulfide bond formation; all other cysteines in these protein subunits form intramolecular crosslinks. Insertion of such genes into the wheat genome might result in a shift downwards in MW distribution of glutenin polymers and, hence, decrease mixing strength and elasticity of the cultivar. Conversely, addition of genes for HMW-GS or LMW-GS that participate mainly in chain extension as a consequence of having two or more cysteine residues available for formation of intermolecular disulfide bonds, should cause a shift upward in the MW distribution of glutenin polymers and an increase in mixing strength and elasticity for the cultivar.

Improvement of Nutritional Quality through Increase In Lysine Content

Wheat proteins are low in certain essential amino acids, particularly lysine, which is the first limiting amino acid (11). Although the lysine content of wheat flour could be improved by increasing the amounts of albumins, which have higher lysine contents, relative to the gluten proteins, this might have the disadvantage of diminishing mixing and baking quality, for which the gluten proteins are largely responsible. In addition, some of these albumins are inhibitors of human α-amylases or proteases (12) and although it has not been established that these inhibitors in wheat cause any problems for humans, there has not been sufficient evaluation of the possibility to proceed with their deliberate increase in wheat endosperm without some concern for possible adverse affects.

An alternative way of improving the lysine content of wheat gluten proteins that should have no effect on mixing and baking properties would be to substitute lysine for arginine and histidine in a few suitable storage protein genes (both gliadins and glutenins) by protein engineering methods (3) and introduce large numbers of these genes into wheat. Because the positions of positively charged residues would be unchanged in the amino acid sequences, there would probably be no adverse affect on the conformational structure of the proteins or on their ability to be deposited properly in protein bodies during protein biosynthesis. By this approach, the lysine content of wheat gluten proteins could be increased up to five times depending upon how great a proportion of the gluten proteins in the transformed cultivar was made up of the lysine-increased proteins. This would not make wheat gluten proteins equivalent to high quality proteins like casein, they would have at best only half the lysine content of casein, but it would certainly result in significant improvement, improvement gained without diminishing mixing and baking quality.

Conclusion

The preceding discussion is obviously highly speculative. My intention is to point out some possible ways in which wheat quality might be improved through genetic engineering approaches. Some of the approaches might be impractical. For example, it may turn out to be impossible to introduce large numbers of new genes into wheat in order to swamp out the effects of existing genes. The simplest approach to wheat genome modification for quality improvement, the introduction of an additional expressed HMW-GS gene, will probably be carried out as soon as the a suitable means for transforming wheat has been demonstrated. The addition of a HMW-GS gene, say the gene for HMW-GS 5 (or its linked partner subunit 10; see ref. 5 for nomenclature), to 'Anza' might very well make a significant improvement in the quality of this high-yielding California cultivar with poor mixing and baking quality.

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CURRENT STATUS OF COMMERCIAL APPLICATION OF PLANT MOLECULAR BIOLOGY

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Molecular biology is beginning to add some new tools to the arsenal of conventional methods which have been and will continue to be essential to the success of plant breeders. These new tools include everything from restriction fragment length polymorphic (RFLP) markers (1,2) to chimeric gene constructs which can be directly introduced into plant cells and give rise to genetically altered plants. I will briefly describe some of the representative successes in these areas and then describe in a little more detail the engineering of insect resistance in plants via the transfer into plant cells of a protoxin gene from the soil bacterium, Bacillus thuringiensis.

RFLP technology offers an important tool to plant breeders but like other tools it has its limitations. Its usefulness is only as good as the scientist's ablity to measure a given trait of interest for which the linkage is being assessed. However, once a RFLP marker is linked to some trait of interest, its contribution to a breeding program becomes apparent. These markers provide a rapid way of following the inheritance of traits genotypically and practically allows the breeder to use a much smaller breeding population.

The direct introduction of genes of interest into plants has been succeeding and new developments make future molecular applications more promising with time. The genetic engineering of plants for insect, herbicide, and viral resistance utilizes a common strategy regardless of the gene of interest. A potential gene for the resistance must be identified, cloned, characterized, modified if necessary, and inserted into a chimeric gene construction. These constructed chimeric genes have been moved into plants primarily using the agrobacterium Ti Plasmid as the transformation vehicle. Resulting transgenic plants have been evaluated in terms of resistance and yield relative control plants.

Resistance of important crop plants to herbicides has been a major focus of many chemical companies because of the obvious commercial benefits to these companies. The tolerance of a transgenic plant to herbicides can result from the detoxification of the herbicide or from changes in the sensitivity of an altered target enzyme. The gene encoding phosphinothricin acetyltransferase which gives resistance to phosphinothricin represents an example of the use of a detoxifying gene (3). When transferred into plants, it givens outstanding resistance. At expression levels as low as 0.001% relative to total protein, transgenic tomato and potato plants have complete resistance to the herbicide. Transgenic plants with an altered acetolactate synthase which is less sensitive to sulfonylurea herbicides have also been engineered (4,5). In a similar way, plants resistant to glyphosate have been obtained by introducing a modified coding sequence for 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase which is a less sensitive target for glyphosate than the wild type gene product (6).

Another important application of molecular biology addresses viral resistance in plants. Virus tolerance has been demonstrated in transgenic dicot plants as a consequence of the engineered expression of viral coat proteins (CP) from tobacco mosaic virus (TMV), alfalfa mosaic virus AlMV, cucumber mosaic virus (CMV), and potato virus X (PVX) (7). Several studies have demonstrated that transgenic plants expressing PC have less chlorotic/necrotic lesions when inoculated with virus than do control plants. In addition, plants making CP have delayed symptom development. The level of accumulation of these CPs in the tolerant plants correlates with the degree of protection. Apparently, protection may be the result of blockage at an early stage of the uncoating of the virus within the cell. The results of field tests on virus protection in transgenic plants have been encouraging (7). Control infected tomato plants suffer a 25-30% loss in yield while transgenic plants expressing CP have shown none. Clearly this approach to viral resistance in plants is an effective one.

As an example of the molecular strategies used in the genetic engineering of a trait of interest into plants, I will describe a gene of interest with which I have worked, i.e. an insecticidal protein from the bacterium, Bacillus thuringiensis (B.t.). This gene was ultimately used to impart insect resistance to transgenic plants. The protoxin gene of Bacillus thuringiensis (B.t.) was identified as a commercially promising gene to clone, characterize, and express in important crop species. The B.t. insecticidal protein has been approved for use on more than 200 crops including broccoli, cabbage, cauliflower, lettuce, melons, tomatoes, grapes, soybeans, tobacco, and alfalfa. B.t. controls over 55 species of insect pests (8). Until recently, all of these pests belonged to the order

Lepidoptera. The commercial use of the crystals in insect control is desirable because of their insecticidal efficacy, specificity, and seeming harmlessness to the environment. In addition, there is little evidence of the development of insect resistance in geographical areas of the U.S.A. where the crystals have been heavily used for 20 years (9). However, some insect resistance has been observed in the laboratory (10).

The mature crystals often exceed 1µm in length and 0.5 µm in width. When they are proteolytically dissolved in the alkaline gut of susceptible insect larvae, they split into several components (11), not all of which are toxic. Thus, while the crystals are composed of repeating polypeptide subunits of MW 135,000, proteolytic activation results in the production of toxic molecules of about MW 68,000 (12,13,14). The gene encoding the protoxin gene was the one we set out to clone, modify, and transfer into our model tobacco system. I will discuss the strategies we used to obtain the protoxin gene, characterize it, and fuse it into chimeric gene constructions as well as the methods used to transform the plants and assay them for the expression of the B.t. gene. Finally, I will speculate on the future application of some new methods and molecular constructions which have the potential of transforming some of our commercially important monocots.

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WILD RICE (*ZIZANIA PALUSTRIS*) NITROGEN RATE AND TIMING TRIALS

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INTRODUCTION

Two replicated small plot experiments were established in commercial wild rice fields in the spring of 1986 in Sutter and Yuba counties in California's Sacramento Valley. Objectives of the trials were to 1) evaluate the effect of preplant rates and split applications of nitrogen fertilizer on several agronomic characters of wildrice, including yield; 2) correlate N, P and K in leaf tissue with grain yield; 3) monitor crop growth and development.

The following report summarizes the data from a single year and is meant as a statement of results for those who are interested in wild rice; no recommendations are intended.

METHODS

Five preplant and four split application nitrogen treatments were applied as ammonium sulfate (21% N)in a randomized complete block design with four replications. Preplant ammonium sulfate was banded at about 23 cm spacings, 5-10 cm deep, into a prepared seedbed. Ammonimum sulfate was broadcast by hand into the flood water at either of two growth stages, designated Jt=early jointing and Efl=early flowering(< 5% flowering on main culm). Phosphorus (0-25-0 granule) was applied at the rate of 28 kg/ha P_2O_5/ac. broadcast over the entire plot area. The Yuba trial also had 110 kg KCl/ha over the entire plot.

Growth was monitored in the Yuba trial at frequent intervals. Plant samples from the Sutter trial consisting of 25-50 most recently matured leaves from tillers, were taken at several growth stages and analyzed for total N, P and K. Heading was measured twice in the Yuba trial by counting percent panicles completely free of the boot. Plant height and lodging estimates were made at harvest. Harvest samples of 2.3 m x 15 m were taken with a SWECO 324 plot combine. Fields were drained prior to harvest and soil was soft but not muddy. Harvest samples were weighed in the field and subsamples taken for oven dry moisture.

RESULTS

Agronomic Effects

Heading was delayed up to five days by increasing nitrogen rates. Split applications also affected heading, depending on the specific split and how efficiently the nitrogen was recovered by the crop. Generally, when more N was available later in the season, from either high preplant rate or late application, heading was delayed.

Mature plant height, lodging percent and grain moisture content at harvest increased as nitrogen rate increased. The range for all three parameters was greater in the Sutter trial where nitrogen responses were generally more dramatic. Height and lodging were less in the split applications compared to the 102 N preplant treatment.

Yield of paddy wild rice yield was adjusted to 35% moisture content. Yield increased to 68 kg N/ha in both locations and declined above that. This N rate is somewhat less than average commercial usage, approximately 110 kg N/ha.

Response to preplant N in the Sutter trial (Table 1) was very dramatic: A sharp increase with each of the first two increments of N, followed by a rapid yield decrease at 102 kg N/ha , and no further yield losses at 136 and 170 kg N/ha. Plant symptoms of N deficiency in this trial were very characteristic of grass family plants: Stunting and yellowing, especially of lower leaves, small panicle size, early heading and reduced height. Yellowness and reduced mature height were the most acute symptoms. Plots that displayed moderate symptoms tended to produce the highest yield, while plots with acute symptoms or none at all produced lower yields. Lodging tended to be greater in higher N plots which partly explains the effect of excess N. These results are consistant with a plant type very growth-responsive to N but incapable of tolerating high rates.

Table 1. Agronomic effects of N rate and timing: SUTTER COUNTY TRIAL

Treatment P + Jt + Flw	Height cm.	Lodging %	Moisture %	Field yield 35% H_2O kg/ha
1. No nitrogen	103	1	30.7	1035
2. 34 N preplant	153	1	33.0	2184
3. 68 N preplant	178	18	33.8	3171
4. 102 N preplant	213	85	34.9	2297
5. 51 + 51 + 0	183	3	34.1	2762
6. 51 + 0 + 51	203	1	34.9	3064
7. 0 + 68 + 34	165	4	33.7	2260
8. 34 + 34 + 34	163	1	36.4	2738
9. 136 N preplant	208	36	37.6	2290
10. 170 N preplant	223	78	39.4	2322
LSD (.05)	19	22	2.5	460

Date from the Yuba trial (Table 2) very closely parallels the Sutter trial except that crop response to all parameters measured, including yield, was over a narrower range. Nitrogen deficiency symptoms and chlorosis were never as severe as in the Sutter trial. One possible explaination is that preplant fertilizer was applied shallowly into moist soil followed by a one week delay to flooding, which may have lead to some N loss.

Yields of split application plots of 102 N were generally higher than 102 N applied preplant but lower than 68 N applied preplant. Therefore, splitting the total fertilizer N was less efficient than applying it preplant. Because the 102 N rate used in the topdressing treatments was too high , little can be inferred from the data regarding best timing; differences in efficiency cannot be separated from the effects of application timing. Future split application work will have to be done at rates that are suboptimal.

Table 2. Agronomic effects of N rate and timing: YUBA COUNTY TRIAL

Treatment	Heading on: 6/26	7/3	Plant Height	Lodging	Harvest Moisture	Field Yield 35% H_2O
P + Jt + Flw	%		cm.	%	%	kg/ha
1. No nitrogen	29	88	173	1	35.8	1756
2. 34 N preplant	24	83	194	1	36.1	2330
3. 68 N preplant	24	71	190	1	37.0	2540
4. 102 N preplant	18	65	209	18	37.3	2184
5. 51 + 51 + 0	18	78	199	16	36.2	2423
6. 51 + 0 + 51	16	70	199	3	36.9	2528
7. 0 + 68 + 34	19	68	193	1	35.9	2447
8. 34 + 34 + 34	18	55	193	3	35.7	2475
9. 136 N preplant	11	60	205	37	40.2	2062
10. 170 preplant	11	48	214	60	39.7	1985
LSD (.05)	13	15	16	22	1.8	293

The pattern of yield response to split applications was identical in both trials, with half preplant and half at early flowering providing the highest yield among split applications, and the treatment involving no preplant N giving the lowest.

Despite the difficulties interpreting the split application data, we can infer that 1) preplant N is more efficient, 2) some N is needed preplant for maximizing yield, and 3) best timing may be at appearance of first heads and might affect nutrition of the tillers more than the main culm.

Correlation of total N, P and K in tissue with grain yield

Leaf samples were taken four times in the Sutter trial at sixth leaf (early to mid-tillering), panicle initiation, boot, and early heading of the main culm. Because the main culm develops earlier than tillers, we avoided sampling it. Samples were analyzed for total N, P and K by the Extension Diagnostic Laboratory in Davis.

Approximate ranges of total N associated with maximum yield was estimated from scattergrams of the data for each of the four growth stages, Table 3,providing an estimated critical range for total N in the most recently matured leaf.

Table 3. Approximate relationship of total N in most recently matured leaf to maximum yield in the Sutter wild rice trial.

	Total			Approx. days
Growth Stage	Nitrogen %	Phosphorus %	Potassium %	after planting
6th leaf	3.8-4.1	.29	3.18	34
Panicle initiation	2.9-3.3	.25	2.74	43
Jointing	2.4-2.8	.23	2.00	49
Early heading	1.9-2.1	-	-	55

Data suggests a good relationship with yield of total N between 6th leaf and early heading of the main culm. Nitrogen declined rapidly with time thru this period of very fast development. Additional work is needed to verify both the accuracy and value of this relationship as a diagnostic tool.

Phosphorus levels declined with time and did not interact with nitrogen treatments, suggesting no P deficiency in either trial. There were similar leaf levels in both trials at equivalent growth stages. Potassium levels declined with time and increased slightly with nitrogen rate, especially in the Sutter trial. Levels in both trials were similar at equivalent growth stages. Table 3 summarizes P and K levels for both trials, averaged across N rates.

Crop growth and development

Regular observations of growth and development were made in the Yuba trial with the intention of identifying key growth stages. Data is in Table 4.

Table 4. Growth and development in the Yuba trial.

Date	Days after seeding	Growth stage	Comments
Apr 24	0	Sow field	By air into water
Apr 29	5	first leaf	Leaf 1.8 cm, root 0.4 cm.
May 1	7	1.2 leaves	Shoot 3.9 cm, root 3.6 cm. water 13-16 cm
May 6	12	2.2 leaves	Shoot 12.5 cm., about 4 roots water 11-13 cm
May 12	18		Shoot 37.1 cm., floating leaf
May 15	21	3.2 leaves	Floating leaf
May 20	26	4.5 leaves	Floating leaf
May 23	29	5 leaves	Tiller initiation, fifthleaf aerial, water 20 cm
May 27	33	5.8 leaves	Water 8 cm, no emerged tillers
Jun 5	42	Tillering	2 leaves on primary tillers, between 4th and 5th leaves, secondary tillers starting between 1st and 2nd tiller leaf, additional primary tillers starting between 5th and 6th leaf; lower leaf senescence.
Jun 10	47	Main culm in boot	First heads in low N plots; flag is 9th leaf; rapid elongation.
Jun 19	56	Tillers in boot	Anthesis on main culm; elongation.
Jun 24	61	Anthesis, tillers	Rapid elongation continues
Jun 26	63		Anthesis on main culm complete,first kernels on lower portion darkening, full heading, tiller elongation.
Jul 13	80		4 to 5 leaves on each plant, ripening, elongation.
Jul 15	82		Three leaves per tiller, some head fully ripe, near full height, heads are two feet above flag leaf.
Jul 23	90	Main culm mature	50% of kernels on main culm are dark, water turned off, 3 leaves functioning, late tiller panicles very small
Aug 8	106	Harvest	Approx 160-180 kernels/panicle

Tiller initiation began four weeks after seeding. The first tillers did not emerge from the water until nearly the sixth week after planting, about two weeks prior to heading of the main culm. Tillers began heading about two weeks later. Asynchronous heading no doubt contributes to poor yield response in wild rice. Three months after planting, 50% of the kernels on the main culm were filled and ripe and the field was drained. In two weeks, the field was ready for harvest.

USE AND INTERPRETATION OF NITROGEN ISOTOPE EXPERIMENTS TO DEVELOP A RATIONALE FOR N TIMING IN DECIDUOUS TREE SPECIES

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The effect of N timing on recovery of the N applied and its allocation to flowers/fruit vs. vegetative organs (leaves, shoots, etc.) in fruit trees is poorly understood. These questions have been addressed in prune, apricot and almond using isotopically labeled N carriers. The data obtained should also reflect the behavior of deciduous tree fruit species other than Prunus sp.

Uptake of isotopically labeled fertilizer N applied as N-enriched KNO_3^- and ^{15}N-depleted $(NH_4)_2SO_4$ by fruit trees permits us to determine the kinetics and recovery of fertilizer N in the organs sampled.

The capacity for uptake of fertilizer N (CNU) by immature, non-bearing prune trees varied seasonally (Table 1). CNU declined precipitously during leaf fall in autumn, therefore, fertilizer N should be applied well in advance of leaf senescence to permit N uptake by trees before winter. CNU remained low during winter and throughout the period of bud swell, but increased substantially during growth of new shoots in spring. CNU remained high and relatively constant until leaf senescence. The closer in time that fertilizer N is applied relative to the period of N demand by the tree, the greater the recovery of fertilizer N by the tree. The relative CNU in bearing tees may be reduced during early- and mid-summer if the distribution of carbohydrates to roots and root growth is reduced (as a result of preferential allocation of resources to developing fruit).

Table 1. Nitrogen uptake capacity (CNU)[1] of non-bearing prune trees following 10-day exposures to ^{15}N-KNO_3 at different phenological periods.

^{15}N-KNO_3 applications	Tree harvests	CNU (%)
Dormant (Jan. 16-26)	Feb. 5, 1976	4.75[2] A
Bud swell (Mar. 5-15)	Mar. 25	4.34 A
Rapid shoot growth (April 2-12)	April 22	30.52 C
Shoot growth cessation		
(May 14-24)	June 3	39.02 C
(July 9-19)	July 29	32.73 C
(Aug. 6-16)	Aug. 26	35.91 C
(Sept. 10-20)	Sept. 30	32.73 C
Mid-leaf fall		
(Oct. 22 - Nov. 1)	Nov. 11	16.14 B
Dormant (Dec. 3-13)	Dec. 23	3.66 A

[1] $\text{CNU (\%)} = \frac{\text{Total label absorbed}}{\text{Total label applied}} \times 100$

[2] Mean separation within columns by Duncan's multiple range test, 1% level.

The distribution of recently absorbed fertilizer N within the tree also varied greatly depending upon the phenology of the plant at the time of N uptake (Table 2). Thus, the small amount of N absorbed during the dormant period remained predominantly within the rootstock (until growth resumption in spring), whereas, 70% of N absorbed by the tree during extension shoot growth was translocated rapidly to these new shoots (Table 2). Extrapolation of these data to the field are consistent with the idea that N absorbed following an early spring application of fertilizer is allocated preferentially to (and may invigorate) vegetative growth. If excessive vegetative growth competes with fruit development, spring applied N (although recovered with relatively high efficiency) may be associated with a N utilization pattern which is horticulturally less desirable.

Nitrogen applied to mature almond trees in August contributed 12 times more fertilizer N to the blossoms the next spring than N applied in December (Table 3). We conclude that N applied in August was absorbed by the tree

Table 2. Comparative distributions of ^{15}N in non-bearing prune trees absorbed during 10-day ^{15}N-KNO_3 applications during various phenological periods.

^{15}N-application periods	Current growth[1]	1-year scion wood	2-year scion wood	Rootstock Trunk	Rootstock Roots
	^{15}N distribution (%)				
Dormant (Jan. 16-26)	-[2]	-	0.1	8.3	81.6
Bud swell (Mar. 5-15)	23.0	4.1	1.9	9.3	61.7
Rapid shoot growth (April 2-12)	70.6	5.3	1.6	3.7	17.8
Shoot growth cessation (May 14-24)	36.8	6.5	3.5	8.6	44.7
(Sept. 10-20)	19.6	3.7	2.3	7.9	66.6
Mid-leaf fall (Oct. 22 - Nov. 1)	13.0	5.8	2.9	11.2	66.4

[1]Includes buds and leaves plus new shoots when present.

[2]Figures represent percentages of total ^{15}N absorbed by the trees.

Table 3. Effects of soil texture and time of fertilizer application (applied as ^{15}N-Depleted Ammonium Sulfate) on relative recovery[1] of labeled N in blossoms the following spring.

Time of Fertilizer Application (1980)	Relative Recovery of Fertilizer in In Mature Blossoms (1981): Delhi Sand	Relative Recovery of Fertilizer in In Mature Blossoms (1981): Yolo Silty Clay Loam
Spring	100%	95%
Spring/Late Summer (split)	80%	84%
Late Summer	77%	-
Dormant	6%	7%

[1]Recovery expressed as a % of maximum recovery - which occurred following the spring application on the Delhi Sand.

before leaf fall, stored over winter in the roots and trunk, and redistributed to the blossoms in early spring. Nitrogen applied in December was not absorbed significantly by the tree before full bloom. In comparison with fertilizer applications during the growing season, recovery of fertilizer N in the crop was reduced 20% and 60%, on the light and heavier-textured soils, respectively, if applied during the dormant period (Table 4). (Presumably this reflected both the metabolic inactivity of the tree during dormancy as well as the accentuated loss by leaching and/or denitrification of fertilizer N from the root zone during this period.)

Table 4. Effect of application time and soil texture on the recovery[1] of fertilizer N by mature almond fruit the year following isotope applications of ^{15}N-depleted $(NH_4)_2SO_4$.

Time of Fertilizer Application (1980)	Relative Recovery of Fertilizer in In Mature Blossoms (1981)	
	Delhi Sand	Yolo Silty Clay Loam
Spring	73%	96%
Spring/Late Summer (split)	67%	100%
Late Summer	63%	-
Dormant	59%	38%

[1]Recovery expressed as a percentage of the maximum recovery - which occurred following a spring/late summer split application on the heavier - textured soil (Yolo Silty Clay Loam).

Soil texture and nutrient/water management may influence the recovery of fertilizer N as much as N timing per se. Thus, in the year following a spring/summer split fertilizer application, the recovery of fertilizer N in the crop was 50% greater in trees growing in a silty clay loam than was recovery by trees growing in the sandy soil (Table 4).

Field trials to evaluate the effect of N timing have often been inconclusive because of previous applications of excessive N. Bearing prune trees did not become N deficient even when fertilizer N was withheld for 5 years (personal communication, W. Olson, Farm Advisor, Butte Co., CA). Mineralization of organic N increases with rising summer temperatures, and, consequently, a fluctuation in available N may be superimposed over the effects of N application periods. Furthermore, blossom development and early spring growth in mature trees have access to the buffering capacity of a large, endogenous pool of N absorbed in previous year(s). Nevertheless, several years data obtained by the late Norman Ross (Farm Advisor, Stanislaus Co., CA) on cling peaches in California indicated that trees fertilized in July out yielded trees receiving the same amount of N in November or March. Midsummer fertilization also reduced preharvest fruit drop, improved uniformity of ripening, and decreased the number of split pits (personal communication, David L. Williams, former Manager, Agricultural Research, Del Monte Corporation). Nitrogen applied in midsummer has not encouraged shoot growth, as resulted from the spring applications.

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COMPARISON OF UPTAKE EFFICIENCY AND PARTITIONING OF N IN WHEAT BEFORE AND AFTER ANTHESIS: EVALUATION OF N MANAGEMENT STRATEGIES.

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The marketability of California hard wheat is reduced primarily by its low and variable protein content. Higher protein levels would give California-grown wheat an excellent market position because of its other desirable qualities such as low moisture, high test weight, and large kernel size (1). Our work on managing N to increase wheat protein content is the subject of this paper.

The availability of N at certain growth stages is a major determinant of both yield and grain N concentration (the latter directly reflecting grain protein content). Since yield varies year to year, the amount of N required to produce a particular protein level will also vary. For example, at 12.5 percent protein 7000 kg of grain contains 49 kg more N than 5000 kg of grain.

Nitrogen uptake from soil after anthesis has been reported to be as high as fifty percent of the N harvested in grain (2), but is typically much less (3). An important determining factor is how much N is available in the soil. When the soil surface is very dry it is difficult to supply N to wheat at anthesis, but with irrigation soil moisture can be controlled.

Over the past three years we have conducted a series of experiments to examine the prospects for improving the grain quality of irrigated wheat with the application of N at anthesis. We have not sought to address the separate economic issue of whether increasing management inputs are justified by current price incentives, but rather have attempted to ascertain what management techniques are necessary for achieving consistently higher grain protein levels.

We have focused on two questions. First, how does an application of N at anthesis compare with increased rates of preplant N in producing higher grain protein levels. Second, if N is applied at anthesis, how efficiently is it used by the plant.

To answer the first question we grew wheat at several preplant N levels, with or without an added application of N at anthesis. In both cases irrigation was applied at anthesis. Replicated experiments were conducted at Davis and the West Side Field Station, using 'Yecora Rojo', 'Anza', and 'Yolo' wheat. N at anthesis consistently improved grain N concentration at all preplant N rates. For example, Yecora Rojo in 1986/87 required 180 kg N/ha preplant to attain maximum yield (Figure 1). The addition of 45 kg N/ha at anthesis improved grain N significantly. Adding 60 kg/ha to the preplant rate (using 240 instead of 180 preplant) resulted in only a small increase in grain N levels.

During the 1987/88 growing season replicated plots in grower's fields received zero or 45 kg N/ha at anthesis. The anthesis N application did not affect yield, but in most cases caused a significant increase in grain N concentration (Table 1). At two sites the added N at anthesis made the difference in achieving the 12.5 percent protein goal, which is considered a minimum standard for high quality wheat.

Determining how efficiently N applied at anthesis is utilized involves two measurements, the efficiency of uptake by the plant, and the efficiency of its partitioning to grain.

To follow the uptake of preplant N and to distinguish it from N applied at anthesis we conducted an experiment using isotopically labeled N. Two plots with identical preplant and anthesis N rates were compared, one having labeled preplant N and the other labeled anthesis N. With this arrangement the amount of N taken up from preplant and anthesis N applications can be determined and any interactions observed. Results from the first year of this experiment indicate that uptake efficiency of N applied at anthesis is considerably higher than that of preplant N (Table 2). In addition, applying N at anthesis did not decrease the uptake of preplant N.

The efficiency with which N from the plant is partitioned to grain is called N harvest index (NHI). This is calculated as the ratio of N in grain at maturity to N in grain plus straw. Since this measurement is made at harvest, it includes all N that the plant took up over the entire season. Many of our experiments involved applying labeled N at anthesis. By determining the amount of labeled N in grain and straw, we can calculate the harvest index of that N which was applied at anthesis, which we call anthesis-NHI. Comparison of NHI and anthesis-NHI from three of our experiments show that in every case the N taken up after anthesis was partitioned more efficiently to grain than the N taken up over the entire season (Figure 2).

In conclusion, our experiments have demonstrated that the grain protein content of irrigated wheat can be significantly improved through application of N at anthesis. This can be accomplished with good N use efficiency if N applications are carefully chosen.

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Table 1. Effect of application of N at anthesis in growers' fields. Values are based upon oven dry grain.

County	Cultivar	Yield	Grain N concentration	
		kg/ha	0 anthesis N	45 kg/ha anthesis N
Kern	YR	8374	2.23	2.66*
Kings	Kl	7692	2.34	2.52*
Madera	YR	7654	2.16	2.36*
Sacto	Kl	9192	2.18	2.17
Sacto	Kl	8966	1.91	2.14*
San Joaq.	Kl	4901	2.69	2.92*
Tule	YR	6716	2.62	2.71

*, significant difference between anthesis N treatments, $p<0.05$

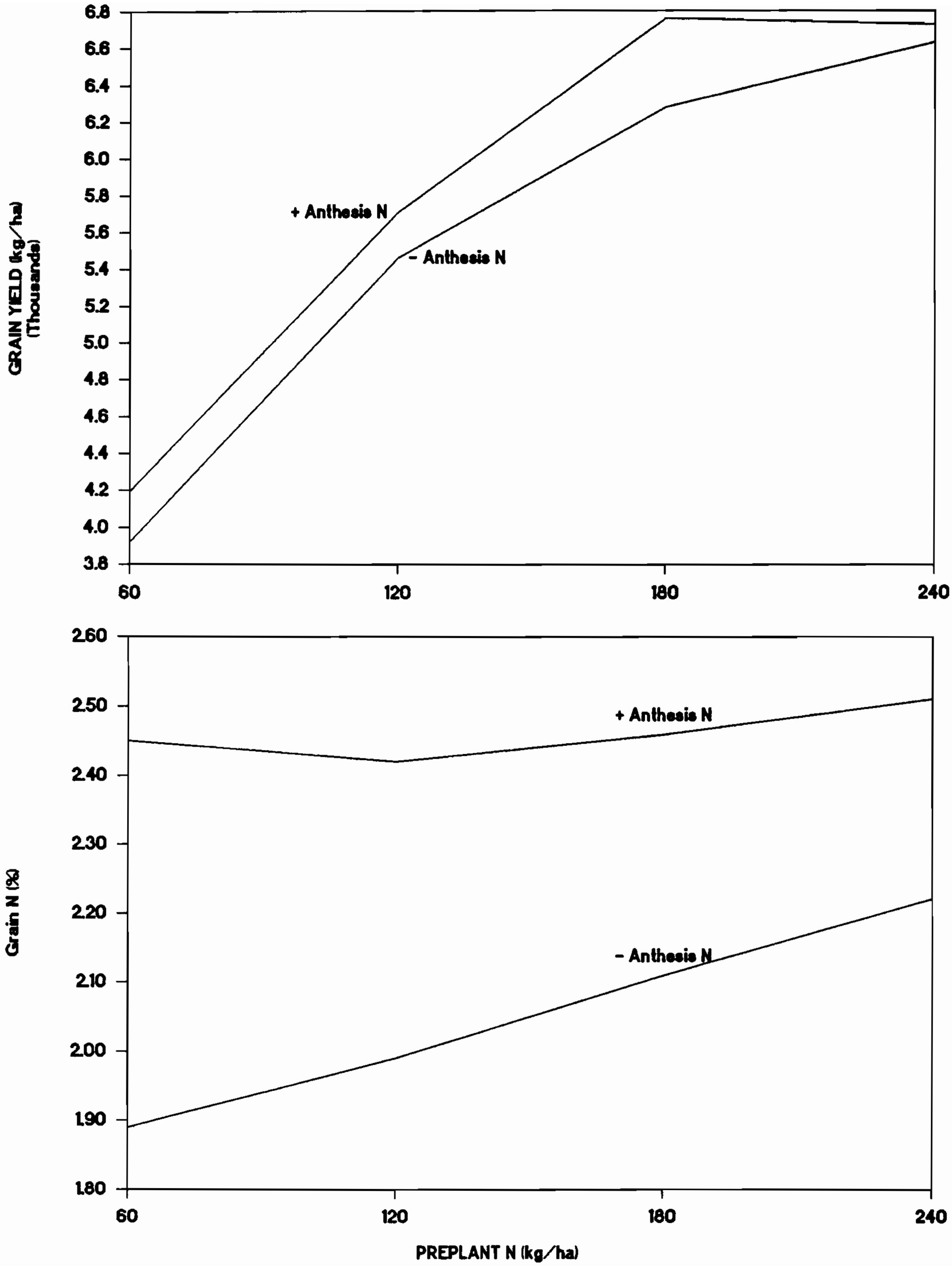

Figure 1. Effect of applying 45 kg N/ha at anthesis on grain yield and grain N concentration of Yecora Rojo wheat.

Table 2. Yield, grain N concentration, and recovery of applied N in wheat plants. Values in parenthesis are percent of applied which was recovered.

Preplant N rate	Anthesis N rate	Grain yield	Grain N conc.	Recovery of applied N Preplant	Recovery of applied N Anthesis
kg/ha	kg/ha	kg/ha	%	kg/ha	kg/ha
120	30	6015	2.03	55 (46)	22 (73)
	60	6249	2.32	57 (48)	48 (80)
180	30	7068	2.18	97 (54)	24 (80)
	60	6869	2.36	99 (55)	44 (73)
240	30	7086	2.28	131 (55)	18 (60)
	60	6977	2.40	133 (55)	33 (55)
Significance					
Preplant		***	***	***	***
Anthesis		NS	***	NS	***
Preplant*Anthesis		NS	***	NS	**

,* indicates a significant F value at $p<0.01$, 0.001, respectively.

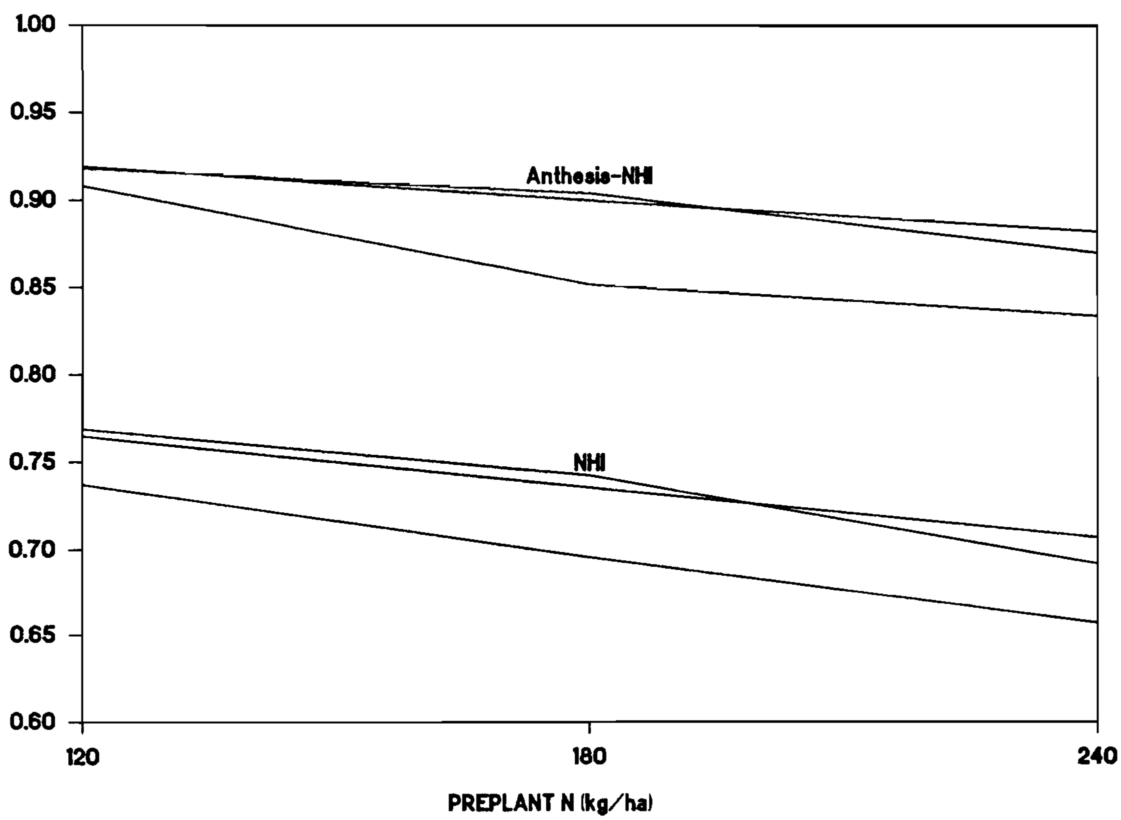

Figure 2. Comparison of anthesis-NHI and NHI of wheat. The three pair of lines represent three different experiments.

Effects of Ammonium Thiosulfate as a Starter Fertilizer Blend on Germination of Tomato;

and

Effects of Pop-Up Starters on Germination of Tomato and of Corn

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Potential damage to germinating crops have been associated with various fertilizer materials and placement. Tests conducted in Yolo County in tomatoes and field corn indicate that starter fertilizers can reduce and delay emergence of these crops and well as influence final yield in some instances. First, a field trial evaluating emergence of direct seeded tomatoes with ammonium thiosulfate combined with a starter fertilizer blend will be discussed. A discussion of pop-up starter fertilizers in tomatoes and field corn will follow.

Ammonium Thiosulfate Field Trial Summary: A field trial was established with grower Harlan Dumars in the Woodland area following a stand failure in a commercial field of canning tomatoes. The area treated with a custom blend of 12-6-6 plus thiosul (ammonium thiosulfate) failed to emerge. Tap roots were shriveled on the few plants that did emerge. Few weeds, mostly nightshade and volunteer tomatoes from the previous year, were present in the seedline area. Ammonium thiosulfate was used as a source of sulfur.

In a bench test at room temperature, tomatoes seeded into pots with soil from the affected seedline area had a 47% emergence compared to soil away from the seedline.

Four starter fertilizer materials were evaluated in the re-plant field. Treatments were 1) an unfertilized control, 2) 8-24-6 at 15 gallons per acre (gpa) 3) 12-6-6 at 25 gpa 4) 12-6-6 3S as ammonium sulfate at 25 gpa and 5) 12-6-6 5S as ammonium thiosulfate at 25 gpa. Materials were applied through CO_2 pressurized tanks attached to the grower's 3 row planter unit. The various starter blends were applied through the existing fertilizer shanks placing the starter less than an inch directly below the seed. Only the center bed of the three row unit was used in the test. Outside rows were fertilized per grower's standard practice of applying 15 gallons per acre of 8-24-6, in this instance. Planting date was May 5, 1987. The field was overhead irrigated twice before emerge began 13 days later.

Counts were taken initially at the cotyledon stage and again at the 2 true leaf stage. Compared to the unfertilized control, a 70% reduction in stand establishment resulted with the 12-6-6 5% thiosul plots. However, statistically, this was no different from any of the other 12-6-6 blends (table 1). Roots of seedlings dug from the thiosul treated plots were again shriveled. Though results from stand counts in the field trial were not conclusive, there is an indication that thiosul placed close to the direct seeded tomatoes along with large quantities of 12-6-6 can reduce stand establishment.

Table 1. Effects of starter fertilizer 12-6-6 +5S thiosul on emergence of direct seeded processing tomatoes in 1987 field trial with Harlan Dumars Ranches, Woodland, CA.

Treatment	Stand Count of 20' 5/21	5/29		% of control
1. Unfertilized Control	119	113	a	100
2. 8-24-6 at 15 gpa	118	84	ab	75
3. 12-6-6 at 25 gpa	97	81	abc	71
4. 12-6-6 +3S as ammonium sulfate at 25 gpa	77	57	bc	50
5. 12-6-6 +5S as ammonium thiosulfate at 25 gpa	49	34	c	30
L.S.D 5%	ns	48		
C.V. %	55	60		

Effects of Pop-Up Starters on Germination of Tomato and of Corn

Pop-Up starter fertilizer placement has been a Ohio and Indiana recommendation for mid-western tomato growers to increase efficiency and reduce planting problems associated with shanking starters in wet soil conditions. The practice was tested in direct seed processing tomatoes and field corn in Yolo County during 1984 and 1985.

The Purdue University recommendation for starter fertilizer as a on-seed placement, "pop-up", is to dilute 10-34-0 fertilizer 1:5 with water and spray 11 gallons of solution per acre into the seed furrow. A spray nozzle is mounted near the back of the seed shoe with the seed being sprayed as the seed falls into the seed furrow.

Tomato results: The pop-up starter fertilizer technique was inferior in a early planted test with direct seeded processing tomatoes in Yolo County compared to a more conventional shanking of 15 gallons of 10-34-0 under the seed. Pop-up treated seeds were slower to emerge and had few percent emergence. Seedlings were smaller and at the end of the season, yielded less fruit (table 2). Plant tissue samples confirmed that less total N and P were taken up by the seedling. Lab analysis of the Yolo test site soil samples showed 5 ppm using the sodium bicarbonate extraction method by Olsen. Increased rates of pop-up starter solutions further reduced emergence. Westside Field Station test conducted by Kent Tyler also showed pop-up to be inferior to the conventional placement of larger quantities of starter fertilizer below the seed.

Table 2. Effects of pop-starter fertilizer on processing tomatoes in an early planted field trial with low soil P levels near Woodland, CA.

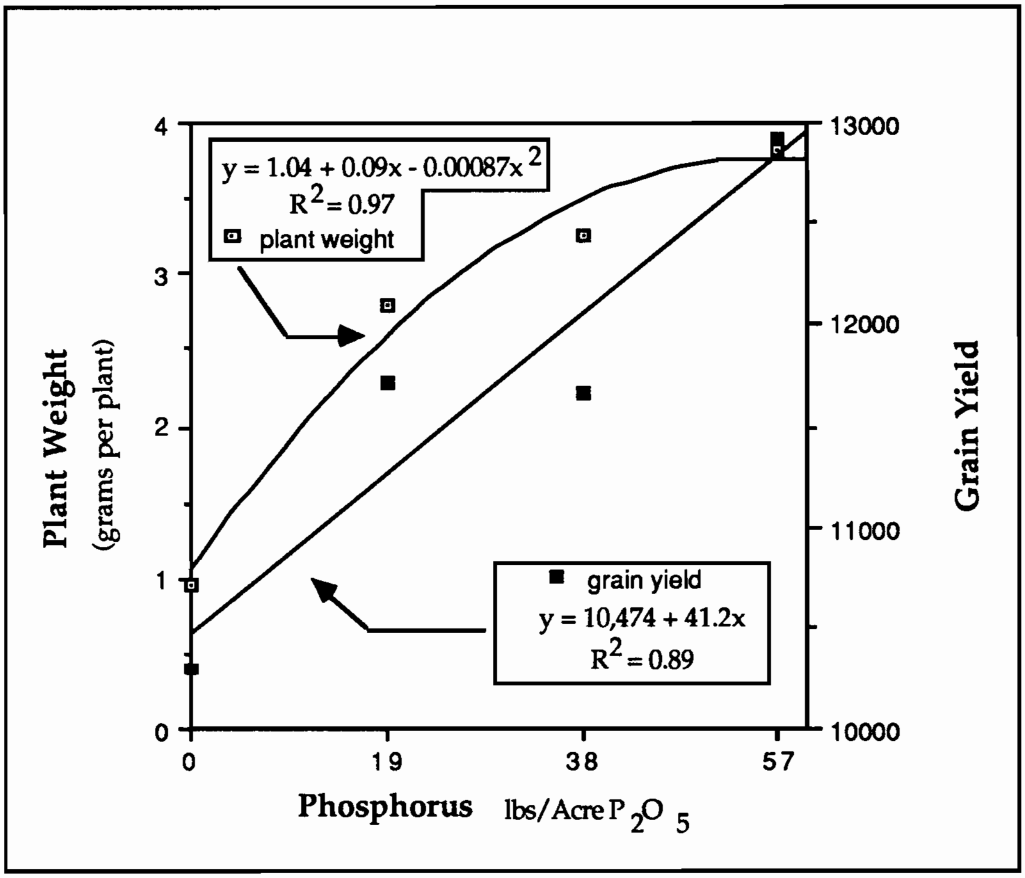
Treatment	lbs/a P_2O_5	# emerged	days to emerge*	seedling growth**	yield tons/a
1. Conventional shank	59	230	16.3	17.4	27.4
2. Unfertilized Control	0	210	17.2	2.8	12.9
3. Pop-Up 1X	9	171	18.0	7.3	19.7
4. Pop-Up 2X	17	78	19.4		
5. Pop-Up 3X	26	32	20.1		
L.S.D 5%		33	1.3	3.2	7.0
C.V. %		19	6	13	20

*mean emergence days
**dry weight in grams per 100 plants

Field corn results: UC Farm Advisor Tom Kearney's tests with pop up in field corn also showed it to be inferior to the normal practice of banding the starter 2" below and 2" to the side of the seed. The test was conducted in same grower field as the 1984 tomato trial. With this low phosphorus soil, there was a linear seedling growth and grain yield response to increased rates of phosphorus (figure 1).

Figure 1.

Effects of Phosphorus on Seedling Growth and Grain Yield of Field Corn, Yolo County, 1983



In another test with corn at the UCD agronomy farm, high rates of 10-34-0 were applied in a field test with pop-up starter. As much as 20 gallons of 10-34-0 was applied diluted 1:2 with water without injury. There was no plant growth response to phosphorus in this site and no differences in grain yield.

Pop-up starter tests in corn were not continued after 1983.

Summary: In general, pop-up starters have not proven more efficient in phosphorus deficient soils. In some cases, pop-up may be detrimental to stand establishment. The pop-up starter fertilizer method is not recommended in California.

Does a Soil K Deficiency Cause Late Season K Deficiency of Cotton in California?[1/]

K. G. Cassman, B. A. Roberts, T. A. Kerby,
S. M. Brouder, S. H. Gulick, F. L. Padilla[2/]

Introduction

Since Stromberg first reported late season K deficiency on cotton in 1960 (1), the cause of this disorder has been debated. At issue is whether San Joaquin Valley (SJV) soils on which the problem occurs are K deficient for cotton (2) or whether the K deficiency is a secondary response to disease caused by a soil pathogen (as yet unseen and only postulated to exist) that reduces root function or causes blockage of the vascular system inducing K deficiency on soils that provide an adequate K supply (3, 4).

In defense of the disease-induction hypothesis, several traits of the late season K deficiency are thought to be inconsistent with the supposition that a soil K deficiency is the primary cause of the disorder. These inconsistencies include: (i) foliar symptoms that are atypical of K deficiency, (ii) lack of a consistent relationship between soil test K levels and cotton response to fertilizer-K addition. (iii) lack of K deficiency or response to applied K for all other field crops grown on soil where cotton is K deficient, and (iv) large differences among cotton cultivars in sensitivity to the syndrome that parallel cultivar tolerance to verticillium wilt.

Over the past four years we have examined soil-plant K relations of cotton in the SJV. Much of this work was conducted in a grower's field where annual additions of 0, 120, 240, or 480 kg K/ha were applied to the same treatment plots in each of three years and cotton response and soil K levels were monitored. Except where noted, results presented here were obtained from that study.

Atypical Foliar K Deficiency Symptoms

Late season K deficiency symptoms begin to appear soon after peak bloom and first show on younger leaves, unusual for a mobile plant nutrient. A boll pruning study was initiated on 27 July 1985, just after first appearance of

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foliar symptoms. Leaf symptoms disappeared on boll-pruned plants and by 17 September both stem and leaf dry matter was two-fold greater on pruned plants than in unpruned control plants (5). Increased vegetative growth of pruned plants was associated with a 95% and 25% increase in stem and leaf K concentration, respectively, above that in plants without bolls removed. On unpruned plants, the dominance of bolls as a K sink is demonstrated by a linear increase in the proportion of total plant K allocated to fruit as plant K supply decreases (Fig. 1). These studies suggest that young, expanding leaves may be most sensitive to K deficiency during rapid boll development since fruit are the priority sink for recently acquired soil K and K remobilized from older vegetative tissues.

Relationship Between Soil K Levels and Response to Added K

Present recommendations propose that a response to added K is not likely when 1 M NH_4OAc-extractable K exceeds 100 mg K/kg, or if below this threshold, when hot 1 M HNO_3 or 5 M H_2SO_4 extractable K exceed 250 or 500 mg K/kg soil (6). But in all studies where both soil K indexes have been measured, significant lint yield responses were obtained from K application on soils with K levels well above these critical thresholds (7,8,9,10). In a survey we conducted across 20 growers' fields in 1985 and 1986 that included six soil series, late season K deficiency was often severe in soil with 5M H_2SO_4-extractable K values ranging from 2400 to 3600 mg K/kg soil.

The presence of vermiculite, a K-fixing mineral, is a common trait of soils on which cotton is K deficient in the SJV, and this confounds the interpretation of present soil K tests. Since most growers rarely apply K to field crops in the SJV (11), crop rotations (especially with alfalfa) are extremely K-depleting (2). Due to the K fixation capacity of vermiculitic soils, large quantities of K must be added to effect a relatively small increase in exchangeable K. The magnitude of this buffering capacity is evident from comparison of K fixation isotherms for the vermiculitic Grangeville sl and the Panoche cl that has no vermiculite (Fig. 2). It is also noteworthy that soils on which cotton suffers K deficiency have very low extractable K values in subsurface soil and a higher K fixation capacity than in the plow layer (e.g. Fig. 2, also reference 2).

In our studies we have found the K concentration measured in an equilibrated water (or 0.01 M $CaCl_2$) extract of soil to provide a much more precise indicator of soil K sufficiency for cotton (Fig. 3) than the NH_4- or H_2SO_4- K indexes. Due to the large K buffering capacity of these soils, a more direct reflection of soil solution K concentration greatly reduces interpretation difficulties that result from differences in soil texture that confound the NH_4- and H_2SO_4-extraction test values. It should also be possible to develop more accurate K fertilization recommendations based on solution-phase K addition isotherms similar to those developed for assessing crop fertilizer-P needs on highly weathered soils (12, 13).

Lack of a K Response by other Field Crops

Direct measurement of soil solution K by miscible displacement (14) in soil on which cotton is K deficient shows the K concentration to range from about 2.0 mg K/L in the surface 0-15 cm to less than 1.0 mg K/L at 45-60 cm depth. These concentrations are very low for agricultural soils (15) and thus plant K uptake is mostly dependent on root surface area development (16). But although the peak K uptake rate required by cotton to avoid K deficiency is equivalent or greater than for other field crops such as alfalfa or wheat, two distinct features of the cotton root system would limit K uptake efficiency by this plant. First, cotton root length density is very low relative to that found under cereal crops (17, 18) or alfalfa (19) measured in the same field. Second, cotton root development in the surface 0-15 cm layer is lower than at soil depths below 15 cm. Since available soil K is highest in surface soil, however, cotton root and available soil K distribution are incongruent (20). Taken together, the high peak plant K demand, the relatively low density rooting pattern throughout the profile, and the lack of compensatory root exploitation in the surface layer when subsoil is low in available K make the cotton plant uniquely sensitive to a limited soil K supply. This supposition is supported by evidence from field studies conducted in the southern USA (21).

Differential Cultivar Response to K Limitation

Cotton cultivars differ markedly in sensitively to late season K deficiency (22). Although those differences parallel cultivar resistance to infection by verticillium wilt (3), we have found distinct cultivar differences expressed in soil with little verticillium disease pressure.

In our field studies seed cotton yield of the K-efficient 'GC510' was 30 to 35% higher than for the K-inefficient 'SJ2' in treatments without K addition, but both cultivars showed a significant yield response to added K (Fig. 4). Increased K use efficiency, defined here as seed cotton yield per unit soil or fertilizer K, was not related to partitioning of K within the plant (Fig. 1) but instead reflected a 60% higher rate of K uptake by 'GC510' from mid-July to late August. Monitoring root development during this period showed that root surface area of 'GC510' was 50 to 100% greater than for 'SJ2' at soil depths below 10 cm. Sensitivity analysis of K uptake using Barber's mathematical model for plant ion uptake (16) suggests that differences in root surface area of the magnitude found for these two cotton cultivars could account for the measured differences in K uptake, and thus yield, in soil with a limited K supply. Indeed, to obtain a 95% maximum yield for 'SJ2' requires a water soluble soil K level 65% greater than for 'GC510' (Fig. 3) and thus an additional 500 kg K/ha would be required to obtain near maximal yield for 'SJ2' on this vermiculitic soil.

Conclusions

Examination of soil and plant parameters that govern K uptake and utilization reveals that the seemingly anomalous characteristics of late season cotton K deficiency <u>are consistent</u> with the hypothesis that many SJV soils are K deficient for cotton, but not for other crops. The dominance of fruit as a K sink, high peak K demand, and a low density root system that poorly exploits surface soil all contribute to the sensitivity of the cotton plant to soil K limitation. Whether plant disease contributes to the unusually high K fertilizer requirement of cotton is not known. But based on the evidence we have compiled it is our belief that late season cotton K deficiency results directly from a soil K deficiency.

As with all soil nutrient limitations, other soil physical, chemical, or biological factors that negatively influence root growth or function would also contribute to the severity of a nutrient deficiency. Given the enormous fertilizer-K input needed to overcome cotton K deficiency on these vermiculitic soils, it is likely that soil rehabilitation will require an integrated management approach that employs less K-extractive crop rotations, reduces soil compaction and improves soil structure, and maintains soil K supply in subsoil layers.

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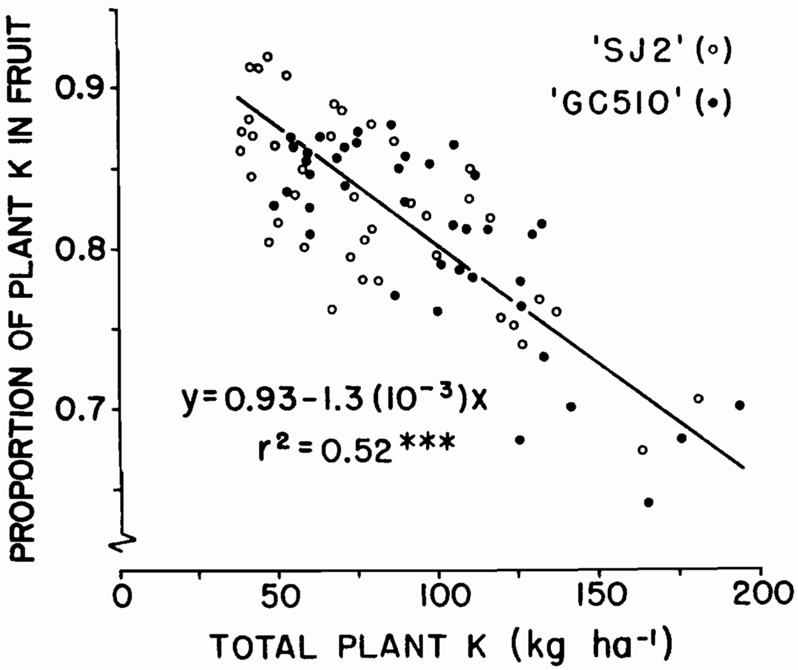


Figure 1. Partitioning of total plant K to fruiting structures (including squares, flowers, and bolls) as related to total plant K accumulation of two cotton cultivars as measured in field-grown plants on 27 August 1987. *** indicates significance at P 0.001.

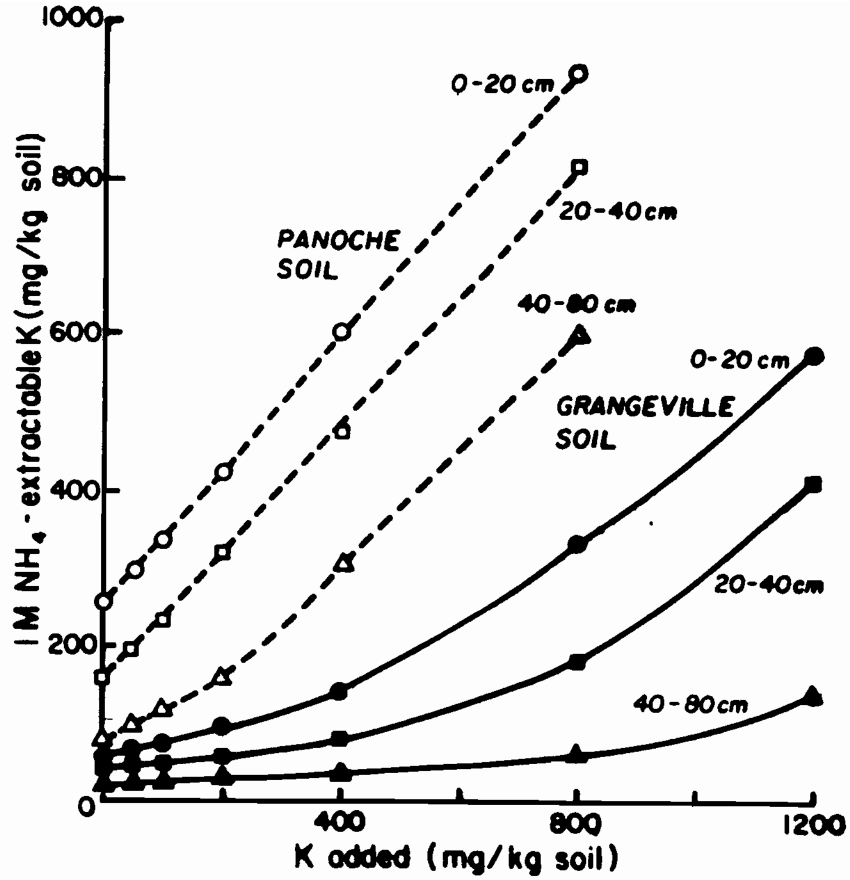


Figure 2. The relationship between soil K extracted by 1 M NH_4^+ and added K in the vermiculitic Grangeville sl (solid lines) and in a Panoche cl that has little K-fixing minerals (dashed lines). Potassium addition isotherms are shown for three depth intervals in each soil.

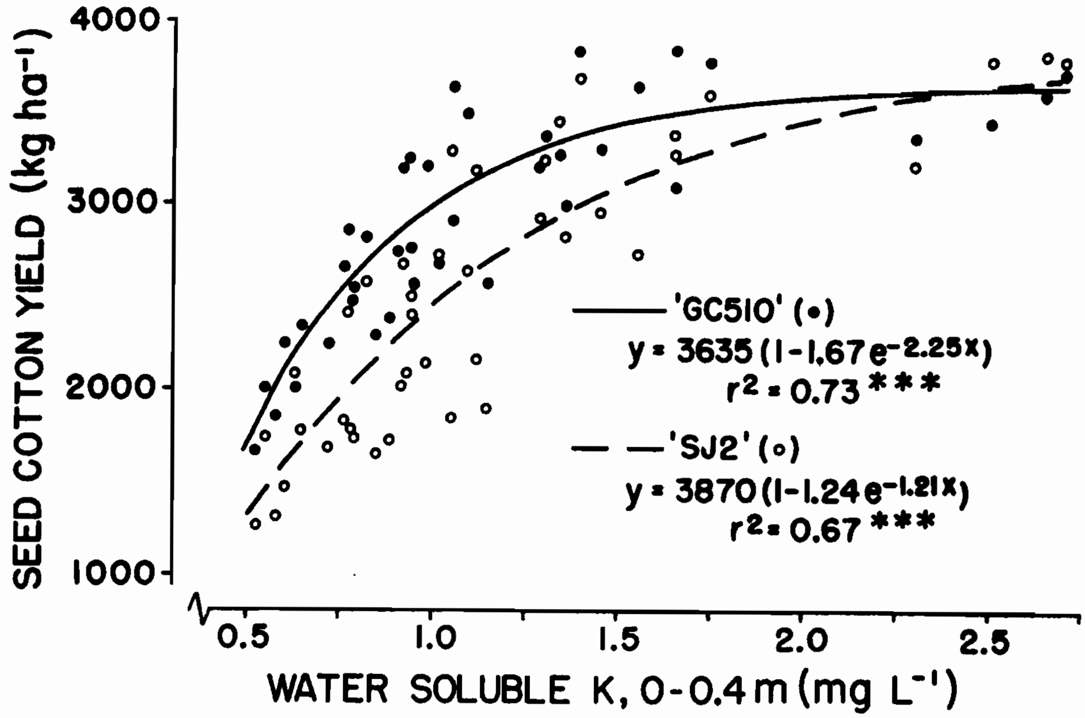


Figure 3. The relationship between seed cotton yield and water soluble soil K^+ in the 0 to 0.4 m depth interval of a Grangeville sl in a field with alternating six-row cultivar strip plots. *** indicates significance at P 0.001.

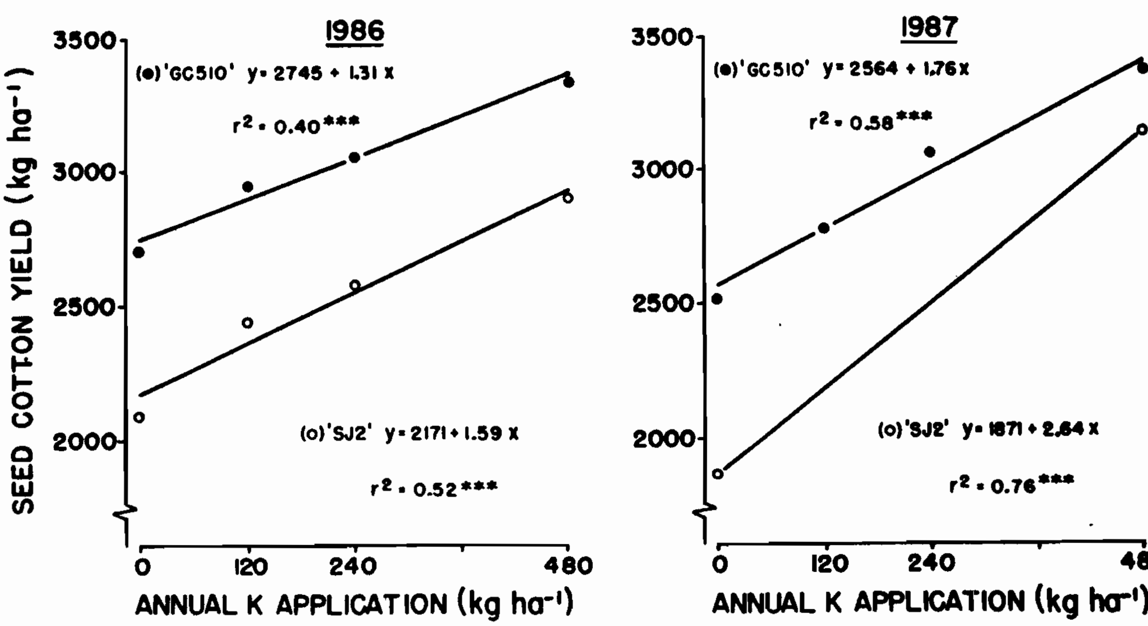


Figure 4. Yield response of two cotton cultivars to annual K addition levels applied to the same plots in 1986 and 1987. Each data point is a mean of 10 replications and r^2 was calculated using replicates.

Effect of drip irrigated urea-nitrogen application on soil characteristics and nitrogen use efficiency in almonds.

Roland D. Meyer, Herbert Schulbach, John P. Edstrom and Robert J. Zasoski

Drip irrigation is a unique method of providing water to trees which makes for a number of challenging management situations. Having a relative small volume of soil being used as the reservoir for water and nutrient uptake which is saturated a high percent of the time during the growing season provides a setting for several unusual chemical reactions in the soil. The use of an acidifying nitrogen fertilizer such as urea may increase the solubility of toxic elements like manganese and aluminum. Plant nutrient uptake and the leaching effect of low salt water on neutral non-calcareous soils are factors that contribute to lowering the pH of the soil. Denitrification may also be occurring at a rather rapid rate which could result in reduced nitrogen efficiency by the crop. Because the answers to a number of these questions are still unknown this project was initiated with the following objectives: (1) To evaluate the effects of different nitrogen rates applied at two water levels on growth, nutrient concentrations in leaves and twigs, and nut yields of almonds. (2) To assess the extent of soil acidification from nitrogen application under drip emitters. (3) To develop recommendations for nitrogen, irrigation and soil management for use in the establishment of almond orchards. (4) Evaluate changes in nutrient movement in drip zone as a result of acidification, leaching and nutrient uptake. This presentation will give information regarding soil characteristics and nitrogen use efficiency as influenced by nitrogen rate and drip irrigation levels.

The orchard was planted (202 trees per acre, 12' X 18' spacing) on the Nickels Trust Ranch in the spring of 1981 to three almond varieties--Butte, Carmel and Nonpareil. In the spring of 1982, ten treatments were established including two water levels-0.6 and 1.0 of evapotranspiration (ET) each with five nitrogen rates-0, 0.5, 1.0, 1.5 and 2.0 oz/tree in 1982; 0, 0.8, 1.7, 3.5 and 7.0 oz/tree in 1983; 0, 2, 4, 8 and 16 oz/tree in 1984; 4, 8, 16, 24 and 32 oz/tree in 1985; 6, 12, 24, 36 and 48 oz/tree in 1986; and 8, 16, 32, 48 and 64 oz/tree in 1987 and 1988. Urea is the nitrogen fertilizer source and it is applied on a monthly basis in six equal increments beginning April 1st.

Soil samples were taken from a large cube measuring 21 by 21 inches to a depth of 18 inches on the low nitrogen-low water treatment and 30 inches on the high nitrogen-high water treatment. This large cube was divided into 3" by 3" by 3" samples and analyzed for ammonium and nitrate nitrogen, pH, EC, Ca and Mg in the saturated paste extract. The corner of the large cube originated at the center of the drip emitter hole which was located three feet away from the tree trunk. Figure 1 gives the soil pH values from the diagonal samples of the large cube. Note the slight degree of soil acidification of the low nitrogen-low water treatment and particularly the lower pH values below 9" depth and to the side of the drip emitter hole. The acidification is much greater where higher nitrogen and water levels have been applied, with pH values of 4.0 and below at the 9" depth and deeper as well as to the side of drip emitter hole. Electrical conductivity (EC) values which are normally in the .2 to .4 range for this soil show little change for the low nitrogen-low water treatment below the surface 3" layer but show elevated levels 12" deep and deeper and 15" or more to the side of the emitter hole for the high nitrogen-high water treatment (Figure 2). Although not shown the calcium and magnesium concentrations have a very similar pattern of distribution to the EC levels. Ammonium concentrations were in the 2 to 7 ppm range from the low nitrogen-low water treatment but were measurably higher in the high nitrogen-high water treatment particularly below 6" depth and as far away as 18" from the emitter hole (Figure 3). Nitrate levels in the surface 3" samples were quite high for the low nitrogen-low water treatment but were 8 ppm or less in the rest of the samples (Figure 4). Nitrate levels in the high nitrogen-high water treatment tended to increase with depth and to the side of the drip emitter hole, reaching concentrations in excess of 40 ppm.

The nitrogen use efficiency is defined as that portion or percent of the applied nitrogen which is recovered in the hulls, shells and kernels when almonds are harvested. It is calculated by subtracting the amount of nitrogen contained in the yield of the control or lowest nitrogen treatment (nitrogen rate of 4 and 6 oz/tree in 1985 and 1986 respectively) from all other treatments and expressing this difference as a percent of the amount of applied nitrogen. Figures 5 through 7 illustrate the nitrogen use efficiency for the three almond varieties across the nitrogen rate and water level treatments during 1984 through 1986 respectively. It is quite normal to see higher efficiencies with a larger range as well at the lower rates of nitrogen application as is indicated in 1984 (Figure 5). The averages of about 30% at the 2 oz N/tree rate going to 20% at the 16 oz N/tree are within the expected range of values reported by researchers particularly if a large yield response to nitrogen is recorded. A somewhat more erratic and constant set of efficiencies of about 15 to 20 percent are recorded for 1985 and 1986. The unexpected higher efficiencies for the 24 and 36 oz N/tree treatments in 1986 is difficult to explain. For some reason the 12 oz N/tree treatment gave very low nitrogen use efficiencies.

a

Depth	3"	6"	9"	12"	15"	18"	21"
3"	6.7	6.7	6.7	7.0	7.0	6.9	6.8
6"	6.5	7.0	6.6	6.7	6.4	6.5	6.1
9"	6.3	6.6	6.3	6.4	6.5	6.4	6.1
12"	5.8	5.9	6.1	6.1	6.2	6.5	6.2
15"	5.8	5.8	6.0	6.2	6.4	6.3	6.3
18"	5.9	5.9	6.5	6.4	6.2	6.4	5.9

b

Depth	3"	6"	9"	12"	15"	18"	21"
3"	7.1	6.7	6.8	6.2	5.4	6.4	6.6
6"	4.7	6.5	5.1	4.9	4.7	5.7	5.9
9"	5.8	5.7	5.1	5.0	4.5	5.2	6.0
12"	4.2	4.3	4.0	4.6	4.0	4.3	5.3
15"	3.8	3.7	3.7	4.1	4.2	4.9	5.3
18"	3.6	3.6	3.8	4.1	4.3	4.6	6.0
21"	4.1	3.9	4.2	4.2	4.4	5.4	5.9
24"	4.0	3.9	3.9	4.1	4.0	4.5	5.6
27"	4.0	4.0	4.2	4.3	4.4	4.5	4.9
30"	4.1	4.0	4.2	4.4	4.7	5.0	5.6

Figure 1. Fall 1985 soil pH of the drip zone from the low nitrogen-low water treatment (a) and high nitrogen-high water treatment (b).

a

Depth	3"	6"	9"	12"	15"	18"	21"
3"	2.12	1.70	.99	.87	.81	.79	1.20
6"	.57	.36	.39	.44	.44	.41	.93
9"	.33	.29	.33	.32	.30	.38	.44
12"	.35	.33	.30	.29	.28	.31	.30
15"	.27	.27	.21	.21	.20	.20	.24
18"	.31	.30	.25	.26	.23	.21	.20

b

Depth	3"	6"	9"	12"	15"	18"	21"
3"	.62	.34	.32	.30	.52	.31	.48
6"	.39	.40	.31	.34	.38	.40	.52
9"	.47	.33	.31	.37	.65	.48	.58
12"	.49	.52	.50	.49	1.24	.67	.75
15"	.31	.32	.35	.41	1.13	.87	1.24
18"	.47	.41	.32	.43	.37	.35	1.21
21"	.36	.47	.33	.45	.86	1.02	1.24
24"	.44	.50	.36	.52	.85	1.24	1.09
27"	.62	.52	.54	.60	.95	1.45	.96
30"	.95	.79	.74	.73	.99	1.19	.71

Figure 2. Fall 1985 soil EC of the drip zone from the low nitrogen-low water treatment (a) and high nitrogen-high water treatment (b).

a

3"	6"	9"	12"	15"	18"	21"
2	2	3	3	4	3	3
7	4	5	5	3	4	4
4	3	3	2	2	4	3
4	4	4	3	4	4	5
4	4	4	4	4	5	4
4	5	5	4	5	5	6

Figure 3. Fall 1985 soil NH_4-N concentrations in the drip zone from the low nitrogen-low water treatment (a) and high nitrogen-high water treatment (b).

b

	3"	6"	9"	12"	15"	18"	21"
3"	9	7	4	7	12	9	8
6"	8	7	10		15	12	8
9"	14	17	17	16	43	16	11
12"	16	18	14	11	42	14	5
15"	25	20	16	11	28	6	6
18"	25	23	15	14	14	9	5
21"	18	20	17	15	17	6	5
24"	16	18	19	16	18	10	5
27"	15	17	17	16	13	12	7
30"	12	16	16	10	6	5	5

a

3"	6"	9"	12"	15"	18"	21"
65	55	35	20	13	15	24
5	6	6	3	5	3	8
6	4	4	4	4	4	1
2	1	2	2	1	1	1
1	2	3	3	2	3	2
2	3	1	1	1	2	2

Figure 4. Fall 1985 soil NO_3-N concentrations in the drip zone from the low nitrogen-low water treatment (a) and high nitrogen-high water treatment (b).

b

	3"	6"	9"	12"	15"	18"	21"
3"	4	6	4	5	7	4	4
6"	10	3	6		10	4	3
9"	5	7	6	10	18	10	13
12"	13	14	11	10	34	14	13
15"	10	10	11	11	37	20	24
18"	13	12	14	11	9	6	26
21"	11	13	10	14	25	28	27
24"	12	15	11	15	23	35	27
27"	20	15	16	18	26	45	24
30"	29	23	23	23	31	36	18

Figure 1. Almond meat yields in 1988 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

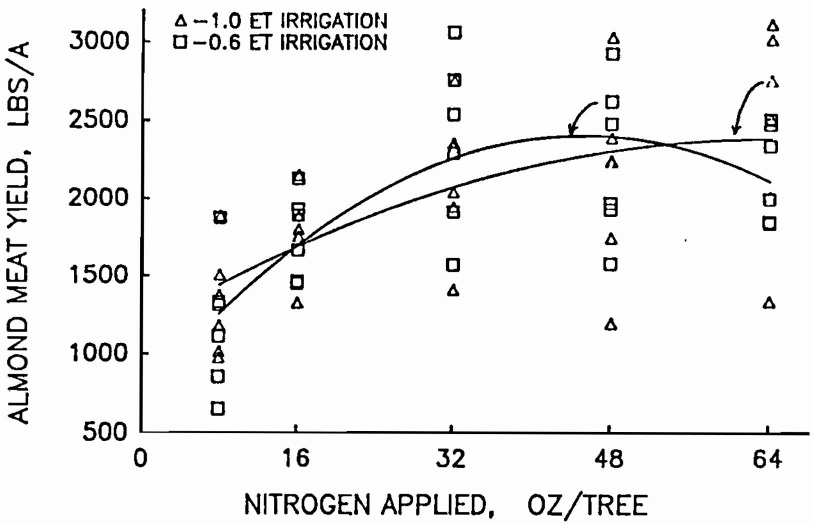


Figure 2. Almond leaf total nitrogen throughout 1987 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

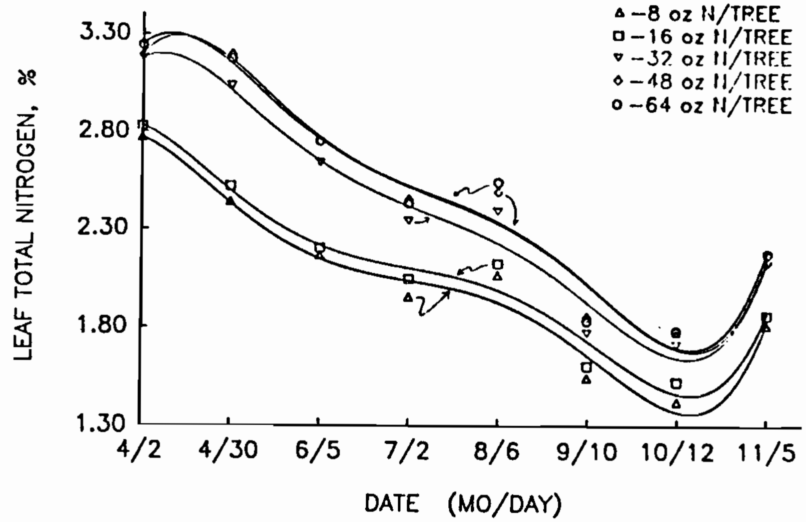


Figure 3. Almond leaf total phosphorus throughout 1987 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

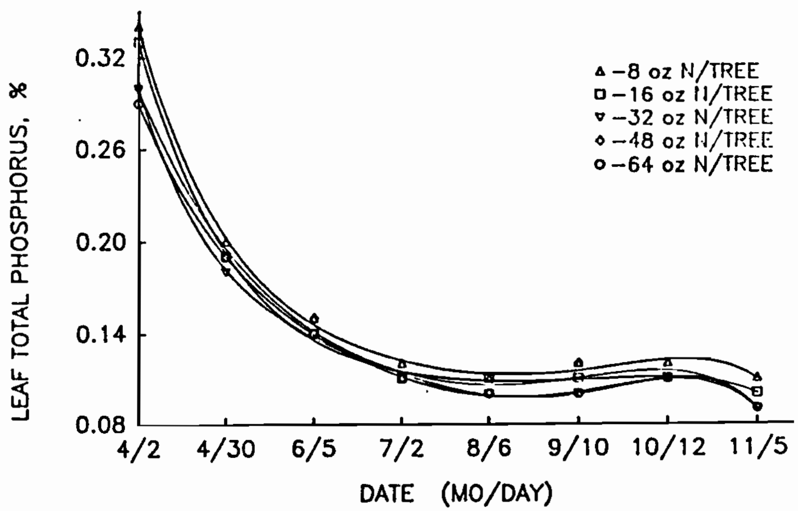


Figure 4. Almond leaf total potassium throughout 1987 for five rates of drip irrigation applied nitrogen. Nickels Ranch.

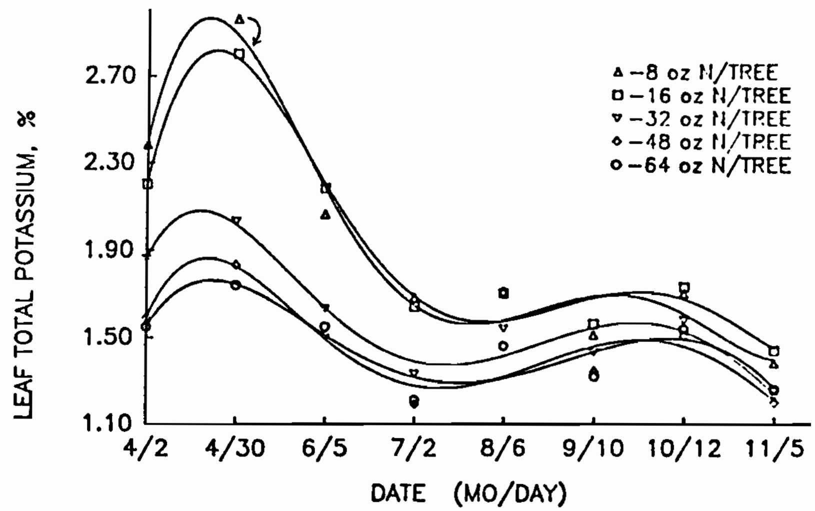


Figure 5. Nitrogen use efficiency of almonds in 1984 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

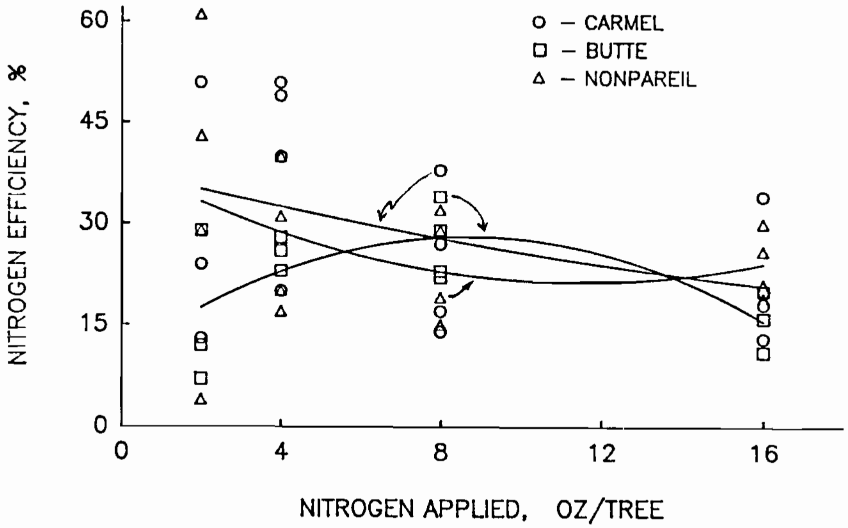


Figure 6. Nitrogen use efficiency of almonds in 1985 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.

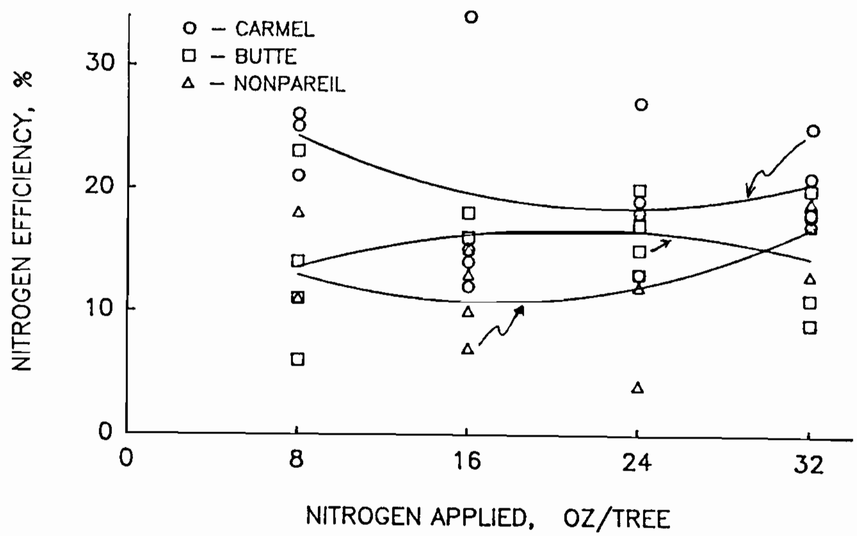
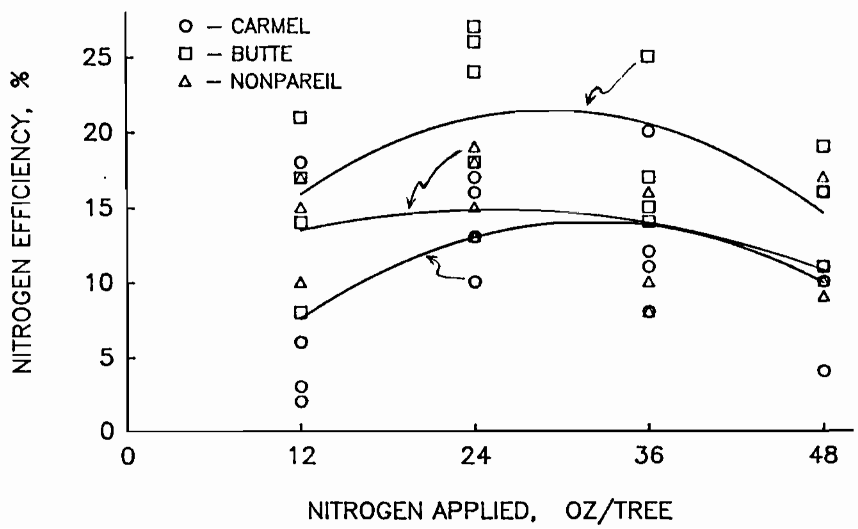


Figure 7. Nitrogen use efficiency of almonds in 1986 as influenced by nitrogen rate and water applied through drip system. Nickels Ranch.



SELECTION AND HANDLING OF COVER CROPS

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In studying nematode damage and control we often need to rear nematode populations either in the field or in the green house. This is accomplished by selecting a favored host of the nematode and then planting it out with a small infection of nematodes. In field situations it can take some years to detect high populations but eventually if soil texture and other factors are correct we can develop high enough nematode populations to evaluate rootstocks or test nematicides. From those experiences we conclude that cover crops can be a mechanism for increasing nematode populations in a vineyard or orchard.

In studying nematode damage in established crops we are aware that many soil factors aggravate or minimize the damage the pests actually cause. Cover crops, including weeds, can improve water infiltration and water holding capacity so that vines undergo less stress and soil pest damage is reduced. Cover crops, however, can be expensive to plant and handle. There are few easy or universal answers relative to cover crops. Below I have listed bits of information relative to selecting and handling the cover crop and have indicated where research is currently underway.

Selecting a Cover Crop

Facts to consider:

1. Relative to the nematodes of orchards and vineyards, grassy type crops tend to be safer to use than broadleaf-type plants.
2. Legumes in general build populations of many nematode species. Several root knot nematode species attack and develop on legumes but do not usually produce galls on the legume.
3. All summer-grown legumes should be expected to build populations of one or more root knot nematode species.
4. There are now 4 winter-grown legumes which have resistance to the 3-major root knot nematode species of tree and vine crops. One of these, Cahaba White Vetch, is also reported to be a non-host to ring nematodes, *Criconemella xenoplax*. Cahaba White Vetch is a host to root lesion nematode, *Pratylenchus vulnus*, but we are still unsure that it is reproducing on the vetch. Cahaba White Vetch should be planted before the end of September and is relatively expensive.
5. Barley and rye are generally good cover crops in that they do not host nematodes which occur in vineyards or orchards.
6. Philosophically, this nematologist does not consider any single cover crop as perfect and growers should plan to rotate to a different cover every 2 or 3 years.

7. Cover crop blends or cover crops that are weedy increase the chance for hosting a wider diversity of nematode species.
8. We have observed in well replicated field trials that cover crops planted around first-year vines tend to reduce vine growth. Actual data will be available soon.
9. Cover crops minimize soil erosion on hillside land. That is perhaps their major attribute.

Current Research Investigations:

Microplot testing of cover crops against a diversity of nematodes which occur in tree and vine crops:

Blando Brome	Winter Weeds
Cahaba White Vetch	Year-long Weeds
Marigold	S. Strawberry Clover
Niblewil	Hubam Sweet Clover
Perennial Rye/Fescue	Barley
Oats	

Handling a Cover Crop

Facts to Consider:

Concerns for frost damage.

Competition for water and nutrients.

Costs of mowing or incorporating.

The value of the green cover is in the amount of refuse turned under.

The cover crop is grown where only 35% of the nematode population resides.

Current Research Investigations:

- Nematode populations can be temporarily reduced by irrigation immediately after incorporation of some plant materials.
- The nematicidal properties, however, need to be delivered to the vine row not the drive row.
- Potential for ground water contamination.
- Active ingredients or mode of action identified.
- Phytotoxicity associated with cover crops.

A Review of Mating Disruption for Insect Pest Management

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The idea of using insect sex pheromones to control pest species was one of the first practical uses suggested for these semio-chemicals as research on pheromones began to develop rapidly in the 1950's and 1960's. It was soon discovered, however, that use of pheromones for insect control was not going to be quite as easy as it was initially perceived. In spite of initial difficulties and drawbacks, however, continued improvements in analytical chemistry technology, knowledge of insect behavior, and instrumentation have enabled biochemists and entomologists to overcome inherent problems, with the result that we can now point to a number of successful control programs that are presently being used in production agriculture and forestry.

Using sex pheromones to control insect populations offers a number of benefits that are not to be found with the conventional synthetic pesticides that have been used so frequently since WWII. Because these pheromones are considered essentially non-toxic they require no special equipment for application nor do applicators require special training or protective clothing such as spray masks, rubber suits, boots, etc. while applying the pheromones in the field. There are also fewer regulatory restrictions involved with the use of pheromones when compared to conventional pesticides. There are no requirements for notices of intent to be filed with local regulatory officials prior to the use of the pheromones nor are treated fields required to be posted against entry by unauthorized persons. There are no re-entry or preharvest intervals that must be observed nor are there restrictions on the amounts of pheromone residue that may be present on fruit or commodities at harvest.

Use of pheromones for insect control is also readily compatible with other cultural and production operations in the orchard. Once the biology and behavior of the target pest species is well understood, the timing of pheromone applications is predictable based on the insect pests' life cycle. Consequently, pheromones can be applied without fear of interference with other operations such as irrigation, cultivation, thinning or harvest on normal schedules. In agricultural commodities such as fresh fruit or vegetables, large amounts of hand labor can still be used in pheromone treated fields without concern about fruit or foliage residues as is the case with insecticide sprays. Use of pheromones also enhances preservation of beneficial insects and mites, and insect pollinators. With continued use of sex pheromones for pest control over the long term, increased levels of biological control of secondary pests should be observed. Similarly, decreased use of insecticides should lead to fewer disruptions of secondary pests such as phytophagous mite populations which are often observed following applications of organophosphate or pyrethroid insecticides. The use of pheromones should also delay or prevent the development of pest resistance to the more common synthetic pesticides. Also, inclement weather such as rain or fog does not effect residual activity or efficacy of pheromones as occurs with sprayed pesticides. Another problem that can be avoided, particularly in California, when using pheromones is the requirement for proper disposal of pesticide containers and rinse water from application equipment.

With all of these factors as strong incentives for the development of mating disruption with pheromones for insect pests there is obviously a great deal of interest in improving this new technology and expanding it to new pest species as quickly as possible. Unfortunately, however, there have been and continue to be several limiting factors that have delayed or slowed the development of pheromones for pest control. One of the first problems that must be overcome is understanding completely the total chemical communication system that is used between virgin females and responding male insects. The sex pheromones that are produced by either virgin males or females are usually very complex blends of several pheromone components or isomers. For example, in the tobacco budworm, a severe pest of tobacco, corn, and other field crops throughout North America, virgin female moths produce a blend of seven different components.

Fortunately, not all insects produce such complex blends of pheromones but in most cases at least three or perhaps four different pheromonal isomers are required in successful mating disruption programs. Because of the number of pheromone isomers required and the necessity to present an optimum quantity of synthetic isomers in exactly the same proportion that the virgin native female insects produce these chemicals, it is obvious that some of these chemical systems are going to be very expensive to produce. Costs presently range from $50.00 - 60.00/gm up to $1200.00/gm for single isomers. Adding to the costs of the disruption program are the complexity of the synthesis steps required to produce the various pheromone isomers along with the proper type of dispenser to release the pheromones in the field, and the cost of application of the dispensers themselves in the field. Current costs for mating disruption of the oriental fruit moth in peaches is ca. $120.00/ac./yr.

The amount of synthetic pheromone required per unit area is also a critical factor in the success of mating disruption technology. Quantities of pheromone required are usually expressed in milligrams per acre (or ha.) per hour. The pheromone dispensers used, regardless of type, must be programmed to release the minimum effective amount of pheromone, particularly during the time when the male or female responding sex is actively seeking the opposite sex for mating. Most insect species only search for mates for a few hours in each 24 hour or diurnal cycle but the pheromone dispensers are releasing the pheromone over the full 24 hour period every day. Consequently, there is obviously a considerable waste of pheromone during the time when responding insects are not actively seeking mates for mating.

The development of suitable pheromone dispensers has also been a critical factor in whether or not mating disruption has been successful in commercial applications. A wide variety of dispensers have been developed over the years but many of these have proved unsuitable for a number of reasons, including suitable release rate, susceptibility to ultraviolet radiation, and susceptibility to weather factors such as rainfall and temperature. To date, most pheromone dispensers used in mating disruption have been constructed of polymers or semi-permeable membranes of various types of plastic. Most of these plastics can be programmed to release single pheromone components at a predictable rate, within normal temperature fluctuations. However, when multiple component pheromone blends are required for mating disruption, release rates of all the pheromonal components in the blend may not be optimally obtained. For example, pheromone dispensers currently under development for the codling moth, a major pest of apples, pears, walnuts, and plums, are loaded with a blend of 10, 12, and 14 carbon-chain alcohols. The pheromone dispenser currently under field use releases the 10 and 12 carbon alcohols quite readily but does not release the 14 carbon alcohol fast enough to provide the optimum pheromone blend. Consequently, within a very short time after placement in the field the synthetic pheromones are not competitive with the virgin female codling moths in the orchards, and mating disruption is difficult to achieve.

The logistics of dispenser and pheromone placement within a commercial field is also a critical factor in the success or failure of a mating disruption program. In permanent crops such as trees or vines where hand labor is readily accepted by growers or in high value annual crops such as fresh market tomatoes, pheromone dispensers can be hand-placed with a minimum of difficulty on the part of the grower. In field or row crops, however, such as cotton or corn, where hand labor is not a commonly accepted cultural practice, uniform application of pheromone dispensers has been more difficult to achieve. In these crop situations the development of mechanized dispenser application, or sprayable pheromone formulations are primary objectives in developing mating disruption technology. Even with hand application of pheromone dispensers in permanent crops, however, placement of dispensers may prove quite difficult in certain situations such as walnut or pecan orchards or in forests where optimum placement of the dispensers is required near the tops of the trees, which may be 40 to 50 feet above the ground. In these situations, sprayable formulations of pheromone would also considerably improve the chances of a successful disruption program. Other factors that also must be considered in mating disruption programs are such things as wind and the type of terrain that is involved in a treatment area. Rolling terrain may lead to unusual types of air drainage or variations in temperatures that would affect the release or movement of pheromones within a treated area.

Another basic requirement of a successful mating disruption program is the ability to monitor the target insect population in several different ways in order to determine the efficacy and potential success of the mating disruption approach. Pheromone traps can normally be used to monitor pest populations, but when massive amounts of synthetic pheromone are released for mating disruption, pheromone traps are no longer effective in monitoring a target species. If, however, male codling moths are trapped in pheromone monitoring traps within a disruption orchard this is an indication that the mating disruption is not being successful because males are still able to find point sources of pheromone as represented by the traps.

Other methods of monitoring the efficacy of a mating disruption treatment would include bait traps, usually involving the use of a food attractant, or virgin females that are tethered in the orchard and are checked periodically to determine if they have been mated or not. The ultimate proof of success or failure of a disruption treatment is whether or not the fruit or commodity to be protected is infested, or whether feeding damage can be found in the field. In most cases, several of these different monitoring techniques are used by pest control advisors and field managers to determine whether or not the disruption approach is being successful. Another factor that pest managers must be aware of in using mating disruption is the ability of mated female moths to migrate from adjacent fields into fields that are being treated with pheromones for disruption. This is one of the more difficult things to measure and is of great concern to pest control advisors, particularly when attempting mating disruption in fresh market commodities such as tomatoes or tree fruit. In spite of all these difficulties, however, the appeal of using mating disruption to control pest populations is still very strong and continued attempts to improve this particular approach will continue at an increased pace in the foreseeable future.

DEVELOPING NEW SAMPLING AND MONITORING METHODS: A CASE STUDY OF TOMATO FRUITWORM IN PROCESSING TOMATOES

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The tomato fruitworm, Heliothis zea (Boddie) is a perennial insect pest of processing tomatoes in California's Sacramento Valley (Lange and Bronson 1981), and has traditionally been the target of the majority of insecticides applied to that crop. Growers not taking action to monitor and control this pest run the risk of exceeding damage standards imposed by the State of California (2%), or by processors who may impose more strict quality standards. Prior to this study, researchers (Lange and Kishiyama 1978) had recommended sampling a minimum total of 500 fruit from consecutive plants at several field locations to estimate damage by the tomato fruitworm, and to treat when damaged fruit reached 0.25%. Few, if any, Pest Control Advisors (PCA's) or growers utilized this sampling technique, which could be considered an absolute, stratified sample. Interviews conducted at that time revealed that PCA's who attempted to quantify their field monitoring often used damage estimated from randomly collected fruit or presence or abundance of larvae obtained from beating plants over a substrate. In 1981, 36 small research plots were established in 3 grower's fields to compare potential monitoring techniques for time and efficiency. From each small plot, 2 plants were removed each week, and the number and location of all fruit, damaged fruit, eggs and larvae recorded. This study revealed large differences in the times required to perform each technique, and in their relative efficiencies. A single 500 fruit absolute sample took 80 minutes, a 20 plant beating sample 80 minutes, a 100 randomly selected fruit sample 15 minutes, and a 30 leaf egg sample 8 minutes.

The absolute fruit sample and the beating sample appeared to be too costly in terms of PCA time input at 80 minutes a piece. Pest Control Advisors who work 60 hours per week and visit 100 fields can only spend 36 minutes to sample and observe all problems in each field including driving time, grower consultation, filing use permits and reports, and other job requirements. The random fruit sample, while less time consuming, was determined to overestimate actual damage by 62% (Zalom, et al 1983a). A limitation of both, the absolute and random fruit samples, was that both provided estimates of damage after the damage had already occurred. Sampling eggs, if it could be performed economically, seemed to provide a better method of predicting damage. Egg distribution data from the plant mapping performed in 1981 and more specific mapping conducted in 1982 and 1983 revealed that tomato fruitworm eggs were most commonly laid on the leaves below the highest open flowers on the plant (Zalom, et al. 1983b). Damage potential was estimated in 1982 and 1983 by artificially infesting small plots in a factorial experiment with different numbers of first instar tomato fruitworms at weekly intervals of plant development (Zalom, et al. 1986). It was also shown that only damage occurring in the 5 weeks prior to harvest remained on the plant at harvest.

The egg sampling method and damage thresholds were validated and first demonstrated on a large scale in 1984 when Area IPM Advisor Craig Weakley, working in close cooperation with Cooperative Extension tomato farm advisors, identified and contacted local growers and pest control advisors, and enlisted their assistance in monitoring one or two fields. In return, PCA's received training, technical support, and a small stipend for the extra labor involved in record keeping. Forty-seven fields were monitored as part of this project. Of 2714 loads delivered to canners, 2663 were graded at "zero to trace" damage. None of the loads exceeded 0.5% damage. An economic analysis of this demonstration (Antle and Park, 1986) indicated that the use of the techniques significantly reduced the amount of pesticides used for insect control, lowered the risk of damage, and had a net positive economic benefit of $7.10/acre. This value increased as the grower's degree of risk aversion increased to a maximum of $60/acre for highly risk averse growers (Antle 1988). Despite these positive attributes, not all growers adopted the new IPM techniques.

A study by Grieshop, et al. (1988) conducted during the growing season of 1986 indicated that 57% of the growers interviewed were using tomato fruitworm egg sampling as part of their pest management program. It was interesting to note that the most significant ($P<0.001$) factor affecting adoption was the use of IPM for other crops. The most frequently mentioned reasons for adopting the sampling method was possibility of financial gain (63%) and possibility of reducing damage (52%).

Subsequent research has improved the tomato fruitworm sampling plan by incorporating the presence of egg parasitic Trichogramma spp. wasps into damage thresholds, and by incorporating the use of pheromone traps to aid in predicting tomato fruitworm flights. Parasitism by Trichogramma spp. has been shown to reach as high as 90% in late season tomatoes. This parasitism can be easily identified as part of the egg sampling program, and should result in fewer treatments. Pheromone traps (Hoffmann, et al. 1986) can be used to detect the initiation of flights and therefore oviposition by the tomato fruitworm. Increased sampling efficiency can result from this information.

Awareness of an innovation and relevance in terms of time consumption, risk reduction and profit are key elements in developing an implementable IPM practice. While significant, other factors including equipment requirements, ease of use, unusual training or educational requirements, grower attitude, and conflicts of interest also influence the adoption of innovations. Research and extension staff, pest control advisors, and managers who wish to reduce pesticide use through new techniques must be aware of these factors, and deal with them as part of both the development and introduction of the innovations.

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Issues in Pest Control: Worker Safety and Pesticide Residues in Food (Presentation Summary)

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Two of the most emotional issues in pest control today are pesticide safety for farmworkers and pesticide residues in food. Superficially, the two subjects appear to have much in common--they concern pesticides and human health. Environmental groups, farmworker advocates, and consumer activists have often tried to tie the two in order to consolidate support for further pesticide regulation and enforcement. In doing this, they have succeeded in elevating the public's anxiety about pesticides but the merging of the two issues may be detrimental to pinpointing methods to reduce hazards associated with the two pesticide problems.

The issue that has gotten the most attention in the last two years is the issue of pesticide residues in food. A recent survey by the Food Marketing Institute states that over 75% of consumers consider pesticide residues in the food they buy at the market a serious health hazard. Some grocery chains have responded to this concern by initiating pesticide residue testing programs of their own and found this to be a useful marketing approach. On the other hand, there has been much less public or media attention to worker poisoning incidents over the past two years.

In the case of pesticide residues in food, the problem revolves around harmful residues of pesticides that remain on food at the marketplace and may be consumed by the general public. At risk is the entire population.

Fortunately, cases of acute poisoning due to pesticide residues on food are rare. In California, the only reported consumer poisonings in recent decades have been the well publicized illegal use of aldicarb on watermelons in 1985. Although arguably other isolated cases of consumer poisonings may have gone undetected, it is generally agreed that the main concern with pesticide residues on food is the more difficult issue of potential chronic problems such as cancer and birth defects due to low levels of residues over a long period of time.

How much are consumers exposed to pesticide residues? Not as much as most people fear, according to the California Department of Food and Agriculture, which reported that in 1986, 85% of the food it tested had no detectable pesticide residues and 98 to 99% was free of residues at the level considered hazardous when consumed regularly over a lifetime.

The issue of worker poisoning has more facets. Although only a fraction of the population is exposed to pesticides through their work, their risk is much higher. Between 1975 and 1986, the California Department of Food and Agriculture reported 8 occupational deaths associated with pesticide use; (several of these were related to crashes by aerial applicators). During the same period, between 1600 and 2000 worker injuries were reported annually due to pesticide exposure. Confirmed worker injuries for 1986 are shown in Table 1. At highest risk are pesticide mixers, loaders and applicators who report a yearly incidence rate of pesticide related illness of 2.06 per 100 employees; field farmworkers who do not directly handle pesticides have an incidence rate of 0.25 per 100 employees (CDFA, 1987). In addition to these acute poisonings, agricultural workers are also at risk for the same types of chronic risks as consumers; however, their risks are higher because they are exposed to residues at work (which may be taken in dermally, orally or through the respiratory system) and at the same time are exposed through the food they eat as consumers.

The argument is made that regulations and procedures developed to protect consumers will also protect agricultural workers. This is only partially true. In general, the pesticides responsible for the most worker injuries are different from those that most frequently turn up as residues on food. For instance, the six pesticides most frequently involved in reported worker injuries in California in 1986 were the acaricide propargite, the insecticides chlorpyrifos, diazinon and malathion, the fungicide sulfur and the herbicide glyphosate. None of these materials is among the pesticides of major concern with the issue of pesticide residues on food.

The pesticides most frequently found as residues on food are the fungicides applied to lengthen the storage life of fresh produce such as dichloran and chlorothalonil. Many of the pesticides most acutely toxic to workers break down fast enough that they are rarely found as food residues. Others are not common as residues on food either because they have a short persistence in the environment or are applied before the crop is in the field. (Glyphosate, for example, is never applied to crop plants because of potential crop injury.) Sulfur is an eye and skin irritant and causes many worker injuries but is not considered injurious when small quantities (e.g. ppm) are taken in orally.

While materials that cause digestive, neuromuscular or respiratory system poisoning or eye or skin irritation are the most commonly implicated in worker injuries, the materials that seem to be of most concern to consumers are those that may have serious chronic effects when consumed in minute quantities over a lifetime. For example, a recent National Academy of Sciences Report (NAS, 1987) noted that synthetic fungicides were the greatest concern in this regard and estimated that 90% by weight of all fungicides applied in the U.S. are potential oncogens.

Although occasionally a material can have both acute and chronic hazards, the methods available to detect and reduce these hazards will be different. The avenues for reducing worker health problems include better enforcement of current regulations and monitoring of worker conditions, more thorough testing of reentry intervals, more studies on the breakdown of pesticides under different field conditions, safer application methods and protective equipment, and better worker safety training. The most promising areas for limiting residues on food are development of better nonpesticidal storage procedures and acceptance by consumers of slightly damaged or cosmetically imperfect produce. There is also a great need to educate consumers about the relative risks of residues on food. Development of alternative control strategies, use of fewer pesticides and less persistent pesticides will reduce both problems; however, these are long term solutions requiring more time to implement.

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TABLE 1

Confirmed Occupational Illness/Injury Reports Associated
With Exposure to Pesticides
Reported to the California Department
of Food and Agriculture in 1986
According to Work Activity and Illness/Injury Type

Work Activity	Illness/Injury Type Systemic	Eye	Skin	Eye/Skin	Total Cases
Aerial Applicator	2	0	1	0	3
Ground Applicator	53	38	34	0	125
Hand Applicator	40	30	20	3	93
Other Type of Applicator	4	12	9	0	25
Coincidental Exposure	91	10	20	5	126
Emergency Response Personnel	18	1	0	0	19
Exposure to Concentrate	53	6	2	0	61
Flagger for Aerial Application	0	2	0	0	2
Chamber Fumigator	4	0	1	0	5
Field Fumigator	1	1	5	0	7
Tarp Fumigator	5	0	1	1	7
Manufacturing/Formulation Plant Worker	4	0	3	0	7
Mixer/Loader for Pesticide Application	27	26	13	1	67
Exposure to Residue on Commodities	26	2	8	0	36
Exposure to Residue in the Field	49	13	223	3	288
Exposure to Other Residues	185	6	2	1	194
TOTAL	562	147	342	14	1065

Total cases received (all potential pesticide-related cases)...........2099
Total cases determined to be related to pesticide exposure.......1211
Total occupational illnesses/injuries....................1065
Total non-occupational illnesses/injuries................ 146
Cases with insufficient data to judge an exposure
to illness/injury relationship..............................464
Cases determined to be unrelated to pesticide exposure.............424

USE OF CANOPY MANAGEMENT FOR CONTROL OF BUNCH ROT IN GRAPES

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ABSTRACT

Incidence of Botrytis bunch rot, sour rot, or "total" bunch rots was significantly (P=0.05 or P=0.01) reduced after canopy management by leaf removal in 3 San Joaquin Valley experiments. Yields were not significantly affected, although there was a trend toward slightly lower fresh weight after leaf removal. The results agreed with those previously reported for control of Botrytis bunch rot by leaf removal in coastal growing areas in California. Canopy management appears to be a viable option for bunch rot control while reducing pesticide usage in California vineyards.

Bunch rot of wine grapes (*Vitis vinifera*), caused by the fungus *Botrytis cinerea*, can cause major production losses in the cooler, coastal growing areas in California. Bunch rot development is favored by high moisture and humidity within the canopy and grape clusters. Savage and Sall (3,4) found that canopy management by hedging or manipulation of trellising wires could reduce moisture levels, thereby moderately reducing bunch rot. Gubler *et al* (1) reported that leaf removal was more effective than other methods of canopy management in controlling bunch rot in coastal production areas, and might replace two or more fungicide applications per year.

The growing season climate of the San Joaquin Valley is markedly warmer and drier than that of the coastal valleys. Even so, Botrytis bunch rot is sometimes severe, especially when late season rainfall occurs. In addition, mechanical damage to grapes by insect feeding, other diseases, or abiotic factors in the San Joaquin Valley often results in sour bunch rot caused by opportunistic fungi, yeasts and bacteria, and spread by *Drosophila* vinegar flies (2). These opportunisic rot complexes are traditionally more difficult to control than Botrytis bunch rot.

The objectives of this research were to determine the effects of leaf removal on bunch rots and grape growth under San Joaquin Valley conditions.

Materials and Methods

Three experiments in commercial vineyards in the San Joaquin Valley (one near Ceres in Stanislaus Co. and two near Livingston in Merced Co.) were done to evaluate the potential of the leaf removal practice vs. a nonleafed control in 1988. Grape varieties were Chenin blanc or Barbera, and experimental vines were cordon-trained. Canopy management was accomplished by manually removing leaves and laterals one node above, opposite, and one node below all clusters when berries were pea-sized. Randomized complete block or completely randomized plot design was used with at least 5 replications x 10 vines of each treatment. Except for leaf removal, experimental vines received the standard cultural practices used by cooperating growers; however, no bunch rot fungicides were applied during the growing season.

Disease and yield ratings were taken just prior to commercial harvest. Three or more vines per replication were hand-picked and fresh weights were taken. Twenty clusters were randomly-selected from each replication and assayed for bunch rot identification, incidence, and severity.

Results and Discussion

The leaf removal treatment provided a less shaded, less humid microclimate around developing clusters. The incidence (% clusters infected) of Botrytis bunch rot and sour rot usually was reduced following leaf removal in the experimental vineyards (Table 1). In some cases, low incidence or high variation in individual rot parameters resulted in statistically insignificant reductions. Nevertheless, when incidence of all bunch rots was composited ("total rot"), significantly less ($P=0.05$ or $P=0.01$) damage was found after canopy management at each site. Reductions in total rot incidence ranged from 44-61% at the three locations. Although data are not presented, reductions in rot severity (% of clusters rotten) were similar to those of incidence. No significant differences in yield between the two treatments were found. A trend toward slightly lower (3-12%) fresh yield was found in leafed vines (Table 1), but this was offset by the much larger increase in berry quality, as compared to nonleafed controls.

We conclude from the data that canopy management by leaf removal is a biologically-feasible alternative to chemical bunch rot control measures in the San Joaquin Valley, as well as in coastal production areas. It appears that leaf removal is effective in controlling both diseases and insect pests (authors - unpublished). However, our conclusions are based only upon data from a single growing season. Additional experimentation is necessary for confirmation of these results. Data from a season with late-season rainfall will be particularly valuable.

Information on effects of canopy management on supplemental pesticide application, and on economic feasibility of the practice also are needed. Normally, grapes grown in the San Joaquin Valley are worth considerably less than those grown in coastal areas. Manual leaf-removal is a time-consuming process, and growers interested in the practice will need to assess the cost/benefit ratio. Machinery capable of leaf removal should be designed and evaluated.

Canopy management by leaf removal currently is being routinely employed by several commercial producers in coastal growing areas. The primary reason is to market quality wines from grapes which received few or no pesticide applications. Several San Joaquin Valley producers independently evaluated leaf removal during the 1988 growing season. Although confirmatory data are needed, it seems likely that canopy management will become a routine cultural practice for grape growers throughout California who want to effectively control bunch rot diseases while reducing pesticide usage on their crop.

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Table 1. Influence of Canopy Management (Leaf Removal)[1] on Grape Bunch Rots and Yield (San Joaquin Valley, CA-1988).

Location, Variety, Treatment	Bunch Rot Incidence (% Clusters infected)			Yield
	Botrytis Bunch Rot	Sour Rot	Total Rot	(lb./vine)
Ceres, Chenin blanc				
Leafed	1.5**[2]	3.0*	9.5*	16.8
Control	11.6	8.5	24.5	17.3
Livingston, Chenin blanc				
Leafed	10.0	19.0**	27.0*	14.1
Control	10.0	42.0	48.0	16.1
Livingston, Barbera				
Leafed	2.7	13.0	17.0*	13.3
Control	8.7	26.3	33.4	14.7

1 All experimental vineyards were cordon-trained. No bunch rot fungicides were applied.

2 Values followed by asterisks are different at P=0.05(*) or P=0.01(**) according to Student's t Test.