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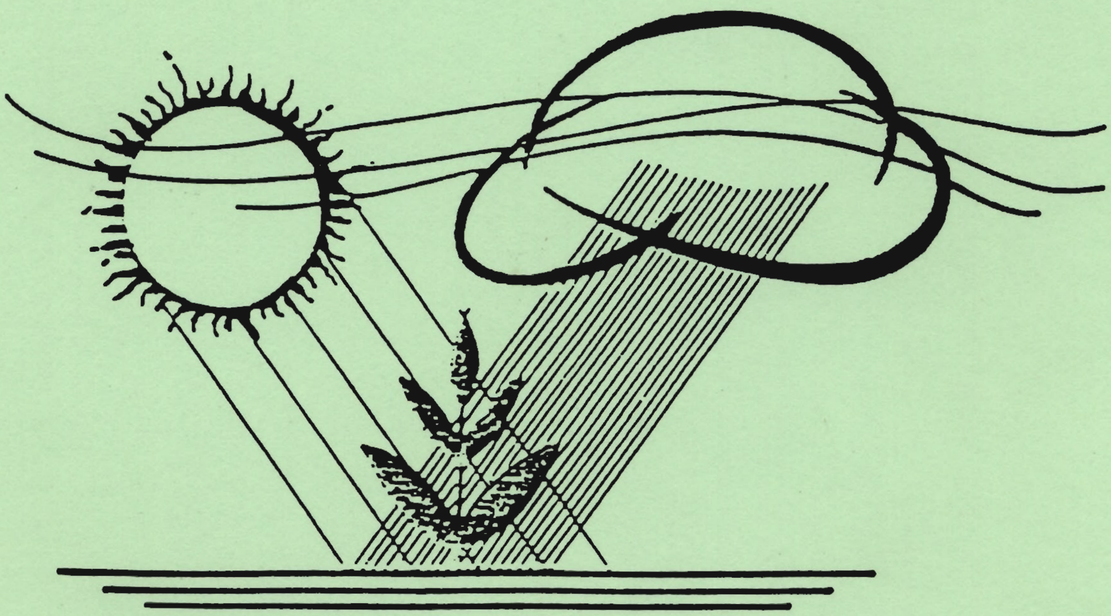
DECISION-MAKING IN AN UNCERTAIN ENVIRONMENT



CALIFORNIA CHAPTER
AMERICAN SOCIETY OF AGRONOMY

CALIFORNIA FERTILIZER ASSOCIATION

January 28-29, 1992
Holiday Inn Centre Plaza
Fresno, California

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Nutrient Interaction

Carl P. Spiva
Agronomist/Consultant

Macronutrient Effects

Soil fertility research has traditionally studied nutrients in isolation rather than in combination. The primary reason for this was because adding variables to any trial substantially increases the statistical analyses computations and there were no computers to do the "number crunching"! In more recent years, with the addition of computers, radioisotopes, and a host of other spectacular technologies, it became possible to study nutrients in combination. As a result, much work is now beginning to be done.

40 years ago, Ohlrogge, of Perdue University, reported that the addition of ammonium nitrogen, with phosphorous, in a band increased P uptake dramatically and that it was also necessary to have the sulfate ion present in order to maximize this effect. Nitrate nitrogen did not stimulate P uptake similarly. He later stated that, "Starter fertilizers can be beneficial on nearly all soils by helping plants withstand insects, diseases and weather extremes better". Researchers have reported that separating N and P by as little as 2 inches can reduce the uptake of P by as much as 50%! Additional studies with other crops have reinforced these findings.

Research with potassium in the midwest revealed that a modest amount of K, in low N, high P, low K balanced starter fertilizer increased yields and also reduced lodging; even on medium and high K soils. Stewart, in Colorado, found that K helped uptake of N and other nutrients on high K soils in cold, wet seasons. Skogley, in Montana, reported similar results. Sugar beets, supplied with modest amounts of K, made better use of nitrogen where soil test revealed normal K levels.

Several researchers have shown that P helps plants withstand weather extremes much better than plants on soils with average P levels.

Nutrient Stress & Plant Disease

There are many citations of the effect of K on disease resistance; sometimes even control of the disease. Reduction of Take All and Common Root in cereals has been reported in cereals. Celery fertilized with potassium chloride exhibited better disease resistance than potassium sulfate, for example.

More recent work with micronutrients can be summarized :

1. Eliminating micronutrient deficiencies generally increases the tolerance and/or resistance of plants to pathogenic diseases.

2. Additional protection in some conditions is provided by a number of micronutrients in concentrations above those needed for host plant growth in disease free conditions.

3. Micronutrients may increase the severity of disease. Interactions between micronutrients or with nitrogen, can introduce an imbalance which makes plants more susceptible to disease.

4. The effect of nutrition on disease resistance is usually only one of of several factors.

5. Yield responses to an element may be due to a combination of (a) overcoming the deficiency, (b) changing the host plant's defense against disease, and (c) having a direct toxic effect on the pathogen.

6. Copper, boron and manganese all effect the synthesis of lignin and simple phenols. Zinc, iron and nickel have generally different effects.

7. Iron may be an element for which host and pathogen compete. The iron-manganese ratio is an important factor in the host-pathogen relationship.

The Future

Much more multi-nutrient fertility research work needs to be done in measuring quality factors, in addition to yields. Fertility effect on longevity of trees, vines, or other permanent crops has been given virtually no attention. Many more crops could be listed.

Our plant breeders have given us new varieties of many crops that out yield the older varieties upon which most of the fertility research was done. They didn't provide us with any more growing days, however, and plants must now take up higher rates of nutrients every day than they used to. Most soils release P, K, and some of the other nutrients at a steady rate. Many plants simply cannot extract the nutrients fast enough during the exponential growth stage and high yields are unattainable. Only when we can supply that "extra" need during this growth stage can we expect to realize the maximum yield potential.

AN EFFICACY STUDY TO EVALUATE THE USE OF FOLIAR-APPLIED UREA NITROGEN FERTILIZER AS A NON-PESTICIDE AGENT TO CONTROL CITRUS THRIPS (*Scirtothrips citri* (Moulton)).

Carol J. Lovatt, Associate Professor of Plant Physiology and **Joseph G. Morse**, Associate Professor of Entomology, University of California, Riverside, CA 92521

California citrus growers are a proactive group. In response to the accusation that the citrus industry has contributed to nitrate contamination of groundwater in California, the citrus industry as a whole has decreased the amount of nitrogen applied to the soil and increased the use of foliar-applied nitrogen fertilizer. However, with current and pending legislation, the citrus industry may have to further reduce the amount of soil-applied nitrogen.

The results of Embleton *et al.* (1986) demonstrated that even if growers used soil applications of nitrogen at the minimal levél required for optimal citrus production (225 kg NO_3^-/ha/yr), nitrate pollution of the groundwater would result. Most citrus growers fertilize with significantly higher rates of nitrogen. Worse still, $Ca(NO_3)_2$ applied to the soil at rates as low as 100 to 300 kg/ha/yr increased soil salinity from 0.93 to 1.56 dS/m (Embleton *et al.*, 1986). Thus, the continued use of soil-applied nitrogen in citrus production is a real and significant threat to both water and soil quality in California. Despite the fact that Embleton and Jones (1974) demonstrated that maximum nutritionally-attainable orange yields were associated with annual nitrogen rates from 0.45 to 0.65 kg/tree regardless of the method of application (soil-applied or foliar-applied), the expense of low-biuret urea and inconvenience of spraying have thwarted greater adoption of foliar nitrogen fertilization. Citrus growers need an economic incentive to abandon the use of soil-applied nitrogen in favor of foliar-applied urea. Our research addresses this issue by demonstrating that citrus growers can actually increase yield without a reduction in fruit size or quality by manipulating the timing of foliar urea application. In light of the fact that there are 258,430 acres (104,627 ha) of bearing citrus in California, reducing the amount of nitrogen applied to the soil by the citrus industry would make a major contribution to California's statewide program to improve water and soil quality.

The potential exists that the citrus industry is also contributing to the degradation of water and soil quality in California through the use of chemical pesticides to control citrus thrips (*Scirtothrips citri* (Moulton). Since the early 1900s, 1 to 4 chemical sprays have been applied during the pre-bloom and post-petal fall period to control this pest in much of California's citrus, especially in the San Joaquin Valley and southern California desert regions, where citrus thrips is a major concern in most years (Horton, 1981; Morse and

Brawner, 1986). Over the past 10 to 20 years, citrus thrips has also become a major problem in other citrus-growing regions of California, especially in the coastal regions of Ventura County. According to the CDFA, over the years 1983-1986, pesticide use for control of citrus thrips in California was 174.6, 190.5, 271.6, and 387.3 (thousand) lbs. active ingredient per year, respectively (Atkins *et al.*, 1989). Thus, 1986 pesticide use for citrus thrips control averaged 1.53 lbs. active ingredient on each of California's 253,681 acres of bearing citrus (Atkins *et al.*, 1989). Although the increase (221.8%) over this 4-year period may be partially due to more accurate reporting, much of the reported increase in pesticide use is real and results from an alarming increase in resistance of citrus thrips to the chemicals which are presently available for its control (Morse and Brawner, 1986; Morse *et al.*, 1986, 1988; Immaraju *et al.*, 1989). Citrus growers need an effective "non-pesticide" approach to control citrus thrips.

A non-pesticide strategy to control citrus thrips would make it possible to convert San Joaquin Valley citrus acreage to biological control (Luck *et al.*, 1986). Growers in the San Joaquin Valley, which comprises a majority (54%) of the state's citrus acreage, have historically used chemicals to control citrus thrips. Broad-spectrum materials such as dimethoate and formetanate, the two main pesticides used over the last 15 years to control citrus thrips, are devastating to biological control agents such as *Aphytis melinus* DeBach (Morse and Bellows, 1986), which can be used to successfully control red scale in citrus. The current use of chemicals to control citrus thrips precludes the use of biological control for other insect pests.

This project is a direct outgrowth of the basic research of Dr. Carol Lovatt, Department of Botany and Plant Sciences, on the role of ammonia and its metabolites in flowering, fruit set, fruit development, and yield of citrus and the applied research of Dr. Joseph Morse, Department of Entomology, in controlling citrus thrips populations and **reducing the economic loss to growers due to fruit scarring by thrips.**

Flower formation in *Citrus* species is promoted by drought or low temperature followed by restoration of climatic conditions favorable for growth (Lovatt *et al.*, 1988a; Monselise, 1985; Monselise and Goren, 1969; Monselise and Halevy, 1964; Southwick and Davenport, 1986). Lovatt *et al.* (1988a, 1988b) have quantified changes in leaf concentrations of several carbon and nitrogen compounds that occur during the low-temperature or water-deficit stress induction period and during the 4 weeks after removal of stress, which culminates in full bloom. For both 5-yr-old rooted cuttings of the 'Washington' navel orange induced to flower by low-temperature stress and a commercial orchard of 16-yr-old 'Frost Lisbon' lemon trees induced to flower by water-deficit stress, the increase in leaf NH_3-NH_4^+ content paralled the duration and severity of the stress.

Flower number was significantly correlated with leaf NH_3-NH_4^+ content: $p \leq 0.0001$ for low-temperature-induced flowering in the 'Washington' navel orange and $p \leq 0.05$ for water-deficit stress-induced flowering in the field-grown 'Frost Lisbon' lemon. No changes occurred in leaf concentrations of total nitrogen, nitrate, glucose, or starch either during or after the induction treatments.

A cause and effect relationship between tree NH_3-NH_4^+ status and floral intensity was established by subjecting trees to minimal stress and artificially raising the NH_3-NH_4^+ content of the tree by foliar application of low-biuret urea at the end of the minimal stress treatments. Increasing the leaf NH_3-NH_4^+ content by foliar applications of urea significantly increased the number of floral shoots and number of flowers per shoot but did not influence the number of vegetative shoots produced (Lovatt *et al.,* 1988b).

Leaf NH_3-NH_4^+ content ranged from 389 to 2,636 μg per g dry wt for more than 100 trees used in the experiments, including trees receiving foliar applications of low-biuret urea. The corresponding number of flowers per tree was from 4 to 3065 (Lovatt *et al.,* 1988b).

Of additional interest to us was the question of whether a winter foliar application of urea prior to or during the normal period of floral initiation preceding spring bloom of *Citrus* in California would increase floral intensity and result in increased fruit set and yield. For two consecutive years, a winter application of foliar urea in January or February increased the yield of 30-yr-old 'Washington' navel orange trees on Troyer citrange rootstock under commercial production at the Agricultural Experiment Station of the University of California, Riverside, in terms of both total fruit weight per tree and number of fruit per tree (without reducing fruit size) compared to control trees receiving only soil-applied urea. (All trees were determined to have optimal levels of nitrogen by leaf analysis).

A January or February foliar application of urea increased yield by just over one carton per tree in 1989-90 and just under one carton per tree in 1990-91 compared to trees receiving only soil-applied urea.

In addition, the increase in yield resulting from the winter foliar application of urea had no negative effect on fruit size in either year of the study. For each year, the treatment having the greatest number of fruit per tree had the greatest number of fruit with diameters from 7.0 to 8.0 cm (carton sizes 88 and 72: an additional carton per tree in 1989-90 and an additional half-carton per tree in 1990-91).

In addition, the results of our research provided evidence that flower ammonia (NH_3-NH_4^+) content and putrescine synthesis via arginine are metabolically linked during early development of the ovary (fruit) through the period of fruit set in navel oranges (Fig. 1) (Sagee and Lovatt, 1991).

FIGURE 1. *DE NOVO* ARGININE BIOSYNTHESIS POLYAMINES

NH_3-NH_4^+ + ATP + CO_2 → → → → ARGININE → PUTRESCINE → SPERMIDINE → SPERMINE

The conclusion to be drawn from these results is that the synthesis of putrescine and polyamines can be increased by increasing the NH_3-NH_4^+ content of developing flowers and fruit by foliar application of low-biuret urea (Lovatt *et al.*, 1988a, b).

Research is rapidly establishing the importance of polyamines as factors regulating fruit development and fruit set in plants. High polyamine biosynthetic activities and polyamine accumulation were previously reported to be associated with early stages of citrus fruit development characterized by cell division (Nathan *et al.*, 1984). Experimental use of exogenous applications of putrescine (10^{-4} M) to apple flowers increased fruit set and yield per tree (Costa *et al.*, 1986).

If these nitrogen compounds are important to fruit development and fruit set in citrus, we should be able to increase fruit set and yield with foliar applications of low-biuret urea during the period of early ovary (fruit) development prior to fruit set, i.e., sometime during the period from March 1 to May 1. This is the hypothesis we have proposed to test. Please note that the use of putrescine itself has little potential as a commercial practice because it is expensive and can cause serious eye and skin irritation.

The future of chemical control of citrus thrips is in question (Morse *et al.*, 1988). Resistance is rapidly developing in most areas of California to dimethoate (Cygon) and formetanate (Carzol) the two main pesticides used over the last 15 years (Immaraju *et al.*, 1989). Pyrethroids have not been registered on bearing citrus as yet but the California Citrus Quality Council has received an Emergency Exemption Permit (Section 18) for the use of cyfluthrin (Baythroid) against citrus thrips in 1991. Pyrethroid use is viewed with some concern because of the potential for scale insect and mite flare-ups in citrus as reported on various deciduous tree crops. It is also possible that abamectin (Agri-mek or Avid) may be registered sometime in 1993 or 1994.

A predaceous mite, *Euseius tularensis* (*hibisci*) Congdon and McMurtry, appears to provide some biological control of citrus thrips, especially where pressure from citrus thrips and fruit scarring is lighter in most years (Tanigoshi and Griffiths, 1982; Tanigoshi *et al.*, 1984, 1985). In general, however, and especially in situations where pressure from citrus thrips is high (e.g., San Joaquin Valley navel oranges = 90,979 acres), a selective chemical is needed to reduce citrus thrips to levels below economic threshold levels. *E. tularensis* is a polyphagous natural enemy of thrips. During warm periods after petal-fall, citrus thrips levels can rapidly increase to levels that the predaceous mite can not control. A selective material that could reduce the level of first generation citrus thrips before this time would be helpful. We believe that foliar urea will prove to be a selective material that is effective in reducing first generation citrus thrips levels. The only other selective materials presently available for citrus thrips control are sabadilla (Veratran D) and ryania (Ryan 50), both marginally effective botanical baits (mixed with sugar), which are in short supply. If as expected with increased interest in citrus integrated pest management including *Aphytis* releases for California red scale control, a moderate number of growers started to use one or both of these materials, supply could not meet demand.

We believe that the use of urea sprays may provide some control of citrus thrips during the critical pre-bloom to petal-fall period while being innocuous to important citrus natural enemies, e.g. *E. tularensis*. In California, bee-toxic pesticides cannot be sprayed from the time the citrus trees reach 10% anthesis in the southwest tree quadrant through 75% petal fall in the northeast tree quadrant as determined each spring by the Agricultural Commissioner in each county. It is of significant advantage to the grower that urea could be used during this period. The level of control afforded by urea sprays might not be very high. However, foliar urea (i) can be used during bloom when most chemical insecticides can not be used, (ii) would supplement biological control of citrus thrips by *E. tularensis*, and (iii) would supplement the use of botanical sprays without an additional expense to the grower since nitrogen fertilization must be accomplished regardless.

In glasshouse studies investigating the effect of phosphorus deficiency (-P) on the nitrogen metabolism of several citrus species, we observed that the leaves of the -P plants, which accumulate high levels of ammonia (Rabe and Lovatt, 1986a, b), had very low levels of polyphagous insects relative to the +P controls. Dr. J. G. Morse, Associate Professor of Entomology at UCR, quantified the survival of young, first instar citrus thrips (less than 24 h post-hatch) on -P and +P leaves. In two separate experiments, only 12 and 3% survived to the prepupa stage on -P leaves, compared to an 88 and 86% survival rate on +P leaves. To confirm that the death of the thrips was due to the high concentration of NH_3-NH_4^+ (1,215 μg/g dry wt) in the -P leaves, the petioles of +P leaves were immersed in 50 mM NH_4Cl for 48 h or in distilled water for 48 h. Results are summarized in Table 1. It is clear that high levels of NH_4^+ (> 1,600 μg per gram fresh weight leaf tissue) cause significant citrus thrips mortality (> 80%).

Results from South Africa confirm that foliar-applied urea can be used to reduce scarring from citrus thrips. The experiments also established that the time of urea foliar application is important. A foliar urea 1% w/v spray applied during bloom significantly

($p \leq 0.05$) reduced citrus scarring caused by *Scirtothrips aurantii* (a species very similar to California citrus thrips). However, a later application made at 100% petal fall had no toxic or antifeedant effect (Grout and Richards, 1988). Grout and Richards (1988) concluded that once absorbed, the urea either must have had an antifeedant or toxic effect for several weeks, or else dramatically reduced the thrips generation that occurred during bloom, to cause such a significant reduction in scarring by citrus thrips (Table 2).

Table 1. Effect of Leaf Ammonia Content on Citrus Thrips Survival

Treatment	NH_3-NH_4^+ (μg/g FW)	Number of thrips	% Reaching prepupa	Days to prepupa	% Reaching adult	Days to adult
Control 1	50	60	98	10	93	14
Control 2	174	60	98	8	97	13
NH_4^+ (48 h)	1,972	60	8	14	8	18
NH_4^+ (48 h)	1,619	60	38	11	18	15

Table 2. Effect of Foliar-Applied Urea on Citrus Thrips Scarring

Treatment	Application date, 1986	Mean percent fruit scarred 10 Nov. 1987
Untreated	---	22.2 a
Urea 1% w/v	Sept. 16 - bloom	8.9 b
Urea 1% w/v	Nov. 13 - petal fall	24.2 a

(Grout and Richards, 1988)

Thus, urea sprays applied during the pre-bloom to petal-fall period from March 1 to May 1 may be optimal for citrus thrips control and also for maximizing the growth regulator-like properties of urea to improve fruit set and yield. If our hypothesis is correct, the results of our field research employing 17-yr-old 'Washington' navel orange trees on Troyer citrange rootstock under commercial production in the Southern San Joaquin Valley will provide evidence that foliar-applied low-biuret can do triple duty: (*i*) as a "non-pesticide" to control citrus thrips and reduce fruit scarring; (*ii*) as a plant "growth regulator" to increase fruit set and yield without a reduction in fruit size or quality; and (*iii*) as a source of nitrogen fertilizer so that less nitrogen is applied to the soil. This will provide citrus growers with an environmentally sound alternative that imposes no economic hardship to citrus growers should the current use of toxic pesticides be restricted and an economic incentive to switch, at least in part, from soil-applied nitrogen in favor of foliar-applied urea to increase yield, thus reducing the potential for pesticide and nitrate pollution of groundwater.

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$pring Wheat Responds to Phosphorus In Low Input Sustainable Agriculture

John D. Walker, Jim Thorup and Greg Blaser[1]

During periods of low wheat prices southeastern Idaho farmers often dramatically decrease or totally discontinue the use of fertilizer in wheat crops. Farmers often feel that the use of fertilizer results in a net decrease in their total profits when wheat commodity prices are less than $3.00 per bushel at area grain elevators.

If any fertilizer formulation is used during poor economic times it is primarily some form of nitrogen used on a limited bases. This opinion prevails due to the high soil test levels for phosphorus and potassium in southeastern Idaho soils. These native high levels came about during the geological formation and deposition of these soils million of years ago.

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It has been generally considered by farm consultants and soil fertility experts in the past, that a soil test level of 14 to 15 ppm for sodium bicarbonate extractable phosphorus provides more than an adequate phosphate level for top wheat production.

Numbers from the most recent issue of *"Fertilizer Summary Data"* (1990) released by Tennessee Valley Authority show that there is still considerable room for improved phosphorus fertilization on wheat. Kansas farmers applied an average of 13 lbs. P_2O_5 per acre of wheat in 1990. Farmers in Colorado and Washington applied 4 lbs. and 6 lbs.P_2O_5 per acre respectively. Considering that wheat removes approximately 0.5 lbs. of P_2O_5 per bushel of production, farmers are still "mining" their soils for phosphorus. Kansas farmers applied enough phosphorus for only 26 bushels of wheat, while farmers in Colorado and Washington applied enough for only 8 bushels and 12 bushels respectively. State average production figures are considerably higher than these numbers. Yields are undoubtedly suffering in many areas as a result of this neglect.

For the past three years researchers, at the Ricks College Hillview Farm, have studied the value of increased phosphorus applications to wheat grown under a irrigated low input sustainable management system. Fertilizer test plots were established in 1989 at this experimental farm which has been under strict no-till management for wheat and barley production since 1976. Continuous small grain has been produced at the experimental site either fall or spring planted.

The scope of study centered around the interaction of nitrogen and phosphorus rates on yield of irrigated hard red spring wheat. The initial soil test level for sodium bicarbonate extractable phosphorus was 15 ppm.

Four rates of nitrogen (0, 60, 120, 180 lbs. per acre) and three rates of phosphorus (0, 50, 100 lbs. per acre P_2O_5) were applied in randomized, replicated plots. Each of the three replications for each treatment were in plots measuring 34 feet wide by 100 feet in length. Nitrogen was applied as ammonium nitrate broadcast just prior to planting. Phosphorus was drilled with the seed at the time of planting using a Concord Air Drill. The large sized plots were used so typical farming equipment could be accommodated for planting and harvesting.

Irrigation was accomplished the first two years by moving hand lines. In 1991 a center pivot system was installed for more even irrigation during climate stress periods.

Plots were harvested using a combine with a 14 foot wide header. One pass was harvested for the full length of each plot (100 feet) giving a harvested area of 1400 square feet. Yields from each plot were weighted and samples were taken for moisture and protein.

Table 1 shows data from the first year 1989. Phosphorus increased yields at all rates of nitrogen by as much as 25 bushels per acre. Data from the second year 1990, showed similar increases due to phosphorus application. Yields were reduced substantially, however, due to excessive heat and wind and the inability to move hand lines fast enough to prevent damage to developing kernels.

In 1991, the third year for the test plots, a decision was made to apply nitrogen to the entire plot where applicable but to apply phosphorus to only one-half of each plot. This would tells us about the residual phosphorus effects, if any from the first two years of added phosphorus. Results are shown in table 2.

The increased economic spring-planted wheat yield from additional phosphorus application occurs due to one or more of the following factors: 1) enhanced spring frost protection, especially during the time period when yield potential is being established by the plant. 2) Wheat plants develop a more extensive root system which make better use of available water and soil nutrients. 3)The wheat crop demonstrates additive competition especially with wild oats. 4) Growers and the environment benefit from the significant extension of the useful life of herbicides needed for weed suppression without additional chemical applications.

Data from this three year study shows the importance of a well balanced fertilizer program to generate maximum returns from hard red spring wheat in Eastern Idaho. The application of phosphorus to wheat crops growing in soils testing medium or below in phosphorus will result in increased yields and improved profits at any market level.

Many researchers are not recommending 22 to 24 ppm phosphorus, sodium bicarbonate extractable, as the critical level for wheat production. Growers whose soil test below this value should put out test strips of phosphorus to determine possible responses on their farms similar to Mr. Bob Parkinson of Rexburg, Idaho. Mr. Parkinson, tested these research results on 1,300 acres of Spring wheat this year. On the 1,300 acres of wheat where he added the additional 50 lbs of P_2O_5 he averaged 105 bushels per acre. On the 40 acre check strip he averaged 91 bushels per acre. The soil test level for both these locations was 15 ppm for sodium bicarbonate extractable phosphorus.

The next two decades will be one of considerable concern for the environment. Excellent fertilizer management will be required by all to achieve economic and optimum production levels. Such management and concern for all aspects of the environment will weld producers and consumers into a common team and guarantee a prosperous agriculture community.

Dr. John D. Walker, Dr. Jim Thorup, Greg Blaser

Table 1 1989 First year of Experiment

Economic Spring Wheat Response to Additional Phosphorus

Treatment		Yield*	Protein	Dollars per Acre Profit **		
NH 4- N0 3	P 2 -0 5	Bu/ Acre	%	$4.00/bu	$3.00/ bu	$2.00/bu
0	0	35.7	13	$144.80	$107.10	$71.40
0	50	62.3	12.5	$237.20	$174.90	$112.60
0	100	62.1	12.3	$224.40	$162.30	$100.20
60	0	41.7	13.3	$153.60	$111.90	$70.20
60	50	67	13.7	$242.80	$175.80	$108.80
60	100	69.7	13.5	$241.60	$171.90	$102.20
120	0	63.5	13.2	$227.60	$164.10	$100.60
120 (# 2)	50	76.6	13.3	$268.00	$191.40	$114.80
120	100	76.3	13.4	$254.80	$178.50	$102.20
180	0	70.6	14	$242.80	$172.20	$101.60
180 (# 1)	50	85.1	13.6	$288.80	$203.70	$118.60
180 (# 3)	100	81.8	14.5	$263.60	$181.80	$100.00

*Yields calculated at 12 % moistrue

**Cost of fettilizer subtracted out: @ nitrogen $0.22/lb and Phosphorus @$.24/lb

Wheat variety used in this study was Borah (a Hard Red Spring)

Shaded lines indicate the lst, 2nd and 3rd best dollar returns on fertilizer rate and formulation at three different prices of wheat per bushel

Ricks College, Rexburg, Idaho (14 yr. continuous no-till wheat for plot area)

Dr. John D. Walker, Dr. Jim Thorup, Greg Blaser

Table 2 1991 Third year of Experiment

Economic Spring Wheat Response to Additional Phosphorus

Treatment		Yield* (Bu/A)		Protein %		Dollars/Acre Profit**		
NH4 N03	P2 05	P-1	Zero P-2	P-1	Zero P-2	$4.00/Bu	$3.00/Bu	$2.00/Bu
0	0	32.4			11	$129.60	$97.20	$64.80
0	50	43.1		11.4		$160.40	$117.30	$74.20
			32.9		10.8	$131.60	$98.70	$65.80
0	100	45.1		11		$156.40	$111.30	$66.20
			37.9		10.5	$151.60	$113.70	$75.80
60	0	51.1			12.5	$191.20	$140.10	$89.00
60	50	55.6		12		$197.20	$141.60	$86.00
			42.4		12.1	$156.40	$114.00	$71.60
60	100	73		12.7		$254.80	$181.80	$108.80
			69.2		12.3	$263.60	$194.40	$125.20
120	0	63			12.4	$225.60	$162.60	$99.60
120	50	77.3		12.9		$270.80	$193.50	$116.20
			61.2		12.5	$218.40	$157.20	$96.00
120	100	77.8		12.8		$260.80	$183.00	$105.20
			66.7		12.7	$240.40	$173.70	$107.00
180	0	74.7			12.8	$259.20	$184.50	$109.80
180 (#3)	50	91.5		13.4		$314.40	$222.90	$131.40
			86.6		13.1	$306.80	$220.20	$133.60
180 (#1)	100	100.9		13.3		$340.00	$239.10	$138.20
(#2)			91.4		13.2	$326.00	$234.60	$143.20

*Yields calculated at 12 % moisture

**Cost of fertilizer subtracted out: Nitrogen @$0.22/lb & Phos @$0.24/lb.

Wheat Variety: NK 751 (Hard Red Spring)

P - 1 Phosphorus applied at planting in spring of 1991

Zero P-2 No Phosphorus applied in 1991, residual from previous 2 years

Ricks College, Rexburg, Idaho (16 yr. continuous no-till wheat for plot area)

IRRIGATION, PHYSICAL AND CHEMICAL CHARACTERISTICS OF NORTH COAST SOILS RELATED TO HIGH–QUALITY WINE GRAPE PRODUCTION WITH COMPARISONS TO CENTRAL VALLEY

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North Coast soils are so different chemically and physically from Central Valley soils that they require a totally different approach for production of high–quality grapes and wines of superior quality. North Coast vineyard soils meeting criteria needed to produce superior wines are limited. Central Valley research, irrigation and viticultural practices have few related applications to North Coast soils. Two that have proven helpful are Boron and Basic Zinc treatments based on work reported by Peter Christiensen – Grape Extension Specialist, Fresno County, California Chapter, American Society of Agronomy, Feb. 1 – 3, 1984.

Grape vine nitrogen uptake work at the Kearney Research station may have potential for North Coast situations. But, except for gravelly and sandy alluvial soils the loams, clay loams and clays currently in production have adequate to more than adequate soil nitrogen levels for wine grapes. Managing the unfavorable effects of too much nitrogen is a far greater problem for North Coast wine grapes than too little nitrogen. Central Valley grapes on sandy and loamy soils such as Thompson seedless variety usually receive annual applications of nitrogen.

Probably the least helpful information comes from both research and conventional wisdom irrigation practices. North Coast soils ranging in texture from loams to clays have sufficient water holding capacity combined with lower water use requirements compared to the Central Valley to carry vines through the season with little or not supplemental irrigation when root zones are plus 4'–5' deep. Sands and gravelly soils with root zones of 8'+ may carry vines through without supplemental irrigation. Root zones shallower than 3'–5' will usually require supplemental irrigation, but on a more restricted water quantity basis than in the Central Valley.

Grape vines will within reason pump out excessive amounts of water over and above what is required. In one test in lower Napa Valley monitored by neutron probe sites, vines pumped out 40 gallons of applied water per week/vine while unirrigated checks on the same soil situation worked off of residual soil moisture. See Table 1. Wine makers preferred the non-irrigated grapes. Vine visual appearance was the same for all treatments. From an environmental standpoint, excessive water use is difficult to justify. From an economic stand point, it reduces profits and based on our experiences may encourage plant root rot diseases and shallow root systems.

Soil moisture monitoring in the root zone can be an effective and efficient way to reduce excessive water applications and unproductive plant water consumption. Decision making is helped by accurate measurement of soil moisture and actual plant water consumption.

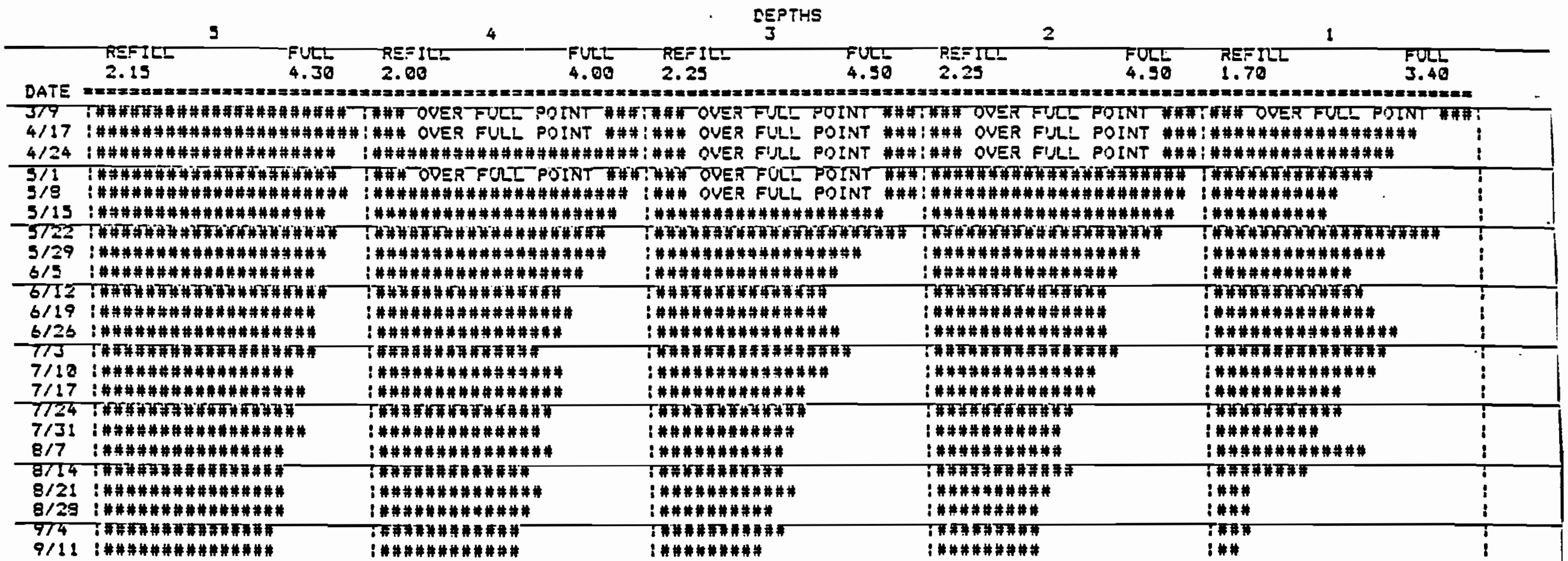
An essential irrigation difference between North Coast conditions and Central Valley soils is winter replenishment of the root zone from rainfall. North Coast soils have had sufficient rainfall each rainy season to totally refill the soil profile since 1986 and including 1990–1991 before bloom. Central Valley soils rarely ever receive enough during the rainy season to refill the entire soil profile. This difference alone results in totally different irrigation management practices and requirements between the two areas.

Dramatic soil chemical differences exist between Central Valley and North Coast soils as they relate specifically to vine growth and wine quality. Potassium (K) is one of the most deficient nutrients in North Coast soils. Potassium utilization by wine grapes is further complicated when grown on soils with high levels of Magnesium in relation to Calcium and Potassium containing Illitic and Montmorillonitic clay fractions with high K fixation capacities. Sandy valley soils tend to have lower clay fixation and higher K levels than North Coast soil.

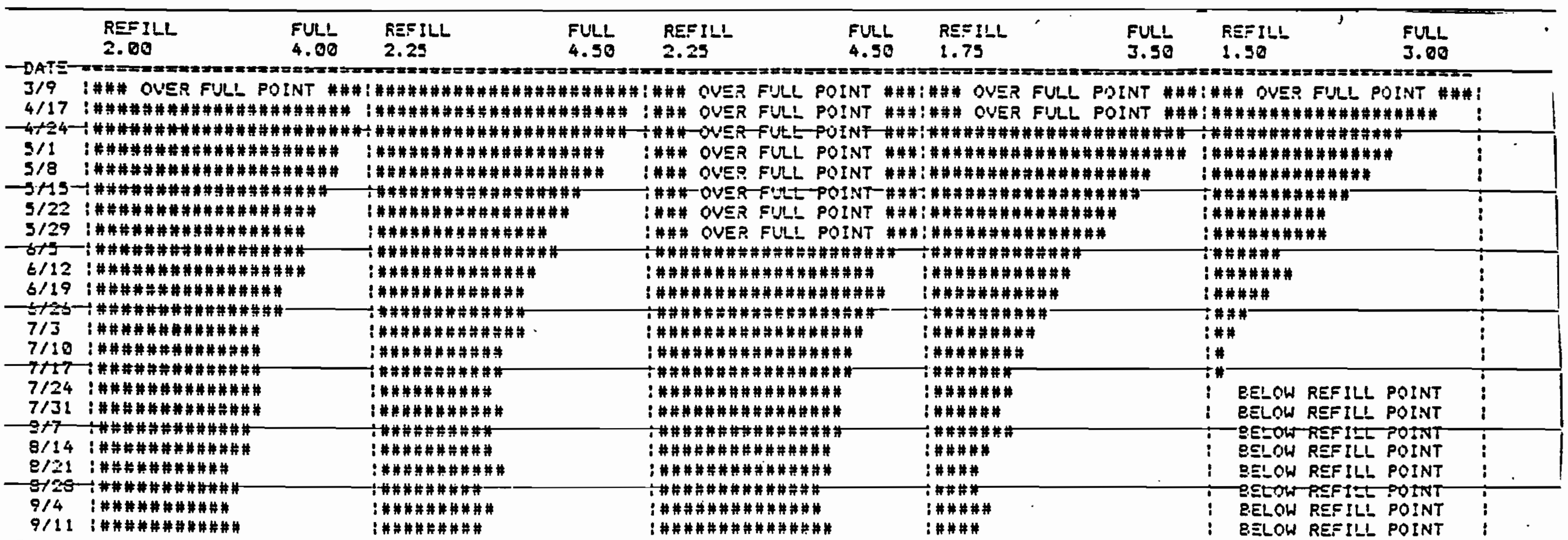
TABLE 1

1987 MOISTURE GRAPH

40 GALLONS PER VINE PER WEEK



0 GALLONS PER VINE PER WEEK



A situation in the San Joaquin Valley, which may be similar, is the Potassium deficiency problem on Cotton grown on heavy clay soils reported at prior chapter meetings. One solution to the North Coast soil problems we have used for improving Potassium uptake commencing in 1982 is placing Sulfate of Potash 2' deep 2' from each vine. Interestingly enough this is almost identical to the suggested placement depth for cotton on those clay soils.

Experience has shown that grape rootstocks such as AXR−1 and St. George do not grow or produce well on clay loams and clays when the Calcium to Magnesium ratio is less than CA 2:Mg 1. These soils will typically contain between 50 to 100 PPM K. The superior wine quality soils will have CA 4+:MG 1 and 200−400 PPM K, but more about them later.

A high percentage of North Coast grape soils are irrigated because of K problems which look to growers like vines need water, whereas, the primary reason is they need K. Vines low in K do not use soil moisture efficiently. You might be surprised at how many "experts" tell growers to irrigate when they should be telling them to apply Potash. How many salt problems and exaggerated vine irrigation practices in the Central Valley might be improved with more adequate K nutrition? 1991 petiole results from vines grown on valley floor soils between Ripon and Merced showed CA:MG relationships of 2:1 and K:MG ratios of 2:1. French researchers report quality and production problems with these kinds of relationships and our experience is identical for North Coast grapes. Superior quality North Coast grapes have K:Mg ratios of 8+:1, and CA:Mg of 4+:1 and K:(CA+Mg) 1+:1. See Tables 2 and 3.

Research on K, CA and Mg relationships has been reported over the years for grapes, fruits, turf grasses and several commodity crops. "Potassium in Agriculture" published in 1985 by ASA, CSSA and SSSA, Madison, Wisconsin is an excellent reference and bibliography resource for Potassium and its relationships to crop production. Potassium effects on plant water

TABLE 2

PETIOLE POTASSIUM, CALCIUM AND MAGNESIUM RELATIONSHIPS – CENTRAL VALLEY BLOOM – 1991

	K %	CA %	Mg %	K:Mg	CA:MG	K:(CA+Mg)
CABERNET SAUVIGNON						
1	1.75	1.62	0.76	2.30	2.10	1:1.36
2	1.66	2.13	0.81	2.05	2.60	1:1.77
3	1.72	1.97	0.90	1.90	2.20	1:1.76
4	1.61	1.93	0.90	1.90	2.10	1:1.76
CHARDONNAY						
5	2.20	2.25	1.06	2.00	2.10	1:1.50
6	1.44	1.94	0.90	1.60	2.20	1:1.97
7	1.56	1.83	0.84	1.86	2.20	1:1.70
8	1.80	1.79	0.76	2.40	2.40	1:1.42
9	1.73	1.77	0.80	2.20	2.20	1:1.49
ZINFANDEL						
10	1.19	1.76	0.78	1.53	2.30	1:2.13
11	2.15	1.93	0.82	2.60	2.40	1:1.28

TABLE 3

BLOOM PETIOLE POTASSIUM, CALCIUM AND MAGNESIUM RELATIONSHIPS NORTHCOAST – VINEYARDS PRODUCING SUPERIOR WINES

CABERNET SAUVIGNON

VINEYARD A

YEAR	K%	CA%	MG%	K:Mg	CA:Mg	K:(CA+Mg)
1989	3.62	3.13	0.36	10.06	8.69	1.04
1990	3.53	1.92	0.40	8.83	4.80	1.52
1991	4.00	2.00	0.31	12.90	6.45	1.73

CABERNET SAUVIGNON

VINEYARD B

YEAR	K%	CA%	Mg%	K:Mg	CA:Mg	K:(CA+Mg)
1988	2.36	1.92	0.26	9.08	7.38	1.08
1990	4.23	2.28	0.34	12.44	6.71	1.61
1991	4.10	2.10	0.30	13.67	7.00	1.71

CABERNET SAUVIGNON

VINEYARD C

YEAR	K%	CA%	Mg%	K:Mg	CA:Mg	K:(CA+Mg)
1991	4.30	1.60	0.47	9.15	3.40	2.08

use are widely recognized and reported by researchers in this publication.

California's agricultural water use efficiency will become more of a future issue than it already is. Understanding plant Potassium/water relationships will require a much more significant research effort than is currently underway. Improving plant water use efficiency may become as important a criteria for evaluation as quality and yield have been in past research efforts.

Without question our single most troublesome nutritional problem for North Coast grape quality is vine Potassium utilization. Potassium, Calcium and Magnesium relationships are the major cause of troubles with grape yields and quality. It appears that high soil magnesium levels are more unique to the North Coast area as compared to other major world production areas. Research studies to determine how much this adds to or detracts from wine quality would certainly make an interesting contribution to our knowledge of our most significant US wine grape growing region.

Over the past ten years we have been actively involved in improving troublesome Potassium situations. In the late 1970's, Dr. Rollie Meyer participated in a study in Pope Valley (just east of Napa Valley). The study measured the response of grape vines newly planted on a high Magnesium high clay soil. The pre–plant treatments involved application rates of from 5 to 125 tons of Gypsum per acre roto–tilled into the soil. Results showed a stair step in vine growth with beneficial effects from the lowest to highest Gypsum treatments.

Based on those results our program has been to lime top 12" of soil to pH7 and then apply 8–10 tons Gypsum per acre per year until vine growth is satisfactory. At the same time we will apply 4 to 10 pounds Sulfate of Potash/vine in a hole 2' deep 2' from the vine or concentrate Potash in a ripper shank at same depth and distance from the vine. The ripper shank treatment is limited to loam or clay loam soils with good physical structure. Potash concentration is essential in all of these methods to reduce clay fixation.

Future treatments will involve all of the above plus higher plant populations to reduce individual vine crop loads, higher potash applications and changes in lime and gypsum placements. Additionally, we are looking at rootstocks which may tolerate higher magnesium situations such as 3309, 1105–P and 44–53M.

The superior soil – superior wine situation we have been referring to throughout this paper has resulted from discussions and tastings with client wine makers. They have told us of vineyard blocks that produce their highest quality wines. Going back over soil analyses and petiole results has shown certain similarities, which lead us to think it may be possible to identify soil criteria positively affecting superior grape and wine quality.

Some of these findings are:

1. Good subsurface drainage all year.
2. Soil textures ranging from loam to clay with or without shale and rocks.
3. Soil Potassium levels of 200–400 PPM.
4. Soil Calcium:Magnesium ratios of 4+:1.
5. Soil rooting depths of 5'+.
6. Non–irrigated.

The above criteria does not attempt to evaluate the positive effects of the wine maker, viticulturist, crop load and vine balance on the fruit produced. It does open some interesting contemplation into soil nutritional management and its potential beneficial effects on grape and wine quality. It raises questions about the adequacy of so called critical "K" levels for wine grapes. Hopefully it will help to stimulate further research investigations into these nutritional and vine water use effects and relationships.

EFFECTS OF FERTILIZER ON POPULATION DYNAMICS OF VARIEGATED LEAFHOPPER ON GRAPES

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The nutritional status of host plants is an important factor in host plant utilization for a number of insect species (Slansky and Rodriguez 1987). Scriber (1984) reviewed numerous studies which found an increase in insect and mite numbers, damage, fecundity, and growth in situations of high plant nitrogen. Although the acquisition of a variety of elements and compounds is essential for plant growth, nitrogen is considered the key nutrient, particularly for plant-feeding organisms.

The variegated leafhopper (VLH) (*Erythroneura variabilis* Beamer) is an important insect pest on much of California's grape acreage (Kido et al. 1984, Pickett et al. 1987). The primary objective of this research is to determine whether various host plant selection and utilization processes by VLH are accelerated by nutritional state of the grapevine (specifically nitrogen), as determined by varying fertilizer type (synthetic vs. compost) and quantity (typical recommended vs. 2X recommended) in a commercial vineyard in California's San Joaquin Valley.

Materials and Methods: The study is being conducted in a 2-acre vineyard (Thompson seedless) west of Fresno, CA, in which the farmer has for years used minimal inputs of fertilizers and pesticides). Treatments consist of: 1) control plots receiving no plant nutrient supplements, 2) standard recommended rate of synthetic ammonium nitrate (75 lbs. N / A), 3) high (twice the recommended) rate of synthetic ammonium nitrate (150 lbs. N / A), and 4) compost (derived from dairy and steer manure, and cotton gin trash) applied at the recommended rate of two tons per acre (from New Era Farm Service, Tulare, CA). Nitrogen content of the compost is 1.6%, providing 32 lbs. N / A. All treatments were applied to consistent plots during 1989, 1990, and 1991.

Each treatment plot consists of five adjacent within-row vines. All treatments contain five replications and are arranged in a randomized complete block design. Leaf petioles and blades from each treatment replicate were evaluated for NO3-N and total N respectively, at bloom and during mid-August during both 1989 and 1990.

The general abundance of VLH and GLH nymphs (VLH comprises over 90% of total nymphs) was monitored each week by sampling three inner leaves and three fully expanded outer leaves on the three center vines of each treatment plot.

During 1989, adult VLH oviposition rates were evaluated twice during the season (July, August). Three time periods of VLH oviposition (April, June, August) were investigated in 1990. Each oviposition trial began once the leaves were fully expanded. Adult leafhoppers (two females and one male) were placed on each bagged leaf for two days. After two days, adult leafhoppers were removed and the number of VLH eggs counted. In 1989, six leaves were caged per treatment replicate. The sample size was increased in 1990 to nine leaves per replicate.

The adult leafhopper source during the April 1990 oviposition trial was obtained by capturing adults that overwintered in the vineyard. In the subsequent trials (i.e., 2nd and 3rd generations), adults were obtained from populations reared within cages enclosing individual canes within each treatment plot. This provides for the testing of adults that were actually reared on the same treatment foliage.

During June and August, newly hatched first instar nymphs were located on marked leaves, and their development times recorded. Six VLH nymphs were placed on each marked leaf for a total of 60 (1989) and 90 (1990) nymphs per treatment.

During both 1989 and 1990, gross raisin yields were measured by harvesting the three inner vines in each treatment plot and drying the grapes in the field at the same time the remainder of the vineyard was harvested commercially.

Results and Discussion: Nitrate N levels (petiole analysis) were significantly greater ($P < 0.05$) in the high (2X rec.) synthetic fertilizer plots on both the mid-May (bloom) and mid-August sampling dates in 1989 (Fig. 1). Grape petiole samples in 1990 (Fig. 2) again revealed that the high synthetic plots had significantly higher levels of nitrate N at both bloom and mid-August. However, leaf blade analyses for total N showed very little variation among the treatments.

Gross raisin yields were not significantly different among fertilizer treatments during either 1989 or 1990. Yields in all plots were commercially acceptable, averaging around 2.5 tons per acre in all treatments (including control).

First generation VLH nymph densities were significantly different ($P < 0.05$) among treatments during the peak density period occurring over two consecutive dates in 1989 (Fig. 3). The standard ammonium nitrate (75 lbs. N / A) treatment had significantly more VLH nymphs than the control and compost treatments, while the high ammonium nitrate (150 lbs. N / A) treatment was greater than the compost treatment. Although there was a similar general trend in 1990 (Fig. 4), nymph count differences were not statistically significant. This undoubtedly related to the considerably smaller overall field population of VLH during 1990.

Results of the two VLH oviposition tests in 1989 (Fig. 5) showed that in July, significantly more eggs were laid in the two synthetic fertilizer treatment plots. Treatment differences again were detected in the June 1990 oviposition study (Fig. 6). Significantly more VLH eggs were laid in the synthetic treatments than in the control or compost plots. The two-year trends in these oviposition studies are very similar to differences found for VLH nymphal densities (see above).

In the VLH nymphal development tests, treatment comparisons among the relatively few surviving individuals revealed no significant differences in average nymphal development times.

Conclusions: During the first two years of this study we have demonstrated considerable changes in the levels of nitrogen among grapevines in plots receiving the various fertilizer treatments. VLH nymph densities and egg-laying rates differed considerably as well. Wherever significant differences have occurred, VLH population parameters have tended to be higher in the synthetic fertilizer plots. For nearly all plant, pest, and natural enemy parameters investigated in this study, values in the compost plots are generally similar to those in the control plots.

While not all first-year results were duplicated precisely in the second year of this study, we feel that the emerging patterns are indicative of a strong relationship between grapevine nitrogen level and VLH population dynamics. The currently ongoing analysis of data collected during 1991 should help elucidate the critical factors involved in the provocative realm of leafhopper nutritional ecology on grapes.

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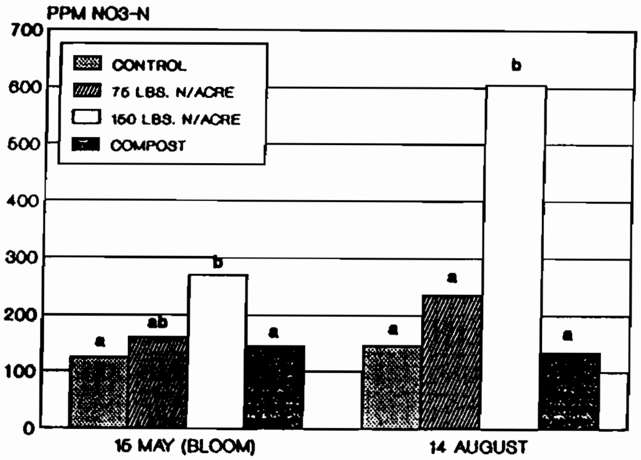


Fig. 1 Petiole nitrate nitrogen levels in 1989.

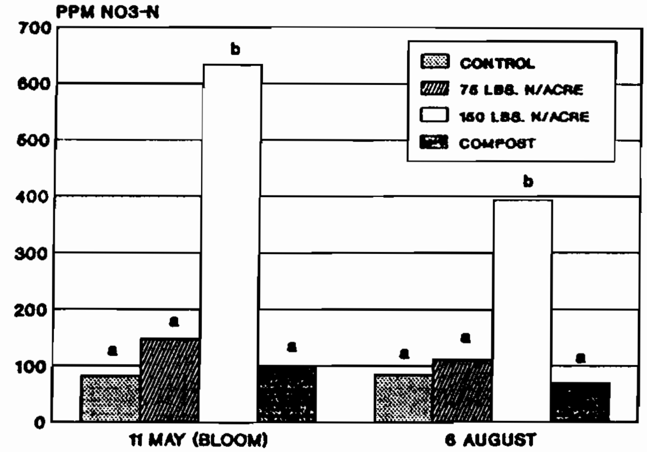


Fig. 2 Petiole nitrate nitrogen levels in 1990.

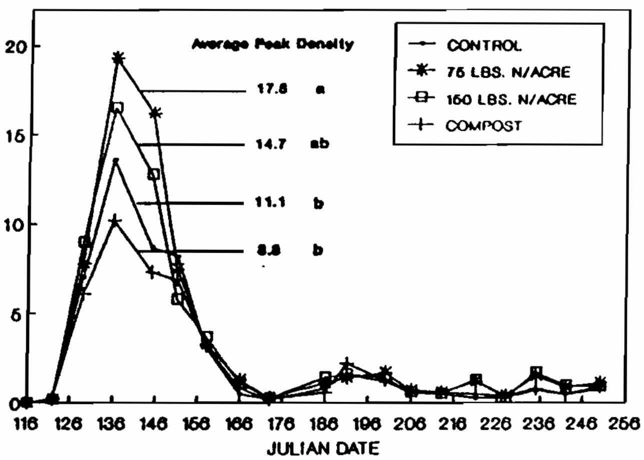


Fig. 3 VLH nymphs per leaf during 1989.

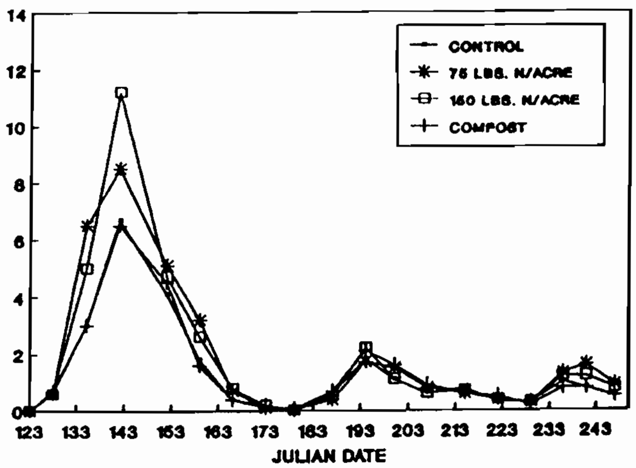
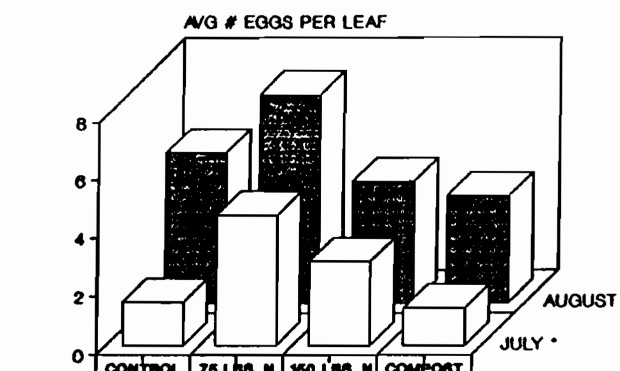
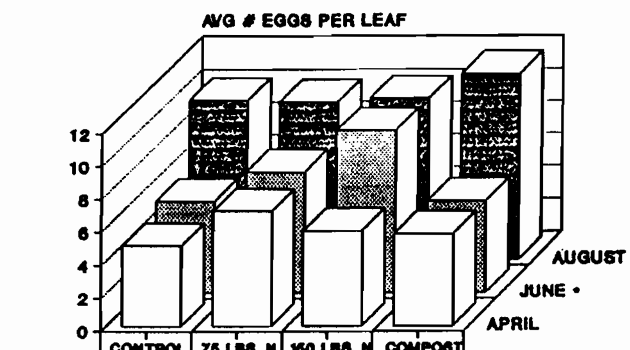


Fig. 4 VLH nymphs per leaf during 1990.



	CONTROL	75 LBS. N	150 LBS. N	COMPOST
AUGUST	6.2	7.2	4.2	3.7
JULY *	1.6 a	4.5 b	2.9 b	1.3 a
OVERALL	3.4	5.9	3.5	2.6

Fig. 5. VLH eggs laid per leaf in 1989.



	CONTROL	75 LBS. N	150 LBS. N	COMPOST
AUGUST	9.8	9.7	9.9	11.4
JUNE *	5.6 b	7.4 a	9.9 a	5.6 b
APRIL	4.9	7	5.8	5.6
OVERALL	6.8	8	8.5	7.5

Fig. 6 VLH eggs laid per leaf in 1990.

Interactions Among Fertilizer, Roots and Pathogen Populations

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There is a direct interaction of root development with fertilizer applications. This can affect pathogen populations by altering the position and density of roots within the soil profile or indirectly by altering the susceptiblity of the roots to infection. Manipulation of fertilizer rates and placement may alter these interactions.

It is possible to manipulate host root growth and health within the soil profile through localized nutrient amendments. Various studies have shown a proliferation of roots in a zone that had additions of nitrogen (N), phosphorus (P) and potassium (K) relative to other zones (Fitter, 1982; Kapur and Sekhon, 1985; Tennet, 1976). This could affect disease by physically changing the location of roots relative to propagules or by physiologically altering the root susceptibility via membrane permeability, root elongation rates or pathogen virulence (Huber, 1980).

Use of nutrients and/or water to manipulate roots away from pathogens may be a possible means of reducing disease. Ashworth et al (1982) reported that potassium nutrition and distribution in a soil profile affects Verticillium wilt in cotton. Grimes and Huisman (1984) reported that fewer irrigations reduced disease incidence, possibly through the change in soil moisture and encouraging deeper rooting of the crop. Philips and Wilhelm (1971) suggested that it is the deeper rooting pattern of <u>Gossypium barbadense</u> <u>L.</u>(with many primary laterals down the entire meter long tap root) that may account for its observed higher field tolerance to V. dahliae as compared to G. hirsutum L..

Nutrient placement, in addition to directing root growth away from pathogens, may influence the infection process either at the root-pathogen interface or within the plant. Broome (1990) recently described a cotton field experiment where added K influenced the expression of foliar symptoms. This study investigated the effect nutrients might have directly on the infection process.

The infection process by soil-borne pathogens has been modeled by various authors in the past decade; inoculum density has classically been one of the most important parameters for these types of diseases. In addition, the width of the rhizosphere/rhizoplane, competency of the propagules, and the importance of host root growth have been included in these models. Gilligan (1979) and Ferriss's (1981) models are based on the probability of a particular inoculum density contacting roots or seeds which have a particular surface-soil volume relationship. Baker et al (1967, 1981) used a physical chemistry model to describe the 3 dimensional (for rhizosphere) and 2 dimensional (for rhizoplane) interactions of inoculum and host roots that lead to root infections and subsequent disease development.

The objectives of this study were to determine if it is possible to (i) manipulate cotton root growth with placements of nutrient fertilizer, (ii) observe root infection by the pathogen at regular depth intervals as it is affected by a nutrient depleted soil and nutrient amendments, and (iii) observe root infection in a controlled microplot experiment and test the appropriateness of various models of soilborne host-pathogen interactions.

Microplots were used to evaluate the effects of nutrient and inoculum placement within the soil profile on cotton root length density, root diameter, root infection, and pathogen propagule dynamics. Verticillium dahliae microsclerotia and fertilizer were applied to four different soil depth intervals (0-15 cm, 15-30 cm, 45-60 cm, and 0-45 cm) in a 3 x 3 factorial experiment with appropriate controls. The proportion of host roots that occurred in a fertilized interval to total root length density increased significantly in the top (0-15 cm) and in the bottom (30-45 cm) intervals. The percentage of infected roots and the total number of root infections were reduced by the presence of fertilizer. Depth affected the increases in microsclerotia observed after 3 months of growth. Microclerotia increased the greatest (from 5 ms/g to an average of 13.2 ms/g) in the top interval (0-15 cm). Using stepwise multiple regression, inoculum density and root radius predicted 75% of the variation in root infections. A solid chemistry model based on a log-log transformation of % infection and inoculum density gave a slope of 0.62 and explained 82% of the variation in root infections. A probability model explained 82% of the variation in root infections, and provided a competency value of 20% and rhizosphere width of 160 μm for unfertilized treatments and 10% and 175 μm for fertilized treatments.

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PM10 ISSUES IN THE SAN JOAQUIN VALLEY

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Given the topography, climate, and geology of the San Joaquin Valley, PM10 (particulate matter less less than 10 microns) is one of the valley's major environmental concerns. The topography creates a bowl effect in the huge valley which prohibits a great deal of horizontal air flow. The climate is dry and air masses often stagnate over the valley which prohibits any significant amount of vertical air flow or mixing. And the geology which lends to making the valley agriculturally rich, the accumulation of fine soil particles common to most valley floors, is the same that lends to the overall PM10 problem.

There is a great deal of activity taking place in the San Joaquin Valley with regards to the PM10 problem. Planning, monitoring, and studying are just a few. In November 1990, President Bush signed the ammendments to the Federal Clean Air Act. Mandated by these amendments are planning requirements which were due to the Federal Environmental Protection Agency (EPA) by November 15, 1991. The plans will be revisited periodically and thus, the planning process will be ongoing. To improve the planning process and subsequent plan updates, PM10 monitoring is being looked at in more detail. Studies are underway at the present time to assess the problem with keener technology. The benefit of the studies will be to define the problem as it is specific to the San Joaquin Valley, including the development of a more accurate PM10 emission inventory.

The plans address anthropogenic PM10 which is the issue and the focus of regulatory mitigation action by both the EPA and the California Air Resources Board (ARB). Anthropogenic PM10 which will be subject to mitigation control measures is the resultant of such human activities as construction and demolition, dirt roads, agricultural waste burning, entrained dust, tailpipe emissions, petroleum processes, and industrial process. One of the difficulties in developing the control measures is the lack of an accurate, current emission inventory. To compound the problem, PM10 is a primary and a secondary pollutant. As a secondary pollutant, it is caused by precursors of nitrogen oxides (NOx) and sulfur oxides (SOx). NOx and SOx react with other chemicals in the air to form nitrates and sulfate molecules that are considered PM10. The rate of transformation of the precursors into PM10 is not known at this time. Therefore, the reduction in emissions of either constituent can not be quantified to show the reduction in PM10. For this reason, the ongoing studies will be especially valuable and the plans can be more specific and direct.

Health effects from PM10 are the overall reason for mitigation action by the EPA and the ARB. Results of studies show direct associations between particulate pollutant levels and coughing, bronchitis, and respiratory illness. The smaller the particulate matter, the greater the health effects. An increasing emphasis is being placed on particulate matter less than 2.5 microns. In its March 1991 report to the California State Legislature, the ARB assessed the PM10 problem statewide. They also included suggested emission controls to reduce PM10 concentrations and prospects for attaining the PM10 standards.

Long-range planning for PM10 is also being developed. A group consisting of representatives from ARB, EPA, the local air pollution control district, and industry is forecasting studies to be undertaken and working to arrange funding for those studies.

PESTICIDE RESIDUES IN AIR IN THE SAN JOAQUIN VALLEY: SOURCES, LEVELS, AND POTENTIAL SIGNIFICANCE

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Pesticide residues enter the atmosphere principally by drift during application, and by post-application volatilization and wind erosion. Our studies have focussed in the volatilization flux of such materials as weed oils from alfalfa, dacthal from onion fields, diazinon from deciduous peach trees, several pesticides from rice fields, and several pesticides from soil. There is now a fairly good understanding of the rate of volatilization, and the extrinsic factors such as surface moisture, wind speed, and temperature which affect it. There is also a growing understanding of the relative importance of simple drift vs. post application processes as contributors to airborne pesticide residue loads.

The fate and significance of these residues is not as well understood. Airborne residues may deposit by both wet and dry deposition, or they may degrade while in the air by principally oxidative processes. We have studied the wet deposition of pesticides via rain and fogwater settling; fogwater concentrates many chemicals, including the organophosphates used as dormant sprays in the San Joaquin Valley, and can result in transfer of these residues to non-target vegetable corps. Parsley plants are excellent sentinel plants to assess non-target crop exposures to airborne pesticides. We recently completed a survey of a 25 square mile segment of the San Joaquin Valley using air sampling combined with parsley plant deposition to detect dormant spray OPs in the air.

The long-range aerial transport of pesticides from the San Joaquin Valley to the Sierra's is also under study. Trace levels of several OPs have been detected in air and rain sampled at the 6,000 foot elevation in the vicinity of Sequoia National Park.

As state regulatory interest focusses increasingly on San Joaquin Valley air quality, the subject of airborne residues will require still more research and, eventually, potentially cost mitigation measures.

BREEDING PLANTS FOR RESISTANCE TO OZONE

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The value of crops grown in California is greater than $15 billion. More than 50% of this value comes from agriculture in the San Joaquin Valley. Air Pollution is already a significant problem in the San Joaquin Valley and with the projected increase in population the problem is probably going to get worse.

The current levels of air pollution in the San Joaquin Valley cause yield losses, more in some crops than in others. In the two most valuable crops, cotton and grapes, the yield loss is 20-30%. In tomato, however, the yield loss is approximately 5%.

One approach to combat this problem would be to breed for crops which do not have a reduction in yield in response to air pollutants. There is ample evidence that this approach is feasible as it has been repeatedly observed that different varieties of a given crop have different susceptibilities to air pollution. The plants in which this phenomenon has been observed include onion, azalea, soybean, alfalfa, and sweet corn.

Results with sweet corn were particularly impressive. In the 1970s the variety Monarch Advance was shown to be very susceptible, while the variety Bonanza was very resistant. Susceptibility was manifested as leaf lesions and an incomplete filling of the ears.

Since the 1970s there has been major progress in the field of molecular biology. It is now possible to analyze the differences between resistant and susceptible varieties at the level of DNA. The method depends first of all on clearly establishing the extremes of phenotype. In collaboration with Rogers Brothers Seed Company, we tested 20 varieties of sweet corn in the field in Riverside in 1990. Two susceptible and two resistant varieties and two susceptible varieties were identified.

The DNA is isolated from the leaves of the test plants and is cleaved into small fragments by enzymes known as restriction endonucleases. More than 100 of these endonucleases are available, each one cleaving the DNA at a site specified by a definite nucleotide sequence. Thus, different sets of fragments are produced from a single DNA by using different endonucleases. The fragments are separated by electrophoresis and then specific DNA sequences, which will hydrogen bond to only a limited number of the DNA fragments on the electrophoretogram. To compare resistant and susceptible varieties of plants a comparison is made of the detection of DNA patterns. Many different samples must be run to be assured that the banding pattern difference is truly associated with ozone resistance/susceptibility.

The immediate goal of this method is to identify DNA fingerprints characteristic of resistant plants. The fingerprint can then be used by seed breeding companies to breed for ozone resistance systematically. In the long run the technology may lead us to ozone resistance genes.

We felt that sweet corn was a good crop to test the feasibility of this approach because of the large amount of genetic and molecular biological information. However, there is no reason that the technology cannot be applied to other crop plants and to species in the National Forests.

EFFECT OF OXIDANT AIR POLLUTION ON CROPS IN THE SAN JOAQUIN VALLEY: Sensitivity of Pima and Acala Cottons to Ozone

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Increasing population within and upwind of the San Joaquin Valley (SJV) is leading directly and indirectly to increasing levels of ozone in the SJV. Current levels of ozone reduce the yield and profitability of many important SJV crops, as shown in controlled experiments using open top exposure chambers (McCool et al., 1986; Olszyk and Thompson, 1989). Yields of Acala cotton (Gossypium hirsutum) are typically reduced by some 10-20% (eg. Temple, 1988). Acala cottons have been traditionally grown in the SJV. In recent years acreage devoted to experimental and now commercial production of Pima cottons (Gossypium barbadense) has increased rapidly. Sensitivity of Pima to ozone has not been investigated.

Modern Acala genotypes selected under SJV conditions exhibit some ozone resistance, relative both to available Pima genotypes and to other G. hirsutum genotypes from elsewhere in the Cotton Belt. This is likely due to selection for yield under SJV conditions, where ozone pressure is moderate but continuous. The Pima genotypes currently being cultivated in the SJV, for example, have been selected under Arizona conditions where ozone pressure is light. Anecdotal evidence indicates that these materials in the SJV exhibit more severe early cutout and foliar symptoms of ozone injury than Acala materials grown in the same environment.

We have undertaken a comparison of yield responses to ozone under controlled conditions, of commercial cultivars of Pima and Acala cottons, using an array of large fumigation chambers under field conditions.

Seed of Pima S-6 and of Acala SJ-2 were planted in soil within teflon-walled, closed-top field fumigation chambers (Musselman et al., 1986) located in Riverside, California. Native soil was removed to a depth of 1.5 m and replaced with uniform potting mix (sand:peat:redwood shavings, 2:1:1) to overcome possible field non-homogeneity. Fertilizer was applied preplant at 25 lbs N per acre (82 g of 16-20-0 per chamber). Seed were planted in early May due to cold weather in April, at a spacing of 0.076 m (3 in) within rows and 0.75 m (30 in) between rows. This allowed 3 north-south oriented rows per chamber. Adequate irrigation was applied weekly through surface drip emitters located within the rows. Kelthane (35WP) was applied twice and Orthene three times during the season to control mites and aphids, respectively.

The field fumigation facility delivered carbon filtered air and unfiltered (ambient) air to each chamber 24 hr per day. The ratio of filtered to unfiltered air was set to a constant value for each chamber. Target ratios were 0%, 40%, 60%, 80% and 100% ambient air for Pima; and 0%, 50%, 75%, and 100% for Acala. Fewer concentrations were applied to Acala since previous yield response curves had been obtained (eg. Temple, 1988). The resulting ozone concentrations thus depended on the severity of the ozone levels in ambient air and on small discrepancies between target and attained mixing ratios.

Ozone monitoring in each chamber began with the appearance of the first true leaves (May 24, 1991) and continued until the final harvest (October 25, 1991). Each target mixing ratio was replicated twice for each genotype, though the resulting ozone concentrations differed slightly and were documented. The seasonal ozone exposure was expressed as the "12 hour seasonal mean", calculated as the mean of hourly means from 09:00-20:00 over the entire season (McCool et al., 1986). Regression techniques were used to relate the yield in each chamber to the actual 12 hour mean ozone level achieved in that chamber.

Irrigation was terminated on 10 October. The central 12 plants of each row were harvested by hand on October 15, 1991 and again on October 25, 1991. Combined total yield parameters are reported here. Total number of bolls was determined. The combined lint from both harvests of all plants in each chamber was ginned together and seed and lint weight determined.

Visual symptoms. Premature senescence was much more extensive in leaves of Pima than of Acala (not shown). In the charcoal filtered (0% ambient) chambers both Acala and Pima leaves were deep green and without appreciable necrotic areas until near the end of the season. Acala plants exhibited considerably more necrotic and desiccated leaf area in the 100% than in the 0% chambers. However, all but the youngest Pima leaves in the 100% chambers were senescent throughout, and the older leaves were generally desiccated by mid-season.

Boll retention. In the 0% chambers the Pima plants retained slightly more bolls than did the Acala plants. However the sensitivity to ozone was considerably greater in Pima (Fig. 1A). Boll number in Acala declined consistently but not significantly with ozone exposure, about 28% between .010 and .055 ppm ozone. In contrast, Pima boll retention was highly significantly reduced, by about 84% between .010 and .055 ppm.

Lint weight. Lint weight was less for Pima than for Acala, as expected, even in the 0% chambers. The response to ozone was consistent but again insignificant for Acala due to experimental variability, about 34% between .010 and .055 ppm (Fig. 1B). In contrast, Pima yields were highly significantly reduced, by fully 100% (ie. no yield) over this range.

Seed weight. As above, the results indicated a consistent but not significant response of Acala to ozone (Fig. 1C). Seed weight was reduced nearly 48% between .010 and .055 ppm ozone. For Pima the reduction was highly significant, about 93% over this range of ozone exposures.

These results indicate that Pima (cv. S-6) is considerably more sensitive to ozone than Acala (cv. SJ-2). The controlled conditions of this experiment allow the relative sensitivities of Pima and Acala cottons to be compared directly for the first time.

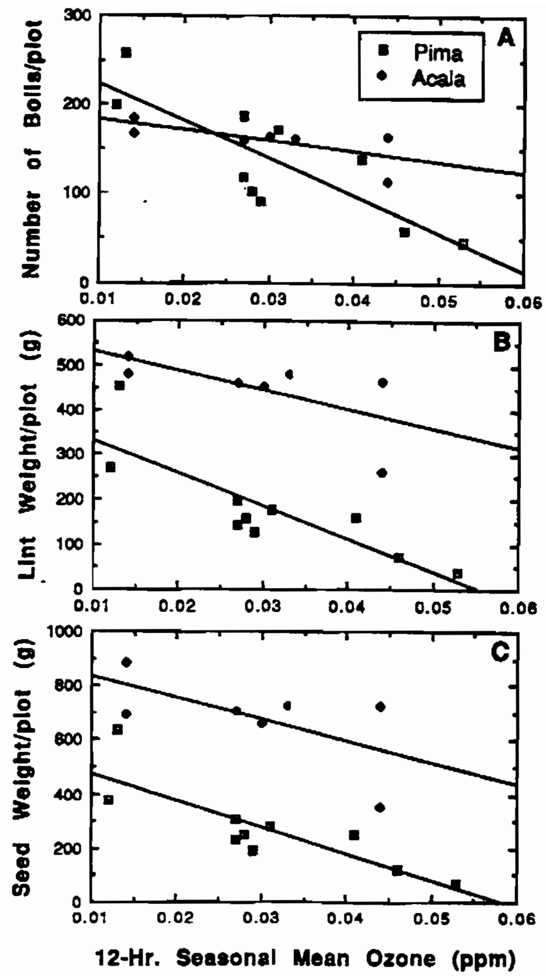

Figure 1. Effect of ozone exposure under controlled conditions on (A) Number of cotton bolls; (B) Yield of cotton lint; and (C) Yield of cotton seed; in Acala SJ-2 (solid circles) and in Pima S-6 (open squares).

The range of ozone exposures imposed in this study represent a rather non-polluted growing season in the Riverside, CA area, where the experimental plantings were established. However, the maximum exposure in this experiment was lower than the actual 1988 seasonal exposure (Mudd et al., 1991) monitored in Visalia (.070

ppm) or Madera (.070 ppm) in the SJV, and only slightly greater than the exposure in the commercial cotton production area near Five Points (.052 ppm). Future ozone levels in the SJV are likely to be even higher.

These data suggest that recent commercial successes with Pima production in the San Joaquin Valley may be partly attributable to relatively low levels of ozone in recent years. In possible future scenarios of high ozone levels in the SJV, Pima yields may be reduced more than Acala yields, with serious economic consequences.

The biochemical basis of the sensitivity of Pima and resistance of Acala lines remains to be characterized. Our preliminary data indicate that rates of photosynthesis of individual leaves are reduced to similar levels in the two following a single pulse of ozone. The difference may reside in the rate with which photosynthetic capacity recovers, which appears to be faster in Acala. If further research confirms these initial impressions, then selection for recovery mechanisms such as anti-oxidant metabolism may be the key to selection for ozone resistance among Pima cottons for the San Joaquin Valley.

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UTILIZATION OF EXOTIC CORN GERMPLASM FOR DISEASE RESISTANCE AND AGRONOMIC TRAITS IN HYBRID DEVELOPMENT

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The purpose of plant breeding is to develop varieties of plants that are better suited to the needs of man. In order to accomplish this goal, there are some basic concepts that should be kept in mind:

1. Living organisms are variable - even within quite closely related groups one finds heritable differences.

2. Organisms develop within the limits of their genetic capacity and express the corresponding traits subject to the pressures of the environment in which they live.

3. Any selection pressure in a population which affects differentially the rate of reproduction related to a trait will move the mean of that trait over generations in the direction of the selection pressure.

4. Any genetic trait that can be measured can be modified by breeding procedure (it is essential to distinguish genetic from environmental variations).

5. In a sense, plant breeding can be called directed evolution.

6. To be successful, breeding programs must have established goals - objectives.

7. The choice of materials to meet a given objective is critically important. Sometimes work is carried out for several years to reach a given point which might have been almost immediately achievable by a better choice of materials.

Stone age man domesticated all of the major food and fiber plants upon which the rapidly expanding world population now depends. As population has grown we have become increasingly dependent on fewer and fewer crop species. Emphasis on the greatest quantity return for the smallest investment of time and labor has been and still is the driving force behind work on the food crops: efficiency of production. Corn (Zea mays) is a major component of the food supply of the world. It is one that has evolved together with man and which depends for its survival on man to harvest, store and plant the seed each year; it is incapable of survival in nature. Unlike the other cereal grains, there is no wild corn now and no written records of such anywhere ever; there is only speculation and sophisticated arguments as to its origin (Galinat, 1977, Mangelsdorf, 1974, 1986). Alley Oop and Fred Flintstone did not keep very good records for us of their field work when they produced the first corn plants.

Corn obviously had its origin in the Americas. It was only after the arrival of Columbus that corn was taken to Europe, Africa and Asia..... a relatively recent event by historical standards. Nevertheless, corn has become a major crop around the world wherever land is cultivated. It has proved to be a remarkably malleable crop to press into widely varied environments, and yet even the best hybrids (varieties) for a given location do not do at all well when moved into very different environmental situations. Corn has the reputation of being very "site specific" in its adaptation. As bulk samples and different varieties have been carried around the world and planted, man has preserved those that seemed most suitable for his needs in each of the myriads of local environments with the result that there has been a mass selection procedure practiced worldwide. The recombination process plus the continuing contribution of mutation at these multiple sites has been the basis of the development of an enormous store of genetic material that has not needed to survive natural selection pressures in nature: man has preserved it in a sort of directed process of evolution. This genetic resource not only provides a huge part of the current supply of food and fiber but also constitutes the building materials from which future supplies must come. Corn depends on man for its survival; man depends on corn for a large part of his food. It behooves us to preserve this heritage.

By the time that Europeans reached the New World the natives of America had already identified and isolated both sweet corn and popcorn types. As settlers reached and populated the central portion of what is now the United States, they planted and tried out the many indigenous varieties of corn as they encountered them and began to mix them up. One of the mixture types was of northern flint varieties with the gourd seed or southern dent germplasm from further south (Anderson, Brown, 1952; Wallace, Brown, 1968). Many such mixings were made and eventually resulted in what we now call "Corn Belt Dent". From among the many local farm varieties of this type there are a couple of names that have persisted as being among the most useful in further improvement work: Reid and Lancaster. More sophisticated procedures and breeding technology evolved along with the corn, and the emphasis on the high yielding genotypes has resulted in a very narrow range of genetic material actually being planted in the U.S. Corn Belt today. One can make a strong argument of the concept that a very large portion of the present U.S. commercial crop has descended from essentially two kernels of corn: one from Reid and one from Lancaster. They were the origin of the lines (or closely related derivatives) from which many of the present single cross hybrids are made. Much of the variation that resulted from the original mixings of northern with southern corn germplasm in the United States was lost as the productive varieties replaced the lower yielding ones. Then as hybrids were introduced and adopted across the country, most of the remaining open pollinated varieties were wiped out. There is real concern now that we may be putting the crop in a very vulnerable position with such genetic uniformity exposed to a specific biological hazard in case one arises. The more subjective traits, and perhaps more complex, such as eating quality, taste, attractiveness to insects, tolerance to diseases, etc. have been largely ignored in the pursuit of agronomic production levels. As the most productive genotype is chosen for each locality, the germplasm base obviously is narrowed for that area. It is a recipe for and invitation to whatever pest or pathogen that happens to thrive on that particular genotype.

There is no question that the present corn hybrids grown in the central U.S. Corn Belt are well adapted there and produce high grain yields. Many of the long list of names of hybrids are either identical or very similar but sold under different names. What happens when these high yielding hybrids are planted in the humid tropics? They are wiped out by insects and diseases and produce nothing; they are totally unsuitable. Somewhat similarly, the best lowland tropical varieties cannot be successfully grown in the Corn Belt due to daylength sensitivity and susceptibility to a different spectrum of diseases and insects. It is not only the corn that behaves differently under different environments, but also the world of pests and pathogens that responds to different ecological situations. But we should not forget that for all its problems and limitations when corn is moved from a given environment to a drastically different one and fails, somehow there are already quite well adapted genotypes existing in both places. The fact is, also, that probably neither of these particular environments is the one in which corn originated. Man has gradually through generations of selection pushed corn into where it now is grown; there must be an element of patience in corn breeding programs to allow time to concentrate the appropriate genetic complement for the particular environment of production and/or the characteristics of the product.

In recent years there has been a somewhat renewed interest in looking at exotic corns, with exotic being defined vaguely as corn from some other country or place. There have been sporadic attempts to incorporate bits of exotic or strange germplasm into many programs over the years, but the net result has been to narrow rather to expand the genetic base of commercial corn in the United States. The initial results for most who have tried have been generally disappointing and for predictable reasons. One of the main factors, of course, is the daylength sensitivity that characterizes to a greater or lesser degree the corns that have evolved in latitudes closer to the equator. As these corns are taken to higher latitudes they remain vegetative longer in response to the longer days and thereby grow taller and later in maturity. When they are crossed to temperate region types, the resulting progeny begin segregating for daylength response as well as the other traits that are involved. Most efforts at incorporation have been to begin selfing and line development immediately in these materials with insufficient time to allow recombination to occur over generations. Nearly everybody seems to be in a hurry to get that new hybrid out and has no time to build a foundation on which to construct the hybrid. In addition to the daylength sensitivity that characterizes many of the exotic corns is the remainder of the genotype: how different or similar is it to the materials that we want to modify or improve? There are tremendous differences among the many exotic corns, and to use something simply because it is different may not be a good idea. After all, when one considers adding to presently available germplasm there should be some reason for doing so, some objective. What is the trait that needs to be added or modified? If the objective is to convert a line with yellow grain to white grain, obviously a source of white grain should be chosen. If we wish to change the cob color of a material from red to white, we should pick out a source with white cobs. Similarly, if the idea is to introduce disease or insect resistance into our material, we should make a real effort to use materials that appear to carry genes for such traits and not just grab the nearest item that is called "exotic". If our choice of materials involves something that is quite sensitive to photoperiod, we must be a little patient and allow for some generations of recombinations while selection is practiced against the sensitive segregates. Relatively few genes appear to be involved in photosensitivity in maize. Additionally, it is useful to choose materials that are as similar as possible overall to the ones being modified in terms of plant height, maturity, etc. so as to have a minimum of differences to overcome. Finally, the selection for the desired traits must be done under conditions where they can be identified. In order to select for resistance to a certain disease, for example, it is essential to have the material under selection exposed to that disease in order to distinguish the susceptible and resistant genotypes. The same concept applies to all traits under selection, and, of course, should be done in the area in which the material is to be grown. Crossing and initial growout can be done anywhere, but selection must be done under the conditions for which the material is intended. It would be nice to be able to somehow extract only that portion of a genome that is needed and insert it into another genome where it is lacking without disturbing anything else. This type of thing is being undertaken by the genetic engineers, of course, but for the foreseeable future there is no substitute for the more proven approaches of crossing and subsequent selection. A potential limitation in the use of the new high-technology transfer of traits is that single gene or simply inherited traits are those that are likely to be the first used and most manageable and when dealing with resistances to diseases or insects will almost surely fall into the classic rat race of pursuing another gene for resistance as is the case with the rust fungus situation in wheat.

Thus far this discussion has been concerned largely with the use of exotic germplasm as a source from which to reinforce agronomic traits in corn in this country. With the expanding list of industrial uses for corn there may well be other reasons for taking another look at corns from completely different backgrounds. The intense pursuit of high grain yields and the very narrow germplasm base that is in commercial use now has resulted in a very uniform yellow dent corn grain in the market. The products that industry derives from this are dependent on the recipes that are applied to the grain in processing rather than to the characteristics of the grain per se. In the search for the highest yielding genotypes, breeders have also accumulated a list of variants of different kinds that are referred to as mutants. The most common, of course, is that of color of the grain with yellow and white as the more obvious. But there are other colors as well, some of which involve one or more parts of the kernel such as the pericarp, the aleurone layer or the endosperm proper. Then there are the other more or less disfiguring mutants such as high amylose, waxy, sugary 1, sugary 2, brittles, shrunkens, horny, dull, opaques, flouries, etc. that have been collected and studied. In addition, there are those that affect the plant in appearance and/or behavior such as dwarfs, coloration of the foliage, disease and insect reaction etc. (Neuffer, Jones and Zuber, 1968).

Interest was stimulated in the nutritional implications of the known mutants (Glover, 1978) of the grain when the modified amino acid profile of the protein in opaque 2 corn (Mertz, Bates, et. al., 1965; Nelson, Mertz, Bates, 1965), was identified in the early 1960's. Little attention was paid to the starch component until more recently. Waxy corn, which was brought to the U.S. from southeast (Collins, 1909) Asia in the early 1900's, has been used in food preparations in Asia for many years. The "opposite" mutant of waxy, high amylose, (Zuber, Grogan, et. al., 1958) tends to vary somewhat in composition depending on the environment in which it is grown as well as on the background genotype into which it is introduced. Both waxy and high amylose varieties are in limited production in the U.S. for specialty purposes. Recently, patents have been obtained for nine specific combinations of endosperm mutants to produce (4,767,849; 4,770,710; 4,774,328; 4,789,738; 4,789,557; 4,790,997; 4,792,458; 4,798,735; 4,801,470) specialty starches for use in the food industry. The objective here is to replace some of the chemically modified corn starches with natural products. With the increasing demand for starches with very specific functional properties this may well be an opening of importance to the food industry and for which a search into exotic corns is justified in looking for useful variants that do not exist in our present uniform commercial crop. With all the variation that exists in maize for everything that can be described as a trait, it is hard to imagine that the starches are all the same except in those cases where a visibly very different appearance of the kernel is also involved.

We have been working with the introgression of exotic germplasm into materials for use in the U.S Corn Belt for several years and have made a number of observations from this work. Among these are the following:

1. Exotic materials can be successfully utilized to modify temperate type genotypes.

2. Choose materials that contain genes that are useful for the specific trait or traits that one wants to change.

3. Do not begin to self and try to derive lines immediately after making a cross. Allow some mixing of generations.

4. No generalized statement should be applied to all cases as to whether 1/2, 1/4, 1/8 or some other fraction of exotic material is the desired proportion to be introgressed. Let the performance of the materials make the decision.

5. Plant standability, foliage disease resistance, ear rot resistance, Fusarium resistance in both plant and grain, maturity, and other agronomic traits are fairly readily modified.

6. Combining ability should be checked with the same testers as used for the line or lines being modified, but surprises can occur when crossed with other materials; some are pleasant surprises.

7. The crossing of distantly related materials in many cases results in the appearance of mutants. Many are re-occurrences of the ones already among the more well known types such as brachytic 2, striate, fine stripe, tassel seed, lemon white, virescent, etc. One interesting mutant grain type with completely normal appearance but with higher protein content and modified amino acid profile was also recovered and is now being marketed on a trial basis by a seed company in Iowa (Seed World, December 1989).

Most of the hybrids that have been developed in the U.S. Corn Belt can be grown in California reasonably well. There is a much lower incidence of foliage disease and rot problems in the dry air environment of California than in the more humid Midwest. However, the much less vigorous inbred lines that are used in making the hybrids present quite a different picture. Many are very susceptible to Fusarium and produce almost no sound grain. The introduction of some tropical germplasm has enabled us to eliminate this problem in all the inbreds that we have attempted to modify. The procedure has been straightforward with crosses and early mixing under the heavy Fusarium conditions of California and with selection practiced both in California and in the Corn Belt. Plantings of the inbreds under development are made in both locations with no seed treatment protection. Yields trials are conducted in multiple locations of the Corn Belt.

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COTTON BREEDING METHODOLOGY:

Yield, Fiber Quality, Disease and Pest Control[1]

H.B. Cooper, Jr., David Anderson and John Pellow[2]

This paper describes the cotton breeding methodology used by Cooper to develop new cotton varieties from 1960 to present. The procedures were established at New Mexico in 1960 - 1964 and used in San Joaquin Valley of California from 1964 to present with very minor changes. The two programs had common objectives: (1) high fiber quality with excellent spinning properties, (2) high levels of Verticillium wilt tolerance and (3) high yields.

Cotton is an amphidiploid. The cotton chromosomes are not well marked. Simple genetic models will not solve the complex inheritance of traits involved in a cotton variety development. Nearly all traits i.e. yield, earliness, Verticillium wilt tolerance and fiber and seed properties, are under qualitative or multi-genic control. The breeding, selections, and evaluation procedures must provide for the accumulation of all desirable traits in a single cotton. Simultaneous selection for all traits has been found to be most efficient.

Traits that we consider important in varietal production are: seed coat tuffness, insect resistance, salt tolerance, Verticillium wilt tolerance, stalk erectness, boll shape (cup or flat), internode length, height to first fruiting branch, plant height, earliness, fruit load, hard-lock, 5-lock vs 4-lock bolls, ease of defoliation, hairiness, yarn strength, yarn evenness, micronaire, fiber maturity, fiber fineness, 2.5% span length (classer's staple of fiber), fiber length, uniformity, fiber strength, fiber elongation, lint percent, seed grade (fuzz density), seed size (index), oil content of seed, protein content and free gossypol. We consider these the more important and more easily evaluated.

The scheme used to combine all of necessary traits for an improved variety is as follows:

1) Broad base germplasm pool. The breeding lines included usually have highly desirable traits but lack the complete balance, i.e. high levels of Verticillium wilt tolerance but late maturity or high fiber elongation but very weak fiber. These lines are derived from the applied breeding program. Varieties and breeding lines are obtained from other breeders which have desirable genes. Genetically transformed lines which do not have the complete genetic balance desired for a variety will be included in the future.

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1. To be presented at the California Plant and Soil Science Conference held in Fresno, California on January 28 and 29, 1992.

2. Director of Plant Breeding, Phytogen, President of Phytogen, Associate Plant Breeder, Phytogen, respectively.

2) Applied Breeding Program. This is the phase of the program where germplasm lines are intercrossed with introduced breeding lines, varieties and advanced strains to attempt to produce new gene combinations. This work provides for the mixing of the cotton DNA which improves the germplasm pool, tests combining ability among lines and provides for new combinations of traits. The crosses are grown in Mexico each winter to produce a new round of segregating material.

Pedigreed plant to row selection is practiced from F_2 through F_5 and to a limited degree beyond the F_5. Each individual plant is evaluated for all observed traits and tested in the laboratory for ginning, seed and fiber properties. Fiber and many seed properties can be established in early generation selection. These procedures require the laboratory facilities and support to evaluate several thousand plant selections each year. It does provide for rapid elimination of material so that only the best stays in the program.

We use three stages of replicated testing where the cottons are advanced from 1 to 3 based upon performance as compared to the official check variety which is Germain's GC510. Uniform F_5 progeny rows are entered into stage 1. The rows are bulk harvested and spinning tests conducted and then selected for entry. Many of the cotton strains which do not make it through the program are moved to the germplasm pool where intercrosses are made to correct deficiencies and provide new segregating populations. We select strains following our second stage of evaluation for entry into the San Joaquin Valley Cotton Board's official testing program through which all cottons must pass before being considered for release for production in the San Joaquin Valley.

This scheme of varietal development has been used to develop germplasm bases or combinations from which several varieties have been developed from 1960 to date. The varieties developed and release dates are as follows:

1) New Acala 1517-70. The scheme was used to develop the progeny row which gave rise to this variety.

2) Acala SJ-1-1967. John Turner developed the germplasm which gave rise to this variety.

3) Acala SJ-2-1973. Cooper's scheme was employed to further evaluate Turner's germplasm which resulted in the release of Acala SJ-2. Acala SJ-2 had essentially the same fiber properties as Acala SJ-1 but had an 8.5% increase in yield. Acala SJ-2 is the top yielding variety in the San Joaquin Valley on soils nearly free or low levels of Verticillium wilt. It is still planted on thirty-five to forty-five percent of the valley acres.

3) Acala SJ-3-1974. This variety resulted from the third genetic base. It provided short term relief to Verticillium wilt yielding 9.7% over Acala SJ-2.

4) Acala SJ-4-1975 and Acala SJ-5-1977. These varieties resulted from the fourth genetic base. Acala SJ-4 was a bulked F_4 and Acala SJ-5 a bulked F_5. Acala SJ-5 was more uniform and tolerant to Verticillium wilt. The yield of Acala SJ-4 exceeded the yield of Acalas SJ-2 and SJ-3 by 21% and 6%, respectively. The yield of Acala SJ-5 exceed that of Acalas SJ-2 and SJ-4 by 17% and 3%, respectively.

5) Acala SJC-1-1982. The fifth genetic base produced this variety. It was a short lived variety due to damage in delinting. This germplasm base gave rise to the Advanced Strains which were released by the USDA in 1979 from which Campbell and Associates released GC510-1984 and GC356-1988.

6) Prema-1989, Royale-1990, and Maxxa-1990. The genetic bases giving rise to these strains were developed following this scheme. These strains were released by the California Planting Cotton Seed Distributors. Royale and Maxxa production is equal to Acala SJ-2 under non or low level Verticillium wilt while exceeding the production of all wilt tolerant varieties listed above as well as others recently released.

We feel that success of this scheme of breeding cotton has been proven over the years. We are building a germplasm base to produce cottons to compete favorably or exceed the performance of all released in the San Joaquin Valley. Anderson and others at the Phytogen laboratory at Pasadena are transforming our cottons with the Bt gene to provide resistance to our worm "friends." Concern has arisen about our "friends" becoming resistant to Bt. The ramifications of this is unknown. Anderson's group is working with another set of genes which hopefully will give a broader spectrum of resistance to insects than Bt. They are also working with genes to give us broad spectrum herbicide resistance. The herbicide would provide control of night shade, morning glory, and nutsedge all of which are very troublesome weeds in cotton. We are also initiating a program to incorporate tolerance to spider mites, and cotton aphid into our breeding endeavors. Sources of resistance have been tentatively identified by Dr. Tom Leigh, UCD Entomologist.

We feel that there are ample opportunities to continue improving cotton from economics of production and utilization of fiber and seed. Cotton breeders and biotech researchers must strive to keep their product in demand.

OILSEEDS RESEARCH AND DEVELOPMENT: A MARKET-DRIVEN PARADOX

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The California climate is virtually ideal for the production of a variety of vegetable oils, in fact the greatest number of oilseed species of any region in the world. These oils are extracted from seeds of such widely-grown agricultural crops as safflower, cotton, rice, and grapes. In addition, the farmers of this state grow many other oil-producing crop plants such as sunflower, canola, corn, peanuts, walnut, almond, and sesame. A number of these crops are grown primarily for a product other than oil and thus the oil is generally a by-product of the conversion or processing system employed to make the raw product usable by society.

Safflower

Of all of these oil-bearing crops, only safflower, which was first successfully established in the early 1950's as a commercial crop in California, has been grown especially for the oil produced in the seeds. Thus, only safflower can truly be characterized as an oilseed species. It is evident in retrospect that the research and development activities conducted on the crop since the early 1950's provide a classic example of a market-driven paradox. Fortunately, throughout these last four decades, active breeding and production research has been an integral part of the production development and marketing programs for the oil and by-products.

During the first three decades of the evolution of safflower production in this state, the mission and primary objectives of the plant breeding research were to produce higher seed yields, higher oil content seeds, lower seed hull percent, reduced seed-head shattering, hybrid varieties and resistance to diseases—especially rust and *Verticillium*. During this same period, extensive agronomic research programs were conducted to determine the most appropriate production practices which included such cultural aspects of production as seed treatment, seeding rates, row spacing, depth of seed placement, optimum planting dates, weed control using mechanical and chemical methods, insect management by cultural and chemical means, harvesting strategies, planting seed production and seed storage methods. Concurrent with the evolution of the plant breeding and field production research was an extensive multifaceted chemical laboratory and oil utilization enterprise expressly designed to identify uses for this totally new oil type. From the outset of this new crop venture, it was an accepted fact that all of these various research, production, processing and marketing activities had to have a very close working relationship. Thus, from the standpoint of the plant breeder, the objectives of the breeding program were carefully designed, coordinated and kept current with the latest agronomic strategies, processing methods and present, as well as, future market utilization of the oil and meal. For at least the first decade of this new industry, only one private organization was involved in all facets of research, production development and product development and utilization. Vertical integration was indispensible to this successful establishment of safflower. From the plant breeder's point of view this made it possible to design genetic, as well as, evaluation programs with both short and long goals. Advances in one segment of activity were communicated promptly to all of the other appropriate segments.

At the outset, total seed yield per unit of area and seed oil percent were the two main breeding programs objectives. Efficiency of testing methods was a major concern. As a result, a number of very revolutionary field and laboratory procedures were discovered and perfected. The application of the cone seeder was a field procedures that had a major impact on the accuracy and dimension of field investigations. This procedure enhanced the establishment of breeding nurseries and yield evaluation tests. An even more important development of the period was the application and perfection of nuclear magnetic resonance for the rapid, accurate and economical determination of seed oil content on small seed samples, even a single seed. This machine made it possible to screen literally thousands of different selections and facilitated in a rapid and consistent upward movement of seed oil percent. During the 1960's seed oil percent was increased from an average of 39 percent to 46 percent with some experimental lines in excess of 50 percent.

The initial market development for safflower oil resulted in acceptance and utilization in both the industrial and edible oil markets. Its unique characteristics were high proportions of polyunsaturated fatty acid, linoleic acid. In the late 1960's, a genetically inherited character was rediscovered which resulted in the production of oil high in the monounsaturated fatty acid, oleic, and low in the polyunsaturated fatty acid, linoleic. This different safflower oil was chemically very similar to olive oil but at the time of rediscovery it was thought that the markets that had been developed for safflower oil would not want a low polyunsaturated oil. In spite of this early conclusion, research was continued and expanded on this classic genetically engineered new type of oil. Export markets in Europe were identified and limited production was begun in the early 1970's. This, in fact,was one of the early successes in the whole field of designer vegetable oils in which the special market in which the oil is utilized determines the specific fatty acid combination demanded.

The primary thrust of the plant breeding research today on safflower and most other true oilseed crops, such as sunflower and canola, is toward fatty acid composition. This is a most interesting paradox, especially in light of recent human nutrition research results, which have shown a distinct advantage in the consumption of fats low in saturated fatty acids and relative high in monosaturated fatty acids. It is a coincidence that high oleic safflower oil is one of the best vegetable oils available today which fits these desired composition requirements along with oleic sunflower and canola oils. This is a clear case in which the advantage of these oils in the human diet was determined after the plant breeding research had been carried forward for reasons other than those of human health considerations. In fact, this research is being pursued today with the objective of identifying new sources of fatty acids for industrial and food applications other than cooking or salad oil uses.

Sunflower

Production of sunflower in California was initially for the whole large-seeded type marketed as roasted snack food and the smaller whole seed as bird seed. A second type, which was the small-seeded oil type, was introduced in the early 1970's for the purpose of production of hybrid planting seed. This planting seed production, as well as, the whole seed production were established in California because the climatic factors were especially favorable and predictable for the production of quality products. In 1984, a third type of specialized production was initiated which involved the production of seed for crushing of the high-oleic-type hybrids. Even though the production of this special new kind of oil was very successful, a market-driven paradox resulted in the termination of the California program. It was determined that seed of comparable quality could be obtained at a lower raw material cost in the upper Mid-west states of this country. Production of high quality hybrid seed continues today on a sound economic and quality basis.

Cotton

Another interesting market paradox certainly has had a bearing on a major oilseed crop, cotton seed. Today a large portion of the cotton seed produced is marketed as whole unprocessed seed to the dairy industry for feed. It is my understanding that at this time there are only two oil mills in the state processing cotton seed for cotton oil and meal. In recent years, the market price of cotton oil has generally been quite low,and thiis is one of the factors that has caused the situation to evolve. Even though cotton oil is an oil that has wide use in the food field, market price of the seed directly to the dairy industry has been at a premium over the prices for the oil and meal. This no doubt has had an impact on breeding objectives in the cotton research programs of this state.

Canola

Canola oil has received major recognition in the popular press and has been supported by specific brand advertising by a number of national food merchandizing organizations. Adaptive field research has been conducted during the last few years in the state and there was commercial production in the 1991 growing season. Production results were not satisfactory and it is quite likely that there is not going to be production in 1992.

Corn

In a number of other states of this country, corn is a multi-use grain for animal and poultry feed, human food and industrial products. However, for some time in California there have been two different types grown, one for animal and poultry feed and the other for human food, with no distinction relative to any specific quality trait for either type other than U. S. grade. During the last three years, comprehensive field testing has been conducted on high oil corn hybrids. One of the specific market uses would be in applications where high energy rations are the cornerstone of the feed composition, such as the broiler industry. Since shortly after the turn of the century at the University of Illinois, breeding for high and low oil in corn seed has been continuously researched as a breeding method for cross-pollinated crops. It is only in very recent time that the characteristic has been incorporated into hybrid combinations which compete with normal oil grain hybrids. It will take time to determine whether this added value will accrue sufficient additional returns to be economically viable for the legitimate production and utilization interests.

Oilseed research and development processes which have evolved in California in recent history clearly demonstrate the importance of a thorough understanding of the free market forces present at any one point in time, in order that a successful breeding/production development strategy can be formulated. In recent years, along with all the traditional forces, an additional market force has been interjected which has made it even a greater challenge to design oilseed breeding programs with reasonable expectations of success. This additional force is our federal government's agricultural crop support programs with all the ramifications. These have, for the most part, resulted in disrupting the usual production and marketing strategies of the producers,as well as, the processors and product marketers. In the main, these so-called supply management programs have resulted in a general decline in the market price of the commodities. Even in the most favorable crop production environments and with government subsidies included, prices farmers receive have been reduced to levels which are barely profitable. Although world supplies of some of the price supported grains are at quite low levels, market prices are continuing to stay low. Coupled with the reduced level of the general world economy and lower availability of funds in many nations around the world, the amount of financial resources dedicated to oilseed research in California will most surely continue to decline even though the opportunities to make major contributions through classical plant breeding and high biotechnology are more promising than we have ever experienced. Oilseed research and development in California will certainly continue to be challenged by the ever present and changing market-driven paradoxes.

AN OVERVIEW OF AGRICULTURAL BIOTECHNOLOGY AND POSITIVE PROSPECTS

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Molecular biology during the 1970's enabled scientists to isolate and manipulate, at the level of the nucleotide sequence, essentially any segment of DNA from any organism. Several plant genes had already been studied at that level. Compelling evidence indicated that all plant genes would one day prove accessible to recombinant DNA technology. In 1980, the horizon was ablaze with the enthusiasm for the application of biotechnology for agriculture. This emerging technology appeared to offer unparalleled opportunities for U.S. agriculture.

Gene manipulation, even at the level of DNA, did not, and does not, necessarily lead to the understanding of gene structure, organization, function, and expression in a crop plant. Thus, model biological systems had to be developed, so that the functions of isolated DNAs could be assayed in the whole plant. From 1980 through 1985, the expectations for short-term benefits to American agriculture from this technology were outrageous, while the experience and the applications of this technology to even the most simple plant genes were essentially nonexistent. Venture capital and corporate dollars were flowing at an unprecedented rate to provide the agricultural business sector with opportunities for a technology that was only an expectation. The Agricultural Research

Service had grave concerns that because of the enormous expectations for the application of DNA technology to production agriculture -- concerns due to the recognized complexity of the plant genome; concern for the lack of documented experience and success in this field of biology; concern that the expectations would not be met, and that corporate enthusiasm would wane --- concerns, that in fact, the opportunity for the application of biotechnology for agriculture would be missed.

Indeed, history has borne out those projections. Only a small number of agricultural venture capital corporations have survived. Corporate managers have moved their attention and their investment to other avenues of investigation. The deluge of short-term recombinant DNA products that were promised, are yet to find their way into plant agriculture.

Uncertainties of oversite from regulatory agencies, for release of recombinant molecules in the environment in 1980, appeared to be a major institutional and societal problem. We are now just beginning to have a view of the oversight future.

Therefore, in less than a decade the projected adjustment of enthusiasm has occurred. During that time great experience has been gained through a steady, productive, realistic pursuit of this technology. The providers of research, both public and private, have moved at a dazzling rate in plant agriculture. The impact of molecular genetics is being felt not through wild expectations but, by careful assessment of an ever increasing high-quality literature based on experience.

It is against this historical background that researchers in biotechnology for agriculture now operate. The scientific community is into a 20-year experiment, an experiment to understand the workings of informational molecules that provide the genetics of our plant systems. These new agricultural scientists are part of a rapidly developing technology that will answer the questions of structure and function; of regulation of development; of how to use traditional genetics, molecular genetics, molecular biology and biochemistry to impact productivity and the value-added opportunities of future production agriculture.

The future is bright. As examples, brief case studies in senescence regulation, insect and disease resistance, a male-sterility system and novel site-specific recombination technology will be discussed.

AN OVERVIEW OF BIOLOGICAL CONTROL AND PROSPECTS FOR THE FUTURE

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The term biological control is used both in plant pathology and entomology to describe the deleterious action of an organism(s) against a pest, thus causing a reduction in disease or pest damage. However, most plant pathologists prefer a broader definition to include such practices as cultural control. Crop rotations and other management practices may change the composition of the microflora to favor the development of beneficial organisms which adversely affect the growth and survival of pathogens. This is definitely a form of biological control but it involves much more than one antagonistic organism. Some plant pathologists have even a broader definition of biological control and include host resistance as one of the tactics. Resistance may be altered by genetic manipulations of the plant, cultural practices that affect its physiology, and colonization of the host by benign organisms that induces the plant to be less susceptible to pathogens. There are many variation of the aforementioned mechanisms such as inoculating plants with attenuated pathogens to block the receptor sites of targeted pathogens, or in the case of viruses, inserting satellite viruses into the plant genome; this protects against the principal virus.

USE OF ONE ORGANISM TO CONTROL ANOTHER: The biological control of plant pathogens is a highly complex field and the strategies and tactics differ greatly from those used in entomology. This is because the organisms and their ecology are so dissimilar. For example, predation and parasitism do not appear to be important in the control of plant pathogens whereas they are principal mechanisms in the control of insects and mites. With plant pathogens, the mechanisms of antibiosis and competition are key means of antagonism. Because of the complicated nature of microbial ecology and the difficulty of working with specific microorganisms, there are not many successful cases of biological control in commercial agriculture where a specific organism has been used to control a plant pathogen. The best example is the use of the avirulent bacterium strain K84 (Galltrol, Norbac) to control crown gall. Another good example is use of a weak strain of papaya mosaic to control the more virulent form of the virus. This is used in Hawaii. In the last few years, several companies have marketed bacterial antagonists such as Quantum 4000, Dagger G, and a bacterium called Pseudomonas cepacia. The latter attracted attention because the Japanese controlled Fusarium of tomato by interplanting the tomato plants with onions inoculated with the bacterium.

Prospects for the future. Many laboratories have published articles about the use of biocontrol organisms (BCs) to reduce plant diseases. There also are many reports on how inoculation of certain bacteria, termed plant growth promoting bacteria (PGPR), can enhance the growth of plants (mechanisms not understood). Examples of disease reduction are the control of the take-all fungus of wheat, (Gauemmanomyces graminis var tritici), Pythium diseases of sugar beet, Fusarium of celery and melons, and root rots of alfalfa. Use of bacteria to enhance growth have been reported on many different plants including potatoes and radish. The problem with most of this work has been the relatively high level of inconsistency. Many of the inconsistencies have resulted from inadequate knowledge of how to culture the BCs, how to maintain viability during storage, and the need to develop effective methods to deliver the inoculum of BCs to target sites such as seeds and root systems.

In general, widespread use of biological control agents in plant pathology must await a better understanding of their ecology. It is not enough to merely inoculate plant parts with a BC, in many cases it will be necessary to provide a substrate that selectively enhances their growth and longevity. All organisms compete for nutrients and BCs need assistance.

Some diseases, such as seed and seedling diseases, are much more amenable to biological control than those that are caused by pathogens that infect throughout the growing season. This is because inoculum of BCs can easily be applied to seeds and seedlings and the duration of protection is necessary for only a short period of time. BCs decline in numbers after their inoculation onto plant parts. This is why protection of roots is a much more difficult. However, delivery of inoculum through drip lines offers an excellent means of depositing organisms on root systems during the growing season. This technology needs further development.

Another promising means of controlling root pathogens is to inoculate plants with organisms that induce host resistance. There are many examples of this in the literature but the field has not been developed enough to allow use of such organisms in commercial agriculture. The concept of induced resistance is that certain organisms infect or colonize the surfaces of roots without causing any or appreciable damage; this results in an alteration of the physiology of the plant, thus inducing it to become less susceptible to certain major diseases.

INDIRECT METHODS OF BIOLOGICAL CONTROL: The use of cover crops and management practices that affect moisture and fertility are important tools in developing an ecological environment that enhances beneficial organisms and not pathogens. Use of plastic mulches can be useful in certain cases. Examples of good management practices will be discussed.

BIOLOGICAL CONTROL THROUGH GENETIC MANIPULATIONS: There is considerable hope that genetic manipulations of organisms can lead to the development of antagonists that will have superior ability to protect the plant. The use of the genetically engineered ice minus pseudomonas, *Pseudomonas syringae*, to control frost causing bacteria is based on this premise. Other examples are: inoculating plants with satellite viruses, defective interfering RNAs, and developing transgenic plants that contain the aforementioned virus components or coat proteins of pathogenic viruses. How long such plants will remain resistant is not known. New biotechnological methods add additional means to controlling plant diseases.

THE FUTURE OF PESTICIDES IN AGRICULTURE

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The daunting list of obstacles to the continued registration and use of many critical crop protection chemicals suggests that agriculture is either on the verge of a revolution or a devolution. The obstacles to minor crop pesticides are particularly imposing:

- the economics of reregistration;
- the impact of conservative risk assessment;
- the unknown extent of pesticide neurotoxicity, immunotoxicity, and reproductive and developmental toxicity;
- the acute effects on mixers, loaders, and farmworkers;
- the EPA attention on environmental effects such as avian toxicity, aquatic impact, groundwater contamination, and endangered species protection;
- the fate of pesticides in food processing wastes;
- the public perception of pesticide use and its impact on processors and retailers;
- the legislative response to public concerns.

How we respond to these obstacles will determine the future of agriculture in the U.S. The wisest response may also be the most disruptive, that is to forego using pesticides as cheap crop insurance and instead employ them judiciously in a systems approach. The goal should be to develop a pest management decision process that considers not only yield, quality, and cost but health, safety, and the environment.

The model for this approach, of course, is integrated pest management (IPM). IPM is a philosophy of pest control that integrates nonchemical controls, such as predators and parasites, disease- and insect-resistant plants, crop rotation, and insect mating confusion with the judicious use of chemicals based on pest-monitoring data.

Pesticides in this scenario will remain important to the success of IPM programs, but their role will become more specialized. Pesticides of the future will be biologically based, narrow spectrum, and unfortunately, expensive. Hopefully, they will also be sufficiently benign to provide a measure of stability to the very uncertain pest management environment in which growers now operate.

Modeling the Fate of Nitrogen in the Rootzone:
Management and Research Applications

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California has a diverse and productive agricultural industry with about 289 commodities and one-ninth of the total U. S. farm cash receipts. This has not come without some environmental cost. Elevated concentrations of nitrate and other constituents have been detected in surface- and ground-waters in agricultural areas throughout the state. Agriculture has been implicated as a major non-point source of nitrate pollution because of the large amounts of nitrogen fertilizers and irrigation water used in intensive farming systems. Assessment of management practices to decrease nitrate leaching from agricultural sources is particularly needed in intensive vegetable production systems which utilize high inputs of water and nitrogen fertilizer.

How do we minimize nitrate leaching losses from agricultural sources? Implementation of so-called 'best management practices' (BMP) has been suggested as a method to control agricultural non-point source (NPS) pollution. What are these BMPs? What criteria are used to determine whether one management practice is better than another? Section 208 of the Federal Clean Water Act of 1977 contains a legal definition of BMPs. In brief, agricultural BMPs minimize NPS pollution, while remaining economically viable for the producer. We could determine BMPs from research field experiments by comparing different irrigation and nitrogen fertilizer management practices and assessing their nitrate leaching potentials and economic returns. But a BMP for one set of crop, soil, and climatic conditions may not be a BMP for another set of crop, soil, and climatic conditions. Though field studies like these could supply the needed information for BMP assessment, there are hundreds of crops in California, grown on different soil types under different climatic conditions and agronomic practices. Such an effort would be time-consuming and costly.

Another approach to assessment of management practices would be to model agronomic systems as a function of crops, soils, climate, irrigation, fertilization, and drainage. Ideally, such simulation models should be field-calibrated and validated. This is the approach we have selected to assess agricultural management practices. Figure 1 is a system flowchart depicting the required scope of such a comprehensive agronomic model. A number of soil nitrogen models have been developed (Tanji, 1982), ranging from input-intensive research models to simpler management models. Other large scale models, similar in scope to that depicted in Fig. 1, have been used for both research and management purposes (Huston and Wagenet, 1989). Primary criteria for model selection are to meet the level of sophistication required to assess BMPs, while reducing the scope of required input data to readily attainable information. General characteristics of some well-known models are depicted in Figure 2. We chose EPIC (Sharpley and Williams, 1990), an applied research model, because it fit most closely the above criteria for model selection. Table 1 describes the components of the EPIC model.

The objective of this study is to demonstrate how physical-chemical-biological modeling approaches can assess environmental and economic consequences of nitrogen fertilizer and irrigation water management. We chose lettuce as the crop for a case study of intensive vegetable production because it is the vegetable crop with the largest cash value and acreage in California. The approach we took was to calibrate the model on an existing database for spring and summer lettuce grown in the Salinas Valley, then apply the model to hypothetical simulations of different rates of applied irrigation water and nitrogen fertilizer.

MATERIALS AND METHODS

Model Calibration

Field data from an 11 hectare lettuce field on a Mocho silt loam were used for model calibration (L. E. Jackson, unpublished data). Spring and summer iceberg lettuce crops were planted May 2 and July 30, respectively, and were harvested on July 16 and October 10, respectively. Residual NO_3-N in the soil profile was 200 kg/ha following a summer 1989 celery crop. Nitrogen fertilizer was incorporated at a 50 mm depth on June 5 and August 28 at 82 kg N/ha, and was applied with irrigation water on October 5 at 22 kg/ha. Spring and summer lettuce crops received 205 and 285 mm of irrigation water, respectively. The crops were virtually free of 'corky root' disease, a prevalent problem in the Salinas Valley, so uptake of nitrogen and water were near optimal.

Daily weather data was input into EPIC from the CIMIS (California Irrigation Management Information System) database, averaging 1990 values for the Watsonville and Salinas stations. Where field values were not available, USDA-Soil Conservation Service SOILS 5 database information was used. EPIC crop growth parameters for lettuce were synthesized from the literature and data from studies in the Salinas Valley. Lettuce biomass and total soil inorganic N were the primary variables used for calibration.

Conditions of Case Study Simulation

The case study was based on the field data used for model calibration with some modifications. Irrigation and fertilization rates were based on data in "Sample Cost to Produce Lettuce in Monterey County - 1986" by J. W. Huffman, Kurt Schulbach, and E. A. Yeary. The maximum rate of N fertilization was 168 kg/ha per crop, close to the rate of 178 kg N/ha reported by Lorenz and Maynard(1988) for a head lettuce crop. The maximum rate of irrigation water was 300 mm per crop. We assumed use of 2 acre-feet/acre of water per lettuce crop at 50% application efficiency or 1 surface foot of effective applied irrigation water. Average measured irrigation efficiencies were 58% in another study ("Season Long Crop Water Use and Irrigation Efficiency Evaluation" 1988, by Kurt Schulbach).

Data for initial soil conditions are given in Table 2. Residual nitrate was assumed to be 60 kg/ha NO_3-N in the soil profile. Nitrogen fertilizer was incorporated at a 50 mm depth on June 5 and August 28 at 168 and 128 kg/ha, and was applied with irrigation water on October 5 at 40 kg/ha. Each crop was furrow irrigated in equal amounts six times during the growing season at 10-14 day intervals. Rates of irrigation and fertilization were decreased from 100% to 0% of maximum at 10% increments for model simulations. Economic modeling involved calculating profit as the difference of revenue from lettuce yield and marginal costs of applied water and fertilizer.

RESULTS AND DISCUSSION

Physical-Chemical-Biological Modeling

Results of model calibration are given in Table 3 and Figure 3. Modeled estimates of total lettuce biomass at harvest (Table 3) and total nitrate in the soil profile (Fig. 3) compared favorably with measured values, though modeled estimates of total nitrate were slightly out of phase with measured values.

Model outputs for the 1990 case study data at 100% rates of irrigation water and N fertilizer are given in Figure 4 a-d, depicting (a) seasonal nitrate sources and sinks, (b) soil N mineralization, (c) water sources and sinks, and (d) crop biomass. Event-dependent interactions between these systems can be inferred from these data: nitrate leaching was primarily associated with deep percolation from irrigations during the growing season: nitrogen mineralization from labile organic matter increased substantially after incorporation of lettuce crop residue.

Break point analyses such as those depicted in Figures 5 an 6 can be used to estimate incremental effects of fertilizer and water inputs on nitrate leaching. Leaching of nitrate was most effectively reduced up to 50% of the 'normal' quantity of applied irrigation water (Fig 5), and at 65% of applied fertilizer nitrogen (Fig. 6). Below these break points, the rate of reduction in nitrate leaching per reduction in irrigation or fertilization rate was much less, becoming zero at 10-15% of the maximum rate. Reducing the quantity of irrigation water is much more effective at lessening nitrate leaching than reducing applied N fertilizer. What effect will reductions in irrigation water or N fertilizer have on crop yield and profit, though?

Both fertilizer nitrogen and irrigation water could be reduced up to 50% of 'normal' with no reduction in yield (Fig. 7). The effect of applied water and fertilizer on nitrate leaching is illustrated in Figure 8. It is clear from this figure that irrigation is a primary variable to manage if nitrate leaching is to be minimized. Since applied irrigation water and N fertilization interact, however, it is important to manage both of these variables together. If one reduces N fertilization without reducing irrigation water, the crop uptake efficiency is reduced because nitrate is swept past the roots in the irrigation waters. If one reduces irrigation water applied, more nitrate is available in the rootzone for uptake.

Economic Modeling

The economic component of the modeling is to provide profit information based on cost and revenue of different management practices that reduce nitrate leaching below the root zone.

Figure 9 relates relative profit to percent of water and nitrogen applied. As seen by the peak in the graph, relative profit is maximized at 50% water and nitrogen application. An interesting characteristic of this 3-dimensional graph is its shape in different regions. For application levels less than 50% water and nitrogen, relative profits decline at an increasing rate. For application levels greater than 50% water and nitrogen, relative profits decline at a decreasing rate. This observation indicates that management practices of over-applying fertilizer and water entail less risk than under-applying these inputs. That high cash crops such as lettuce are over-irrigated and over-fertilized is not surprising since this lessens the risk of obtaining sub-optimal crop yield and quality.

Figure 10 give examples of relative profit to percent of nitrate leached for 3 different management practices. The three practices modeled include: independent reduction in applied water and nitrogen and fixing the applied water at 75% of maximum and varying nitrogen application. The figure displays which of the 3 management practices obtains the highest relative profit for different levels of nitrate leached. The highest relative profit is obtained from the practice of 75% water and varying nitrogen application. The practice of nitrogen fertilizer reduction with 100% water application is shown to be not a cost effective management practice since other practices involving reduction in water application obtain a higher level of relative profit.

CONCLUSIONS, MODEL LIMITATIONS AND FUTURE WORK

The model assessment of case study data for head lettuce grown in the Salinas Valley suggested profit is maximized by cutting water and fertilizer addition up to 50%. Optimal rates would be 150 mm of applied irrigation water and 84 kg N/ha fertilizer per crop. Implementation of these management practices would reduce nitrate leaching by about 75%.

For confirmation, the data for model calibration was from a grower who uses about half the water and fertilizers of these 'normal' rates as a usual management practice. Lettuce yields were at or above the county average, while marginal costs for fertilizer and water were less, thereby increasing profits. However, our modeling effort is in the developmental stages, and calibration of the model was conducted using data from a lettuce crop grown under near-optimal, disease-free conditions. Further work will be necessary to verify the model results from the case study. Some features that may need further evaluation are: reduced efficiency of water and N uptake because of corky root disease, crop quality considerations, the low salinity tolerance of head lettuce.

Future work will address the issue of non-uniformity of irrigation water application. This is a key constraint as growers shoot for uniform crop growth, they often water and fertilize the entire field at above-optimal rates to compensate for those areas that have lower water or nitrogen availability because of soil spatial variability or irrigation system distribution uniformity.

ACKNOWLEDGEMENT

This research was supported by the State Water Resources Control Board through Interagency Agreement No. 0-141-250-0.

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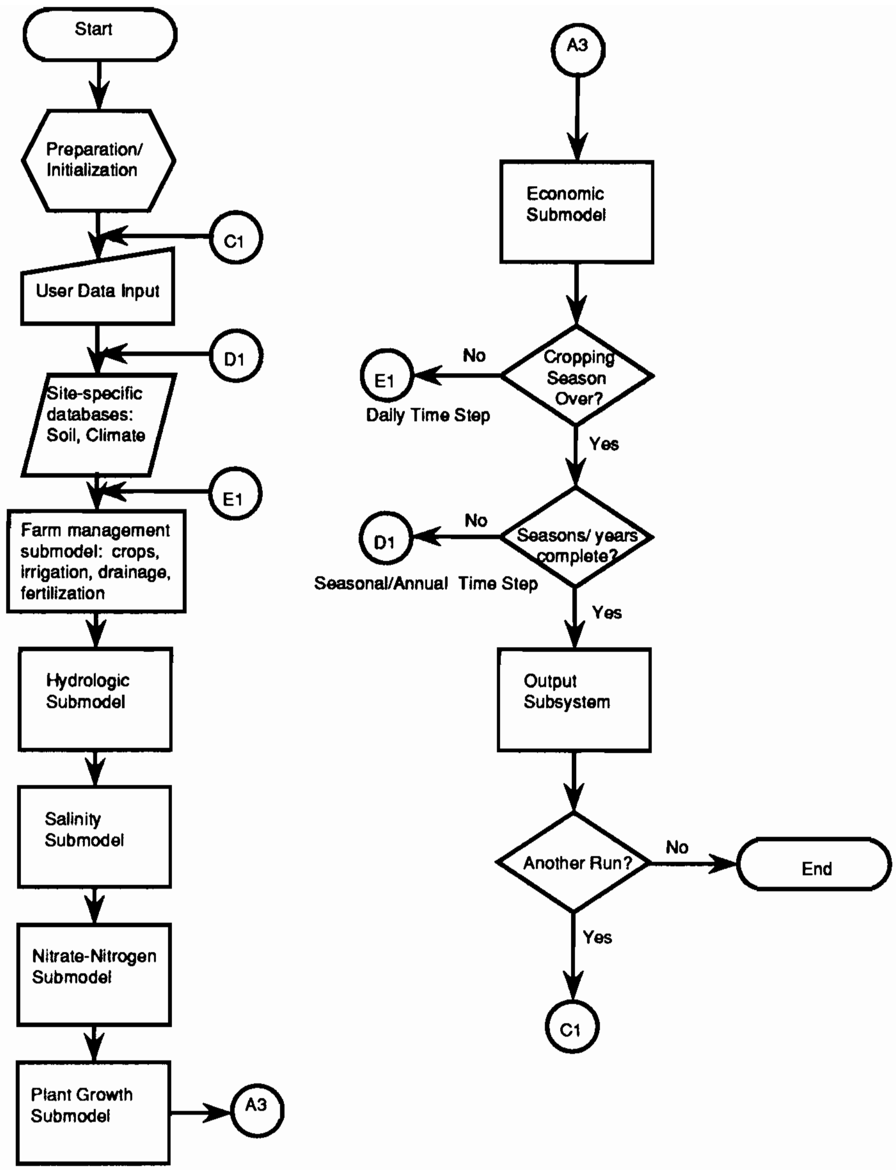

Figure 1: System flowchart of an agronomic nitrogen management model.

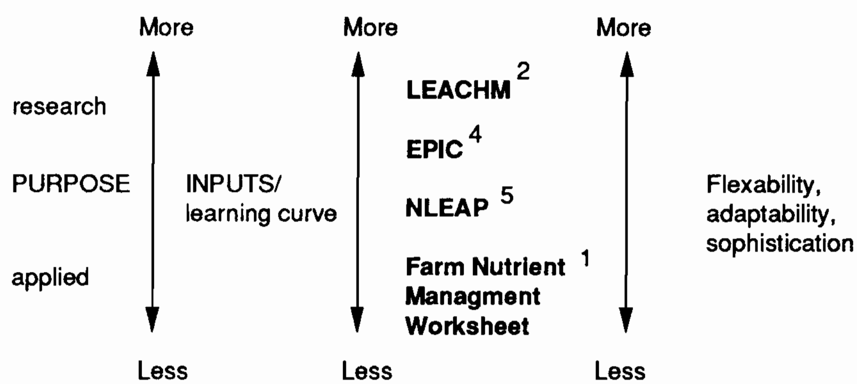

Figure 2: Comparison of Agronomic Nitrogen Models.

Table 1: List of EPIC Model Components.

NUTRIENTS	HYDROLOGY	CROP GROWTH MODEL
Nitrogen	Surface Runoff	Potential Growth
nitrate loss in surface runoff	runoff volume	Water Use
NO3-N leaching	peak runoff rate	Nutrient Uptake
NO3-N transport by soil evaporation	Percolation	nitrogen supply and demand
organic N transport by sediment	Lateral Subsurface Flow	biological nitrogen fixation
denitrification	Evapotranspiration	phosphorus
mineralization	potential ET	Growth Constraints
immobilization	soil and plant evaporation	biomass
Phosphorus	Snowmelt	water stress
soluble P loss in surface runoff	Water Table Dynamics	temperature stress
P transport by sediment		nutrient stress
mineralization	WEATHER	aeration stress
immobilization	Precipitation	root growth
mineral P cycling	Air Temperature	water use
	Solar Radiation	winter dormancy
SOIL TEMPERATURE	Wind	
	Relative Humidity	PLANT ENVIRONMENT CONTROL
TILLAGE		Drainage
	EROSION	Irrigation
ECONOMICS	Water	Fertilization
	rainfall runoff	Liming
	irrigation	Pesticides
	Wind	Furrow Diking

Table 2: EPIC Soil data for Mocho silt loam.

	Soil Layer Depth (m)			
	0-0.15	0.15-0.45	0.45-0.75	0.75-1.05
Porosity (m/m)	0.472	0.396	0.434	0.472
Field Capacity SW (m/m)	0.252	0.227	0.179	0.228
Wilting Point SW (m/m)	0.118	0.093	0.074	0.109
Soil Water (m/m)	0.152	0.126	0.100	0.139
Sat'd. Conductivity (mm/h)	8.75	1.50	11.34	10.86
Bulk Density (Ton/m^3)	1.40	1.60	1.50	1.40
Sand (%)	14.8	17.8	22.8	20.3
Silt (%)	63.0	63.5	64.5	64.8
Clay (%)	22.2	18.7	12.7	14.9
pH	7.3	7.5	7.4	7.3
CEC (cmol/kg)	24.9	22.8	20.3	23.1
Nitrate (g/Ton)	8.0	1.0	4.0	6.0
Active Org. N (g/Ton)	152.0	86.0	26.0	26.0
Stable Org. N (g/Ton)	814.0	457.0	380.0	394.0
Organic C (%)	0.88	0.62	0.37	0.43
Crop Residue (Ton/ha)	12.0	8.0	0.00	0.00

Table 3: Model calibration: comparison of measured total lettuce biomass at harvest with model estimates.

	Spring crop	Summer crop
	g dw m^{-2}	
Measured	3.60 ± 0.57	2.96 ± 0.26
Modeled	3.61	2.92

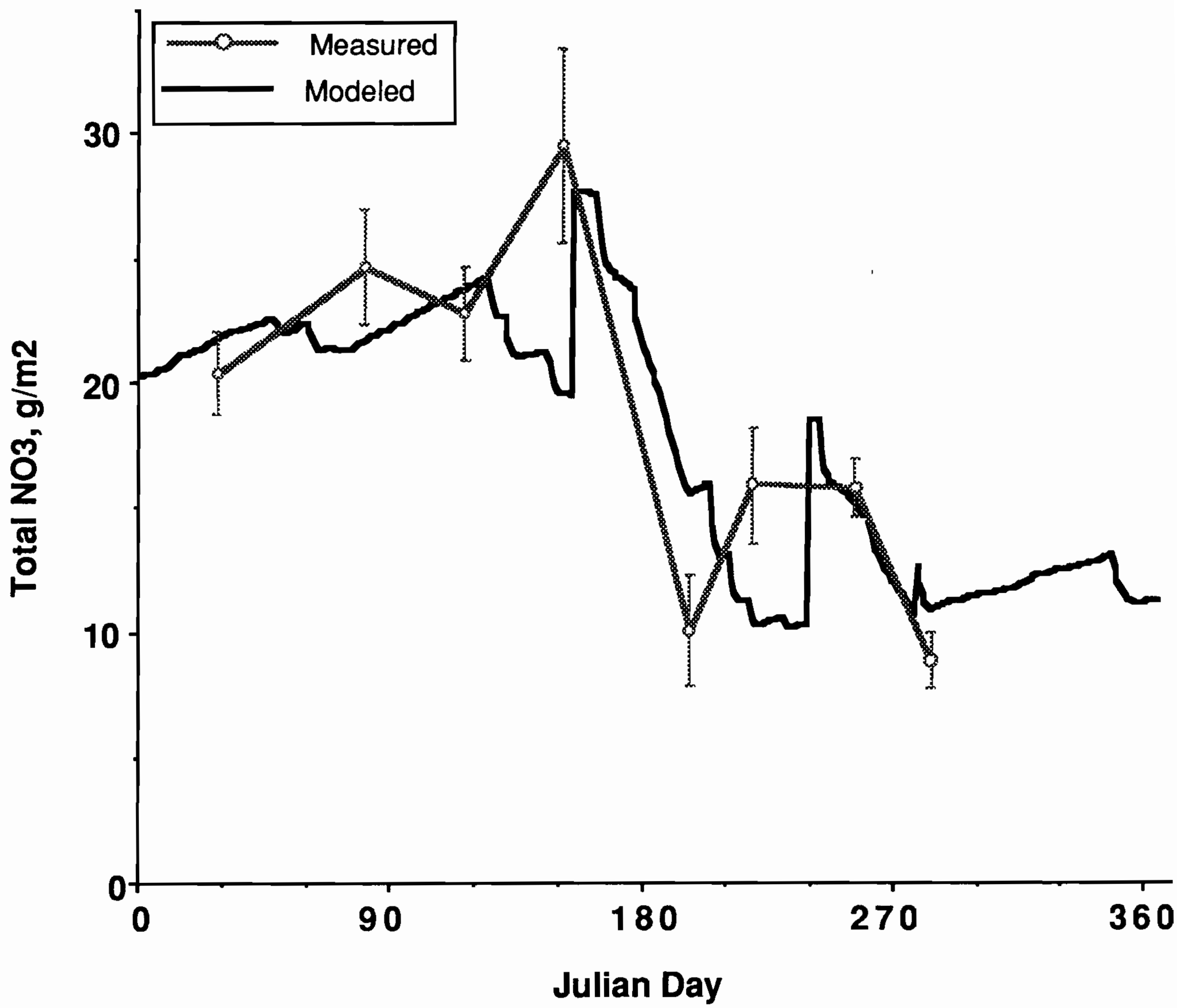

Figure 3: Model Calibration: comparison of measured total soil profile nitrate with model estimates.

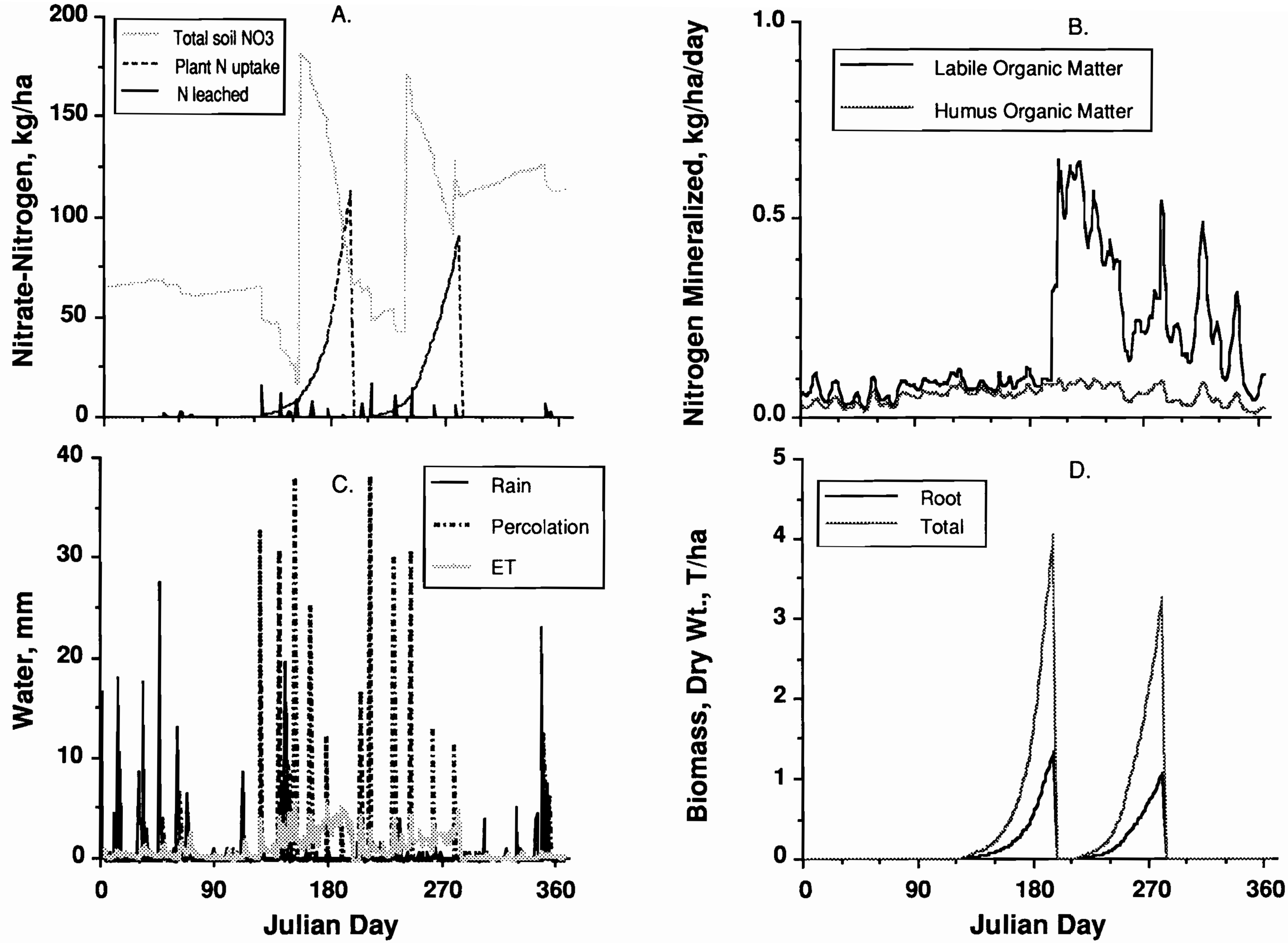

Figure 4: EPIC model output: A. nitrate sources and sinks; B. soil N mineralization; C. water sources and sinks; D. crop biomass.

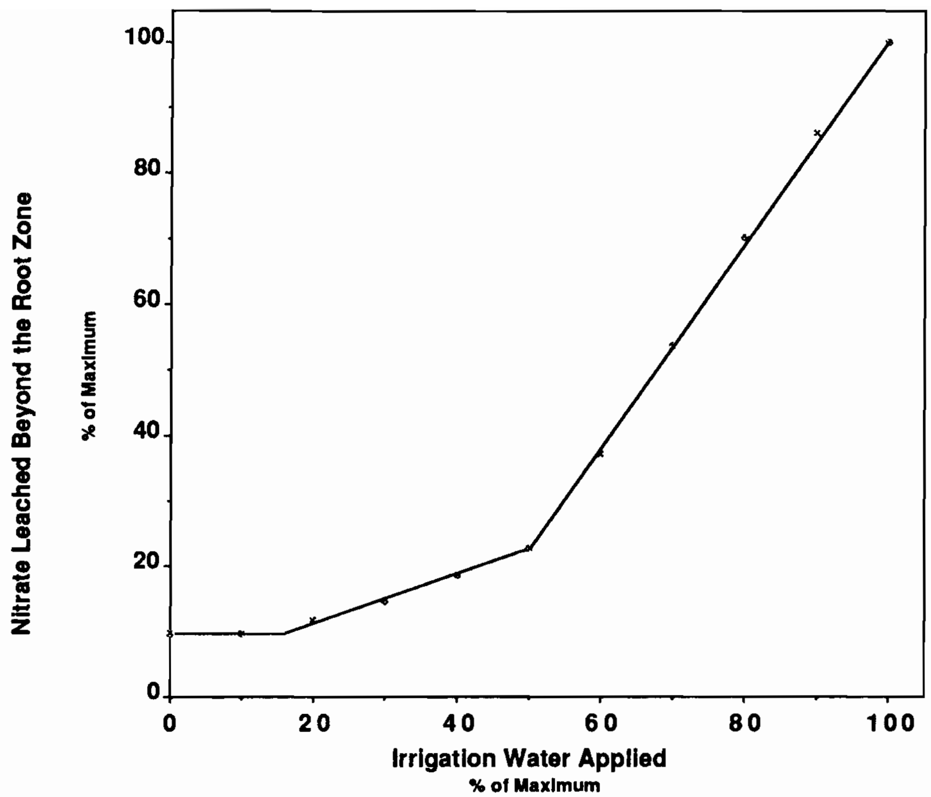

Figure 5: Effect of quantity of irrigation water applied on nitrate leaching.

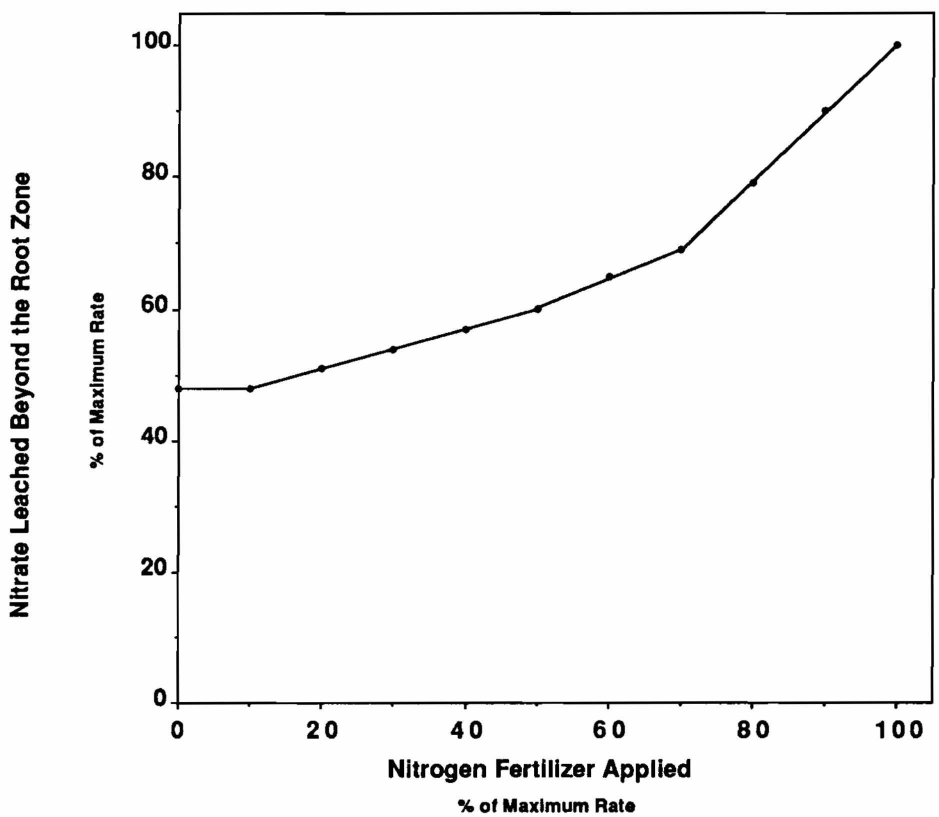

Figure 6: Effect of nitrogen fertilizer rate on nitrate leaching.

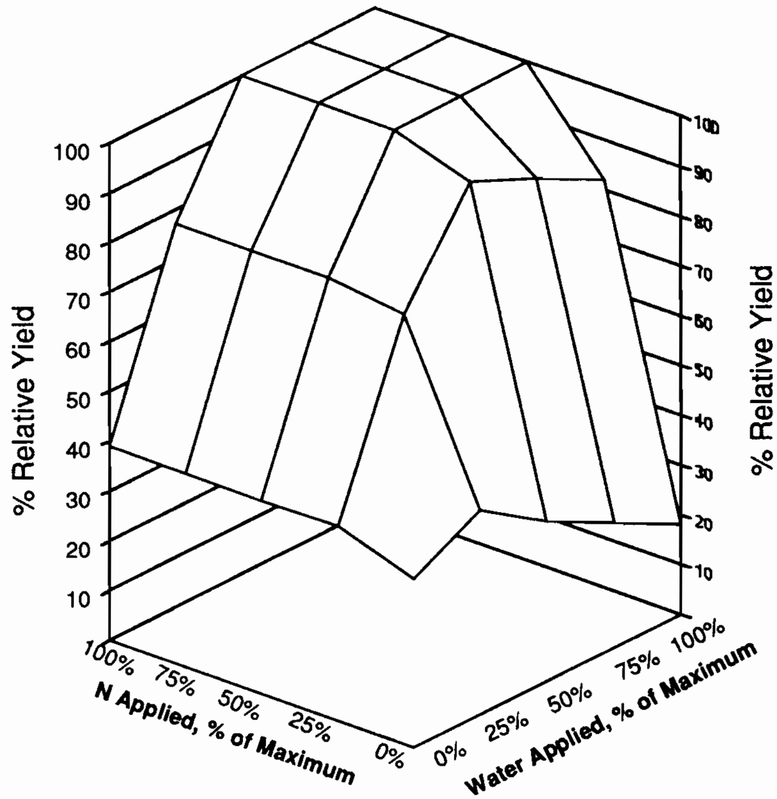

Figure 7: Interactive effects of irrigation and N fertilization on lettuce yield.

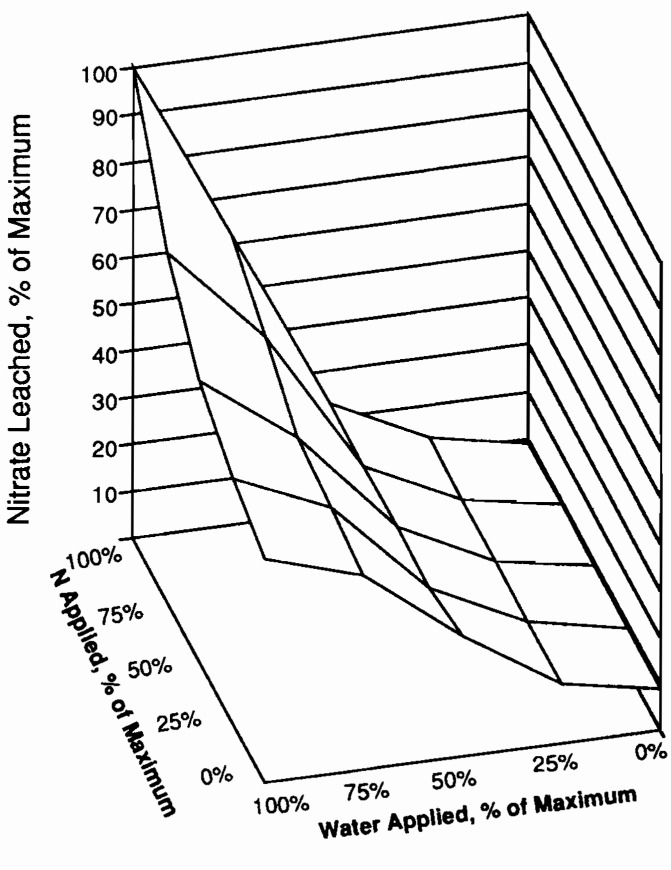

Figure 8: Interactive effects of irrigation and N fertilization on nitrate leaching beyond the root zone.

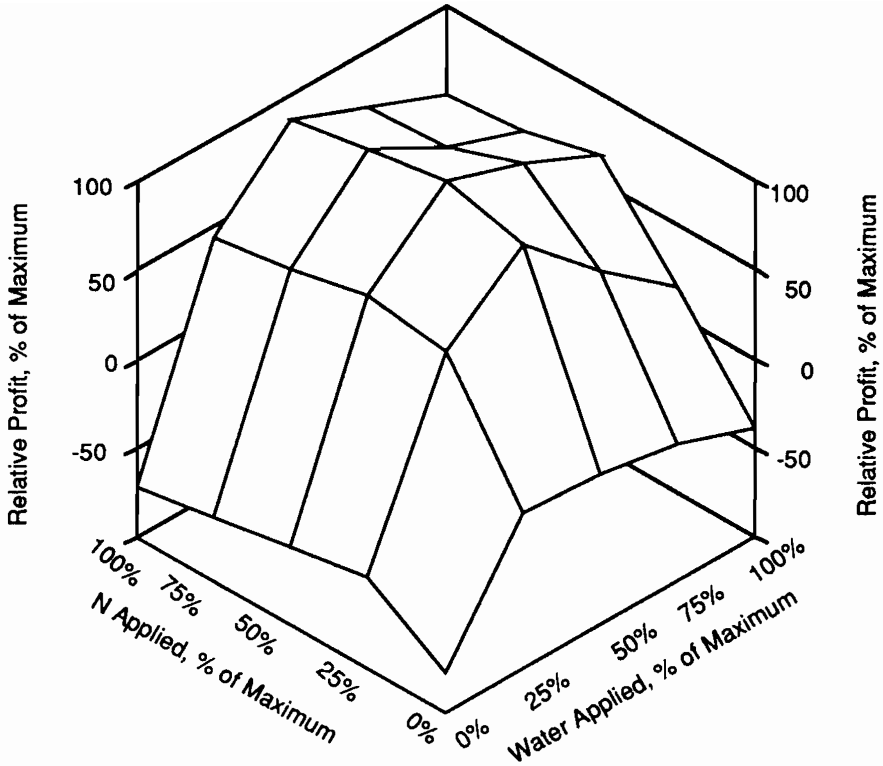

Figure 9: Interactive effects of irrigation and N fertilization on relative profit.

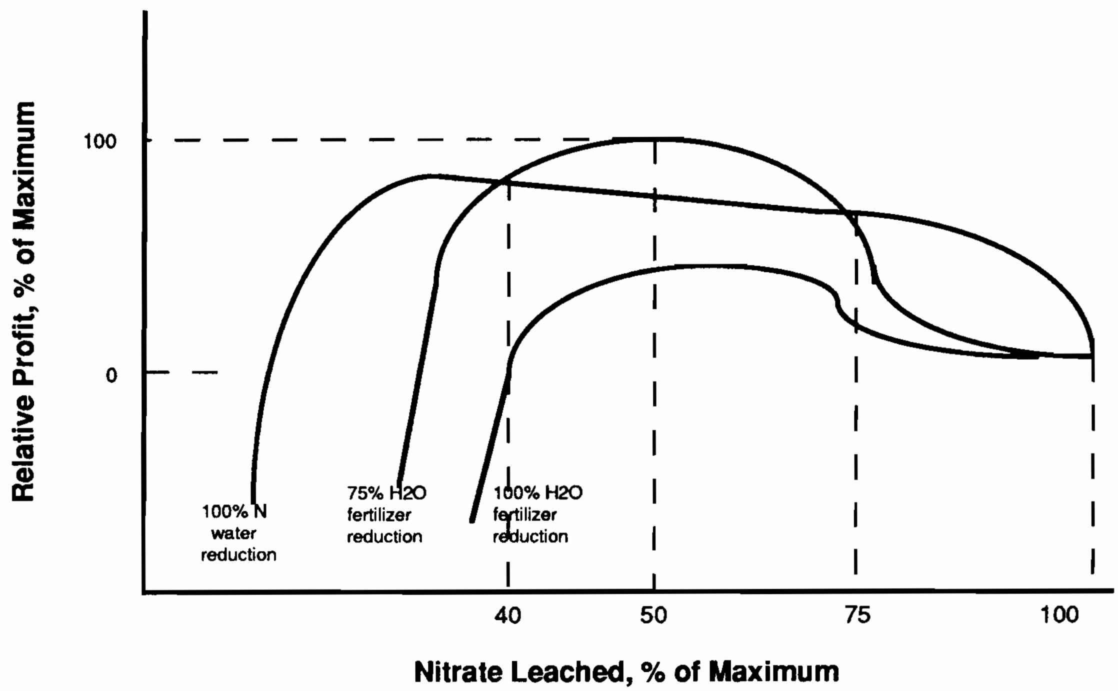

Figure 10: Salinas Valley—Head Lettuce: Economics of Irrigation and Fertilization Management.

CONTRIBUTION OF LIVESTOCK AND HUMAN WASTE TO CALIFORNIA'S N BALANCE

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Livestock in California produce manure each year equivalent to that from a human population of 73 million. In times past, nearly all livestock manure was recycled to range and cropland, fertilizing the crop and improving the soil physical condition. Today, most of California's dairy and beef feeder cattle, swine, and poultry are reared in confinement in large-scale facilities. In some locations, for example the Chino-Corona dairy area east of Los Angeles, the amount of cropland and urban landscaping within economic hauling distance is inadequate to receive the manure. Public concern about water pollution has led to restrictions on landfill disposal and excessive rates of application to land. The physical facilities are not available for discharge to the ocean. Livestock producers face the same choices for waste disposal encountered by other industries and municipalities: Incineration, or long-distance hauling (possibly preceded by composting or other processing) to reach markets for the "reprocessed waste". These options are likely to be costly to producers, exorbitantly so if the manure solids are in dilute wastewaters.

To evaluate disposal options (or more optimistically, the best use of manure) one must consider the costs and benefits. For incineration one must weigh the costs (transportation, incinerator operation and maintenance, air pollution control, ash disposal) against benefits (value of power produced by incinerator). If use as fertilizer or soil amendment is considered, one weighs various costs against the fertilizer nutrient and soil improvement value.

In this paper we examine the plant nutrient and soil amending value of manure for the entire state: How does the tonnage of nutrients contained in the state's livestock manures compare to the fertilizer nutrient requirements of its crops and landscaping? Is the amount of cropland sufficient to absorb the nutrients from livestock waste and sludge? Or asked from a different perspective, if organic farming techniques were to be adopted on a wider scale in California, to what extent would manure and sludge be able to provide the required plant nutrients? We will include in our analysis the nutrients contained in municipal wastewater and sewage sludge because some of the alternatives and issues are the same for livestock and human manure

Fertilizer Nutrients

Table 1 shows the tons of commercial fertilizer nutrients (expressed in the traditional fertilizer forms of N, P_2O_5, and K_2O) reported sold annually in California beginning in 1950. Fertilizer use increased steadily from 1950 to about 1980, reflecting the expansion of irrigated agriculture and the tremendous success of the fertilizer industry in developing low cost, concentrated fertilizer materials and the infrastructure to distribute and apply them. During that time, fertilizer nutrient prices rose at a much slower rate than did most other farming expenses. Fertilizer nutrient use peaked during the early 1980s. Federal government programs such as PIK (Payment-In-Kind) and the Conservation Reserve and prolonged drought have kept N and P use below the peak reached in the early 1980s, but potassium use has continued to increase.

TABLE 1. Fertilizer N-P-K sold in California

	Tons nutrient/year		
Year	N	P2O5	K2O
1950	116,234	52,381	14,319
1960	266,430	90,390	24,230
1980	631,065	190,871	75,415
1985	569,851	155,919	61,993
1990	555,309	172,426	91,376

Source: Fertilizing Materials Tonnage Report, California Dept. of Food & Agric.

Livestock Manure Nutrients

Table 2 shows estimated livestock manure nutrients produced annually in California. Collectable nutrients for N, P, and K amount to 20, 72, and 173% of the recorded fertilizer sales in 1990. We have not attempted to estimate what percent of manure solids are collected and stored as a liquid. This is important in considering the value of manure nutrients, as will be discussed below.

The values on adjusted populations and amount of manure generated in Table 2 are taken from data compiled by the second author. The amount of manure and nutrient contents were based on values in "Manure Production and Characteristics" (American Society of Agri-

TABLE 2. Livestock manure nutrient production in California

Animal	Ave. Adjusted Population (x1000)	Manure solids dry ton/yr (x 1000)	Nutrient Content Fresh Excreta, % dry basis			Assumed % collectable	Total collectable nutrients, tons/yr (assume 50% N loss)		
			N	P2O5	K2O		N	P2O5	K2O
Beef, nonfeedlot	3,052	3,800	4.00	2.48	2.96	5	3,800	4,712	5,624
Beef, feedlot	435	540	4.00	2.48	2.96	90	9,720	12,053	14,386
Dairy, milking	948	2,900	3.75	1.79	2.90	90	48,938	46,719	75,690
Dairy, nonmilking	967	1,800	3.75	1.79	2.90	60	20,250	19,332	31,320
Sheep	823	280	3.82	1.81	3.49	15	802	760	1,466
Lambs	274	33	3.82	1.81	3.49	15	95	90	173
Swine, all	140	38	4.73	3.75	3.16	90	809	1,283	1,081
Horses, all	750	2,000	2.00	1.08	2.00	20	4,000	4,320	8,000
Broilers	37,500	281	5.00	3.12	2.18	95	6,674	8,329	5,820
Layers	30,000	330	5.25	4.29	2.25	95	8,229	13,449	7,054
Breeders		37	5.25	4.29	2.25	95	923	1,508	791
Turkeys	9,800	330	5.17	4.39	2.40	80	6,824	11,590	6,336
Breeders	500	17	5.17	4.39	2.40	80	352	597	326
						TOTAL	111,415	124,741	158,065
				TOTAL, % 1990 fert. sales			20	72	173

cultural Engineers, ASAE D384.1, rev. 1988). Percent manure collectable is the first author's best guess of percent of animals in confinement (excluding pastures where manure collection is impractical). To simplify calculations, it is assumed that between excretion and application to land, 50% of N is lost as volatile ammonia. The actual amount will depend on method of collection, drying, and storage as well as environmental conditions. Zero loss of P and K was assumed. Where manure is exposed to leaching, K losses could be high.

Some manure -- broiler litter with a 3-2-1 analysis for example -- is sold with a guaranteed analysis and is included in the CDFA fertilizer tonnage statistics; but this represents an insignificant part of the manure nutrients.

Sewage Sludge and Municipal Wastewater

About 375,000 dry tons of sludge were produced in 1988 in California according to a survey conducted by the California Association of Sanitary Agencies. Assuming an N content of 3 percent, the entire amount of sludge would contain 11,250 tons of N, or about 2% of the commercial fertilizer N sold in 1990. Although it is difficult to estimate the amount, a larger amount of N is contained in treated wastewater than in the sludge. According to the Department of Water Resources (Bulletin 160-83, DWR, Sacramento CA), 3.40 million acre-feet of treated municipal wastewater were produced in 1980 in California. Assuming that the wastewater contains at least 10 mg/liter of N, the total N contained in the wastewater produced annually would be 45,900 tons or about four times the amount contained in the sludge.

Amount of Wastes Currently Applied to Land

Estimating the portion of manure and municipal wastewater solids already being used as a fertilizer or soil amendment is difficult, first because accurate statistics on disposition of several categories of waste are not available, and secondly because even if the portion applied to land is known, there is no information on how much nutrient value is obtained by the farmers or how much of the waste is being applied at excessive or "disposal" rates.

In a 1988 survey of dairy producers, Meadows and Butler (U.C. Davis Department of Agricultural Economics) found that statewide, 54% of the solid manure and 91% of the liquid waste was applied to the farm of origin. About 19% of the solid manure was sold off-farm, and another 18% was hauled away at a cost to the dairy farmer. Therefore about 80% of the solid manure statewide is applied to land. These figures do not reveal how much of the dairy manure is applied at disposal rates.

Swine are now reared completely on concrete and nearly all manure is collected as a slurry or liquid. To our knowledge, swine producers have not been surveyed regarding waste disposal practices.

Poultry manure because of its higher nutrient content usually can be marketed as a fertilizer more easily than other manures. Both composted and uncomposted poultry manure is used by organic farmers even when it must be hauled several hundred miles. Very high application rates for the purpose of disposal are probably rare.

What about sewage sludge and treated municipal wastewater? According to the 1988 survey mentioned above, only 25% of sludge was applied to land or distributed as a soil amendment. The remainder was disposed of in landfills, stored indefinitely at the treatment facility, or incinerated. For wastewater, according to the above-mentioned Department of Water Resources estimate, only about 25% of the 3.4 million acre-feet of treated wastewater generated in 1980 was intentionally reclaimed or reused coincidental to discharge to the fresh water system. The remaining wastewater was either discharged to the ocean or the Salton Sea (72%) or lost as unproductive evaporation (3%). During the 1980s, the amount of wastewater reclaimed for irrigation and other uses increased, and this trend should continue. But it is unclear how much of the nutrients in wastewater are substituting for fertilizer nutrients that otherwise would have been purchased. In some cases, high loading rate of wastewater may have contributed to ground water pollution due to excessive nitrogen loading and low irrigation uniformities.

Economic Value of Manure and Sludge Nutrients

Bulk prices for the least expensive forms of fertilizer are currently in the neighborhood of \$.15-\$.19/lb for N as aqua or anhydrous ammonia, \$.26/lb for N as UAN-32, \$.31/lb of P_2O_5 as triple superphosphate, and \$.13/lb of K_2O as potassium chloride. Using the UAN-32 price for N, manure contains N, P, and K worth somewhere between \$10 and \$30 per ton at 30% moisture content. Cooperative Extension leaflets in the Midwest USA value dairy manure at \$3 to \$6 per wet ton on a 60 to 80% moisture basis. In California's drier climate, a 30% or lower water content is more common.

The actual manure fertilizer value will depend on the availability of nutrients and the crop nutrient needs. P and K in manure and sludge are usually equal in value to P and K in manufactured fertilizers. N in the short run (one year) is perhaps 30 to 50% as effective as synthetic fertilizer N, but in the long run, a portion of the residual N is converted to plant-available form.

Manure nutrient ratios do not usually match crop nutrient requirements. If manure is applied as an N fertilizer to a crop that does not require a P or K application, then obviously no economic value can be assigned to those nutrients. For dairy manure rich in potassium, it may make more sense (if the goal is maximize efficient nutrient use) to apply the manure to K-deficient cotton ground. The manure N will then meet a part of the cotton's N requirement, but the P may be wasted. Alfalfa on some soils will benefit from the P in manure, but the N applied will merely substitute for biologically fixed N. In few instances will the entire potential NPK value be realized.

Non-nutrient Value of Manure, Sludge, and Compost

Some farmers use organic amendments mainly for soil physical improvement and only secondarily for the nutrient content. Well-composted manure and sludge is used to rehabilitate soils damaged by mining or construction activities. Litter or bedding materials such as rice hulls and wood shavings adds to the value of manure used for this purpose. Compost, broiler litter, strawy manure, etc. are used as topdressing in orchards and vineyards in California to improve or maintain water infiltration in medium- and coarse-textured soils that tend to seal or form crusts. Where truck crops are grown on low-organic matter, coarse-textured soils, regular additions of compost or well-rotted manure will over time increase water-holding capacity which can provide the farmer with a greater margin of error in scheduling irrigations. It is difficult to assign a monetary value to such soil physical improvement, and few long-term studies have been conducted in California to measure the rate of improvement or its economic value. Apparently the tilth of many soils in California has been maintained without manure additions.

Potential for More Use or More Nutrient-Efficient Use of Manure and Sludge

A significant portion of manure and wastewater solids is already being applied to land, although it is hard to say what nutrient value is being obtained. The total amount of N available in these organic wastes annually is perhaps 30% or less of the current sales of fertilizer N in California. In contrast P in these wastes is close to the amount of fertilizer P sold, and K far exceeds the amount sold as fertilizer. Because crop requirements and soil nutrient status varies so much, it is not possible to obtain full value from all the NPK contained in these wastes.

What other factors limit the additional use or value obtained from manure and wastewater solids?

Here are the main considerations:

1. Transportation, handling, storage, and application costs for most manures and sludges are much higher per unit nutrient than for inorganic or manufactured fertilizers;

2. Salt content of livestock manures presents a limit both for individual farm fields and on a regional scale. Several years of below normal rainfall have contributed to the appearance of excessive salinity in heavily manured fields. It takes more water or more-uniformly applied water to leach salts out of the root zone. On the regional scale, schemes to transfer livestock manure and sewage sludge from Southern California to the Southern San Joaquin Valley run contrary to the need to remove salt from a basin with no outlet, not bring more in;

3. A substantial portion of livestock manure and sewage sludge is collected as dilute wastewater. Wastewater is impractical to transport more than a short distance from its origin. Dairy producers have greatly reduced labor costs by using flush systems for cleaning facilities, but in so doing have reduced marketing or disposal options for the wastewater solids. The procedures for separating solids from dairy wastewater leave most of the nitrogen in the liquid portion.

4. Manure and sludge adds organic matter to soil, but the nutrients have serious disadvantages compared to inorganic manufactured fertilizers: Nitrogen behavior is notoriously unpredictable, encouraging overapplication; N-P-K ratios are inflexible and often too high in P and/or K; fertigation -- application of nutrients in irrigation water -- is not possible with manure; banding of nutrients-- which often improves nutrient uptake efficiency -- is usually not practical with manure or sludge. Note that about 80% of the fertilizer N used in California is as liquid materials which offer great flexibility in application and mixing with other nutrients and agricultural chemicals.

5. Public health/legal liability concerns are greater with manure, more so with municipal sludge and wastewater, than with inorganic fertilizers. Proper composting can reduce the basis for this concern, but composting can result in loss of nitrogen. Also, the market for compost is not infinite. Other materials such as municipal garbage, leaves and landscape prunings, waste paper, and food processing wastes will compete with manure and sludge for the compost market.

APPLICATIONS OF BIOTECHNOLOGY IN ENHANCING RESISTANCE TO PLANT PESTS

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Effective crop protection strategies employ an integrated approach that includes the judicious use of pesticides, biological control and resistant cultivars to control pest damage. Ecological concerns are exerting increasing pressure to develop alternative methods to decrease and/or eliminate the use of agricultural pesticides while continuing to increase productivity and product quality. Development of tolerant and resistant varieties has proven to be an effective method for pest control and constitutes and integral component of integrated pest management. However, the introduction of resistant genes into cultivated species is restricted by reproductive barriers and is consequently limited to related species as sources of resistance. The advent of agricultural biotechnology in the development of genetically engineered germplasm with enhanced pest resistance has added a new dimension to crop improvement and pest management practices.

Bioengineering of pest resistant germplasm enables the transfer of a single resistance trait between crop species without the confounding affects of linkage drag following introgression of exotic sources of resistance. Genetically engineered resistance crops are advantageous over chemical applications for the following reasons: 1) protection is provided throughout the growing season and protects regions of the plant not readily accessible by sprays, 2) weather does not influence the efficacy of protection against pests, 3) endogenous resistance acts primarily against the most sensitive stage of the pests' life cycle, and 4) only crop-damaging pests are targeted for control. The future also looks promising for the alleviation of limitations inherent to current methodologies such as 1) the identification and isolation of resistance genes, 2) efficient transformation of major crop species, 3) manipulation of traits under multigenic control, and 4) integration of foreign genes at random and multiple sites in the host plant genome.

Plants, viruses, bacteria, insects, fungi and animals all hold promise for an unlimited source of resistance genes for the bioengineering of pest resistant transgenic plants. Documented cases describing the expression of foreign genes in transgenic plants from nonplant sources illustrates the extent of untapped resources for crop improvement. The most publicized cases of genetically engineered resistance in plants are the expression of the gene encoding a viral coat protein to control virus disease and the Bt protein to control Lepidopteran insect pests. When expressed in transgenic plants, the Bt toxin of the soil bacterium, *Bacillus thuringiensis* (Bt), serves as a lethal toxin to a select group of insect species. Following ingestion, the toxin induces paralysis and death. Field trials of transgenically altered cotton conducted by Monsanto throughout the Cotton Belt in 1990 were a resounding success. The proposed release of the resistance cotton in 1995 is anticipated to decrease pesticide use against target insect pests by 60 to 80%.

Plants have devised a diversity of physical and chemical defenses as deterrents to ward off pests. Although notable progress has been made, efforts to unravel the signals involved in plant defense mechanisms are still in their infancy. The expression of many plant defense genes are confined to specific cells and tissues or are induced only in response to attack. When present at steady levels, however, defense proteins have been shown to confer a broad spectrum of resistance against both Lepidopteran and Coleopteran species. Another growing group of plant defense genes exhibiting antifungal activity have also been identified.

A family of diverse plant proteins that specifically bind oligomers of the carbohydrate *N*-acetylglucosamine (GlcNAc) and chitin, a polymer of GlcNAc residues, have been shown to deleteriously affect the growth and development of chitin-containing insects and fungi (reviewed in Chrispeels and Raikhel, 1991). The characteristic chitin-binding domain designated the hevein domain, is named after the chitin-binding protein isolated from rubber tree latex. The hevein chitin-binding domain is common to all members of this protein family, including basic chitinases, wound-inducible proteins and chitin-binding lectins from cereals, tomato, and stinging nettle. The lectins of wheat, barley and rice each contain four highly homologous chitin-binding domains that have apparently evolved by gene duplication. In artificial feeding experiments, larvae development of the cowpea weevil (Huesing et al., 1991), European corn borer and Southern corn rootworm (Czapla and Lang, 1991) were significantly inhibited upon inclusion of wheat germ agglutinin (WGA), rice or stinging nettle lectin in the diet. The delay in larvae development is presumably due to disruption of nutrient uptake resulting from binding of the lectins to chitin in the insect midgut.

Recently, constitutive expression of a bean chitinase gene produced increased resistance to a fungal pathogen (*Rhizoctonia solani*) in transgenic tobacco plants (Broglie et al. (1991). Hevein and stinging nettle lectin also exhibit antifungal properties but are more effective against particular fungi or are inhibitory at lower concentrations or (Broekaert et al. 1989; Van Parijs et al., 1991) than chitinase.

Cotton is plagued by a host of insect pests and soil-borne diseases. Pest control in cotton utilizes 40% of all agricultural pesticides used annually in the United States. A major objective of our research is to decrease pesticide use and increase the production and quality of cotton through development of novel germplasm with enhanced pest resistance. To achieve this goal, we have introduced genes encoding the chitin-binding lectins from barley and stinging nettle, and hevein into cotton using standard biotechnology techniques. We are very hopeful that this approach will provide adequate control against a broad spectrum of pests.

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RHIZOSPHERE BIOLOGY IN RELATION TO ROOT HEALTH OF TOMATO

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A significant number of important pathogens of major crops, including tomato, either attack roots or gain entrance to the plant through the root system. Efforts to manage these pathogens by cultural manipulations, biological control, or a combination of these approaches must focus on the biology of the rhizosphere. Progress in this area has been slow, at least in part, because of the complexity of the microbial interactions that occur at or near the surface of plant roots.

According to Bowen and Rovira (1991), the root-soil interface can be conveniently regarded as the rhizoplane (the root surface) and the rhizosphere, the zone of soil influenced by the root. Most of the microorganisms with the potential to affect plant roots, be they non-infective (i.e. restricted to the rhizoplane or rhizosphere) or infective, whether they are helpful (such as nitrogen-fixing symbionts or mycorrhizal) or harmful (such as pathogens), have a critical rhizosphere stage that governs whether they persist and affect the host plant. It must be emphasized that there is no such thing as a static rhizosphere environment, for it varies in time and space. Factors that can affect the rhizosphere include nature and concentration of organic substances released by roots, metabolism of the compounds by microorganisms, soil characteristics, and the microbial composition of the soil.

In our studies on rhizosphere biology in relation to root health we have emphasized tomato because of its importance in California and the fact that it is amenable to both greenhouse and field research. The primary approach of our investigations is to monitor qualitative and quantitative changes in root associated fungi, root health, and plant growth in response to treatments known to alter the rhizosphere environment. These treatments include the application of a soil fumigant, metham-Na, and the use of plastic mulch.

The plant growth response that results from soil fumigation, as well as heat pasteurization, has been recognized and investigated for many years. Although several hypotheses have been proposed the mechanism of this intriguing effect is not understood. In many situations a soil treatment is directed toward specific pathogens and the effects can be interpreted in terms of reducing the population of these organisms. Frequently, however, there is a marked growth response following fumigation or pasteurization that cannot be directly attributed to recognized root pathogens. It is well known that fumigation releases nutrients, yet the growth response occurs under conditions of soil fertility considered to be optimum.

A wide range of techniques are being employed. These include video image analysis to determine growth, immunological approaches to characterize quantify major genera of root fungi, and standard microbiological methodology.

In a field study done at the Westside Research and Extension Center in 1991, we found that metham-Na at a rate of 80 gallons/acre, black plastic mulch and a combination of metham plus mulch gave a statistically significant increase in yield of tomato. An early season growth response was only observed in the mulch treatments. Data on root appearance, however, revealed that metham appreciably improved the root systems whereas the mulch was no better than the check. As might be expected metham significantly decreased the incidence of corky root caused by *Pyrenochaeta*.

Enumeration and characterization of root associated fungi was done at intervals throughout the growing season. Species of *Pythium*, a common and frequently damaging root attacking fungus, were isolated throughout the season. *Rhizoctonia* spp. were isolated at a high frequency toward the end of the season. There was a tendency toward less *Pythium* and *Rhizoctonia* in the metham treatments compared to the mulch only and check plots. A diverse array of other fungi were present in close association with the roots. These were predominantly species of *Fusarium*, primarily *F. oxysporum*, *Aspergillus* and *Penicillium*. A species of *Stemphylium* or closely related genus was frequently isolated as well as the occasional recovery of other genera. An interesting observation was the "patchy" distribution of these fungi. A particular root system might have a high proportion of a single species that would occur infrequently or be absent on roots of other plants.

A key question is what effects, if any, do these root associated fungi have on root function and plant growth. We know, for example, that species of *Pythium* can have deleterious effects on plant growth by destroying feeder roots. The possible role of the many other fungi that are consistently present in high numbers is, however, not known. A major thrust of our program is to determine whether the various root associated fungi have an impact on root health or are merely incidental inhabitants of a niche created by nutrient availability. Preliminary studies in the greenhouse suggest that at least some of the species do exert an influence on growth of the plant. It is of interest that we have observed indications of both beneficial and detrimental effects.

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RECENT SUCCESS STORIES IN APPLYING IPM FOR MANAGEMENT OF INSECTS AND MITES

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Overriding concepts in the philosophy of integrated pest management in the 1990s include (1) ecosystem management with optimization of pest control, (2) a multidisciplinary, systems analysis approach, and (3) choice of economically viable and environmentally sound practices. IPM is considered to be a *strategy* for preventing crop losses by pests. Pest management actions are taken after careful monitoring of the system indicates a need as determined by predetermined *control action* (or economic) *thresholds*. Maximum use is made of factors that control pests naturally in the field including natural enemies, pest resistant or tolerant crop vrieties, weather, or modification of normal cultural practices. When pesticides are necessary, they are applied in ways that are least disruptive to the cropping system and in a manner that preserves and augments natural control to the extent possible.

The term integrated pest management was coined in the 1970s during the Nixon administration, the integrated control concept for insect pest management originated in the 1950s, and many senior entomologists are quick to point out that many of the principles of IPM have been with us since the 1930s. Certainly the idea is not new. However, the 1990s appear likely to be a time of unprecedented adoption of IPM programs by growers now backed against the wall by loss of pesticides, increasing pesticide regulation, ever-rising pesticide resistance among pests, and general concerns of farmworkers, the public and growers themselves about the hazards of pesticides to health, groundwater and the environment.

The case of arthropod management in California peaches illustrates some of the issues contributing to the need for reduction in growers' reliance on pesticides and also shows how University of California entomologists have been able to resolve most of these problems with more environmentally sound IPM practices. Critical to the success of these programs have been the complementary efforts of a number of experiment station and extension researchers, an excellent demonstration and extension program, and willingness on the part of growers to try out new strategies.

California peach growers in the late 1980s faced numerous problems associated with their use of pesticides. First was environmental contamination; wildlife biologists had been able to document significant injury to raptors and other birds inhabiting or resting in orchards due to the organophosphate component of dormant sprays for insect pests. Second was hazards to human health; researchers looking at cholinesterase levels of pickers have begun to accumulate evidence of worker exposure to pesticides even when they were used in total compliance with the law; although the amount of exposure might be considered within "safe" levels, any measurable effect is of concern to most growers and workers. A third problem was consumer concerns about pesticide residues on marketed fresh fruit; the Natural Resources Defense Council (NRDC)'s contraversial book *Pesticide Alert* identified peaches as second only to strawberries among the 26 fruits and vegetables studied in terms of the amount of pesticide residues found on marketed fruit. Insecticide residues included parathion, carbaryl, and endosulfan. Growers were also suffering under an increasing burden of regulations associated with pesticide use--especially the use of the most toxic materials. Among these regulations were new licensing requirements for applicators, stricter requirements on pesticide safety training growers must give farmworkers who work with or around pesticide applications, and increasing paperwork for getting use permits for many materials. Probably the most startling regulatory change for growers was the withdrawal of parathion, one of the key insecticides used in peaches, at the end of 1991. Finally, growers were faced with an increasing inability to control their key pest, the oriental fruit moth, because of the development of insecticide resistance to most of the organophosphates traditionally used for control.

The first real breakthrough in the pest management program was in the control of the key pest, the oriental fruit moth, *Grapholita molesta*. This pest damages both growing shoots and fruit. Larvae boring into the fruit feed around the seed and make it unsuitable for marketing. Traditionally, the pest has been treated with organophosphate and carbamate insecticides during the growing season with up to 3 treatments. However, insecticide resistance coupled with health and environmental concerns made these treatments not only less effective but increasingly less desirable. In the late 1980s, a revolutionarily new control product became available--pheromone dispensers. These dispensers, applied at a rate of about 400 per acre, inundate the orchard with pheromone, disorienting male moths so they are unable to find mates. Where they are properly used, the pheromone dispensers have made insecticide sprays for this pest unnecessary.

A second key pest for peach growers is the peach twig borer, *Anarsia lineatella*. Like the oriental fruit moth, the peach twig borer damages shoots and invades fruit, making it unsuitable for market. The most important time for treating this pest has traditionally been during the dormant season, and it is organophosphate sprays for this pest that have been especially implicated in the injury to birds in winter. In season sprays are also common for this pest, especially when dormant sprays were poorly applied or timed. Research just begun in the last two years has resulted in a new, much more environmentally sound pest management procedure for this pest. Researchers have shown that two carefully timed applications of the microbial insecticide *Bacillus thuringiensis* at bloom can successfully control this pest as it emerges from its overwintering hibernacula to feed on new shoots and leaves. Control is increased with a dormant spray of narrow range oil. Both of these materials have minimal impacts on wildlife, human health and natural enemies of other arthropod pests.

A third key pest is the San Jose scale, *Quadraspidiotus perniciosus*. This pest feeds on twigs, branches, and fruit; heavy infestations can kill twigs, branches or even entire trees. Traditionally the pest has been controlled with the dormant sprays of oil and organophosphate also applied to manage peach twig borer. However, light to moderate infestations can be controlled with a dormant application of relatively nontoxic narrow range oil alone. If populations get out of hand in the spring, a degree day program and monitoring procedures have been developed to assist in precisely timing a spring spray so that optimum control can be achieved when a more toxic material is required.

Numerous other arthropod pests occasionally cause damage in peaches. But many of these are secondary outbreak pests which occur when pesticides applied for one of the three key pests above kills off their natural enemies. Use of the new IPM program for arthropod pests should reduce or eliminate most problems with these pests. A case in point is spider mites, *Tetranychus* species. In a nonsprayed orchard predators including western predatory mites, six spotted thrips and spider mite destroyers should be able to provide adequate control. The western predatory mite, *Metasieulus occidentalis,* is available commercially for release in orchards deprived of predators, but this is rarely necessary. Oils sprays are a pesticide with minimum environmental/ health hazard that can be used to manage mites as well.

The arthropod IPM program for peaches incorporates a myriad of environmentally sound techniques for management. These include pheromone dispensers, microbial insecticides, reliance on natural enemies, narrow range oils, pheromone and sticky trap devices, and a degree-day model for timing pesticide sprays. Under development is an expert system CALEX/peaches that will help growers diagnose their pest problems. The university uses a number of extension techniques including workshops and publications--notably the UC Pest Management Guidelines--to keep pest control advisers and growers informed about new developments in this ever-evolving program.

The benefits of the new program are clear--elimination of all organophosphate insecticides for arthropod management in most years. As a result all known environmental contamination, health hazards, consumer concerns, and pesticide resistance problems associated with insecticide use in peaches have been eliminated. Additionally, growers needs to train and equip workers for pesticide application are lessened. Not all problems are solved forever, of course. New insect pests may arise over time, and current methods may later become ineffective and some of these new methods must still be fine-tuned to suit local conditions in some areas of the state. Moreover, applications of fungicides to control key pathogen pests including brown rot, ripe fruit rot, peach leaf curl and shot hole disease are still needed; several of the commonly used fungicides are of health concern or likely to come under further regulatory restriction. Further research will be required before need for these fungicides can be eliminated.

Acknowledgement: Research reported on in this paper was carried out by a number of researchers and some of it is unpublished. I would like to acknowledge key contributors to this program: Frank G. Zalom, UC Statewide IPM Project, UC Davis; William Barnett, UC Statewide IPM Program, UC Kearney; Richard Rice, Department of Entomology, UC Davis and UC Kearney; Barry Wilson, Avian Sciences, UC Davis.

PLANT GROWTH STAGES AND SALINITY

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Crops grown in saline soils usually experience varying levels of salt stress throughout the various stages of their growth cycle. Salt concentrations in the soil profile change with time and almost always vary with depth. Plant growth and development are directly affected by this changing environment as roots encounter different levels of salt in the rootzone. It is clear, therefore, that better information about crop responses to salinity at different stages of growth would certainly improve *decision-making in this uncertain environment.*

Germination and seedling emergence are critical stages in the plant growth cycle because of their obvious effects on plant stand and eventual yield of the crop. Salinity stress during these crucial stages can greatly increase plant mortality. Seeds of most crops are capable of germinating at higher salinity levels than the plants can tolerate at some later stages. However, salt stress often delays germination and emergence. Delays could be fatal if the emerging seedlings, already weakened by salt stress, encounter additional stresses, such as water stress or soil crusting. Since salt concentrations are usually highest at the soil surface, juvenile roots of emerging seedlings are exposed to more stress than are most roots of more mature plants.

Salt tolerance during emergence varies considerably among crops but does not correlate well with tolerance parameters as determined from yield response functions. Of course, different criteria are used to evaluate plant responses to salinity during these different stages of plant development. Tolerance at emergence is based on survival, whereas tolerance after emergence is based on decreases in growth or yield. Unfortunately, little information is available on the tolerance of plants during emergence. Germination data obtained in Petri dishes are not valid indicators of a seedling's ability to emerge through the soil surface.

The seedling stage is one of the most sensitive stages of growth for many crops. Greenhouse experiments on corn and wheat indicated that dry matter yields of three-week-old plants were reduced by concentrations of salt that were lower than those that reduce grain production (8, 9). It is generally agreed that plants become increasingly tolerant as they grow older. The earlier plants are stressed, the greater the reduction in vegetative growth. For determinate plants, the proportion of biomass that is subject to growth reduction becomes less the later they are stressed. Of course, the duration of stress would also be shorter. In an experiment where salinity treatments were of equal duration, it was found that the later cowpea, an indeterminate crop, was stressed, the less vegetative growth was reduced (10).

Salinity stress during the vegetative stage suppresses growth of all plant organs, although root growth is usually affected less than shoot growth. The number and size of leaves, stem growth and branching are all reduced by salinity. In cereal crops, our data indicate that the rates of both leaf primordia initiation and leaf appearance are decreased with salt stress (3). Salinity, however, has a negligible effect on the duration of leaf primordia initiation. Tillering can be significantly inhibited by salt stress (6, Unpublished data). The onset of tillering may be delayed or, with sufficient stress, some tillers, particularly secondary and tertiary tillers, may not appear at all.

The sensitivity of plants during reproductive development is especially critical for the production of fruit, grain, and seed crops. Cereals, for example, are especially sensitive during spike or panicle differentiation. In sand culture experiments designed to test the relative effects of salt stress at different stages of growth on grain production, sorghum (11), wheat (9), and cowpea (10) were most sensitive during the vegetative and early reproductive stages, less sensitive during flowering, and least sensitive during the grain-filling stage. In those experiments, salt stress treatments of equal duration were imposed at different times in order to separate the effects of treatment timing from treatment duration. The results suggest that cereals become increasingly tolerant after the booting stage and were not particularly sensitive during flowering. This latter point appears controversial for rice. Pearson and Bernstein (12) found that rice was sensitive during pollination and fertilization, whereas Kaddah et al. (4, 5) did not.

Salt stress prior to and during shoot apex transition from the vegetative to the reproductive stage can significantly affect the reproductive development of cereals. It significantly accelerates spike development, i.e. it decreases the time between double ridge (spike differentiation) and terminal spikelet formation. Salinity also significantly reduces the number of spikelets per spike, kernels per spikelet, and spike-bearing tillers per plant (1, 6). The most serious effect of salinity on the seed yield of wheat (both *Triticum aestivum* L. and *T. turgidum* L.) is caused by the reduction in number of mature tiller spikes (6). Soil water salinity equivalent to an electrical conductivity of 14.5 dS/m reduced the number of tiller spikes to about half that for the control plants; but it had little effect on the weight of seed produced per tiller.

Salinity also significantly alters the patterns of kernel distribution in main stem spikes (2). The spikes are shorter, fewer spikelets are produced, and the number of kernels per spike is reduced. This decrease in kernel number is compensated for by an increase in the weight per kernel and the number of kernels per spikelet.

SUMMARY

Most studies seem to indicate that crop seeds are capable of germinating at higher salinity levels than they can tolerate at later stages of growth, although germination may be delayed. In general, plants are most sensitive during seedling emergence. The combination of greater sensitivity and the typically higher levels of salinity near the soil surface is often the cause of high seedling mortality. Although experimental data are limited, it appears that plants become increasingly tolerant as they grow older. Salt stress during the early reproductive stage can markedly reduce yields of seed crops, particularly cereals. Experiments on wheat show that stress at this stage shortens the reproductive phase of apex development, decreases the number of spikelet primordia per spike, and significantly reduces the number of spike-bearing tillers. If the full yield potential is to be attained, salt stress must be avoided prior to and during spikelet development of main stem and tiller spikes.

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DELTA SALINITY STANDARDS
A GAUGE FOR AGRICULTURE'S FUTURE

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This paper attempts to present, from our perspective, some of the information that has been background to the State Water Resources Control Board's D1485 (1978) water quality objectives and the more recent 91-15WR (May 1991), "Water Quality Control Plan for Salinity for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary." These standards or objectives are established in order to supply a reasonable amount of protection for all the beneficial uses of water within this specific Bay-Delta area.

The authority for the SWRCB's action comes from the State Porter-Cologne Water Quality Control Act and the Federal Water Pollution Control Act (PL 92-500). In 1986, as a result of a legal challenge to the 1978 Delta Plan and D1485, the State Court of Appeals directed the SWRCB to "take a global view toward its dual responsibilities to the State's water resources." The Court further directed that in its water quality roll, the SWRCB objectives should "provide reasonable protection for beneficial uses, considering all demands made on the water."

Water quality objectives in the latest plan have been established for:

- Salinity at municipal and industrial intakes;
- Salinity levels to protect Delta agriculture;
- Salinity levels to protect export agriculture;
- Salinity for fish and wildlife resources in the Estuary.

Water rights and in-stream flows are not a part of this plan but are to be considered in the very near future by the SWRCB.

Delta Agricultural Beneficial Use

The Sacramento-San Joaquin Delta is defined in Water Code Section 12220 as roughly a triangular area of near 738,000 acres, extending from Chipps Island near Pittsburg on the west to Sacramento on the north and to the Vernalis Gauging Station on the San Joaquin River in the south. The area includes those waterways above the confluence of the Sacramento and San Joaquin Rivers, which are influenced by tidal action and about 512,000 acres of agricultural lands which derive their water supply from these waterways.

Major tributaries to the Delta include the Sacramento and San Joaquin Rivers. Minor contributors are the Consumnes, Mokelume and Calaveras Rivers, and Dry Creek and the Yolo Bypass. Water is exported from the Delta at the following major locations:

Tracy Pumping Plant (CVP), 1951;

Clifton Court Intake (SWP), 1967;

Contra Costa Canal (CVP), 1940;

City of Vallejo Intake at Cache Slough, 1953;

North Bay Aqueduct Intake at Borker Slough (SWP).

By 1975, combined deliveries of waters exported by both the CVP and SWP totaled 4.8 million acre feet per year. Total CVP and SWP exports are projected to reach 6.6 million acre feet per year by the year 2000.

Salinity is one of the major water quality factors affecting beneficial uses of Delta water supplies. Beneficial use of the Delta water include domestic, municipal, agricultural, and industrial supply; power generation; recreation; esthetic enjoyment; navigation; and preservation and enhancement of fish and wildlife and other aquatic resources or preserves. Water exports and delta water inflows directly affect delta water quality as well as do outflows to the Bay, which expel and dilute downstream water salinity.

The Delta's climate and soil permit a wide variety of crops to be grown. In the organic soils of the Delta lowlands, irrigated corn and cereal grains are predominant at 31% and 23%, respectively, followed by tomatoes, alfalfa and pasture. Additionally, approximately 2 percent of Delta lowlands produce salt-sensitive crops, including beans, peppers, carrots, lettuce and onions.

Delta lowland soils generally fall into two categories--organic and mineral. Farmed organic soils constitute 68 percent, while mineral soils are the remaining 32 percent. Organic soils are usually found in the Delta lowlands which are those below an elevation of +5 feet mean sea level. Delta organic soils or peatlands were formed through partial biological decomposition of marsh plants and grasses under anaerobic conditions. The high groundwater table, along with problems associated with the typically uneven surface of organic soils, makes surface irrigation difficult. However, subirrigation is well adapted to these organic soils and is the primary method of water application. (Subirrigation is the controlled delivery of water to plant roots by periodically but temporarily raising the water table into the root zone to meet the crop water demand.)

Since subirrigation does not apply water to the surface, salts tend to accumulate at or near the soil surface during the growing season due to capillary rise of moisture (containing small amounts of salts) from the water table. The salts accumulate during the growing season as the water is used by crop or is lost through the usual process of evapotranspiration. The accumulating salts are subsequently or at least partially leached by the following winter's rainfall before next year's crop is planted.

If the winter rainfall is inadequate, salts will continue accumulating and within a relatively short period (perhaps one to three years) may accumulate to a concentration that will cause a reduction in crop yield. Many farmers will leach by flooding to reduce salinity prior to planting a moderately salt-sensitive crop such as corn. If wheat is to be grown, leaching is seldom done. Some farmers will flood large fields, not primarily for leaching, but to control weeds or insect pests, or for duck or wetland habitat or for other more or less recreational purposes. Any salt leaching accomplished is a secondary benefit.

Delta uplands are generally mineral soils where surface irrigation is the common irrigation method. Water is applied to the soil surface, usually through furrow, sprinkler, or flood irrigation. Unlike organic soils, salts in the surface-irrigated mineral soils are brought into the soil column from the surface with the applied water. Excess salts are removed after harvest by applying irrigation water to flush the salt into the lower ground water table. Some leaching may also be accomplished with winter rainfall.

Development of Water Quality Objectives

In Decision 1485 of August 1978, the State Water Resources Control Board issued water quality objectives for the Sacramento-San Joaquin Delta and Suisun Marsh that superseded the older Decision 1379 standards (adopted July 28, 1971). The D1485 decision followed 32 days of evidentiary hearings beginning Nov. 15, 1976 and concluding Oct. 7, 1977. An Environmental Impact Report was prepared and finalized. The authority for the SWRCB's action came from the State Porter-Cologne Water Quality Control Act and the Federal Water Pollution Control Act (PL 92-500).

The Decision D1485 is intended to effectively control water quality to protect the several beneficial uses of water. It was considered to be binding on both the State Department of Water Resources (SWP) and the U.S. Bureau of Reclamation (CVP). These standards were expected to be effective over the next ten years (1978-1988).

The South Delta was believed to have special problems, not directly related to water quality in the Delta, and these D1485 standards did not appear to be enforceable in the Southern Delta. The quality problems of the Southern Delta were to be addressed by negotiation, physical facilities or regulation as new information became available. The water quality standards for the Southern Delta enacted May 1991 have now been set at 0.7 dS/m from April 1 to August 31 and 1.0 dS/m from Sept. 1 to March 31. This will protect salt sensitive crops such as beans during the regular growing season and tree crops such as almonds at other times of the year but assume a leaching fraction of 15% is or can be achieved by good irrigation management on the mostly mineral soils.

Table 1. Current Water Quality Objectives

The most recent (May 1, 1991) agricultural water quality objectives for the Western, Interior, South Delta, and Export waters include the following. Electrical conductivity of water in dS/m (1 dS/m - 1 mmho/cm).

Western Delta			
Sacramento River, at Emmaton		0.45 EC	EC from last date shown to 8/15
	Wet years	= 4/1 - 8/15	--
	Average normal	= 4/1 - 7/1	0.63
	Below normal	= 4/1 - 6/20	1.14
	Deficient	= 4/1 - 6/15	1.67
	Critical	= 4/1 - --	2.78
San Joaquin River, at Jersey Point		0.45 EC	EC from last date shown to 8/15
	Wet years	= 4/1 - 8/15	--
	Average normal	= 4/1 - 7/1	--
	Below normal	= 4/1 - 6/20	0.74
	Deficient	= 4/1 - 6/15	1.35
	Critical	= 4/1 - --	2.20
Interior Delta			
South Form Mokelumne, Terminous		0.45 EC	EC from last date shown to 8/15
	Wet years	= 4/1 - 8/15	--
	Average normal	= 4/1 - 8/15	--
	Below normal	= 4/1 - 8/15	--
	Deficient	= 4/1 - 8/15	--
	Critical	= 4/1 - --	0.54
San Joaquin River at San Andreas Landing		0.45 EC	EC from last date shown to 8/15
	Wet years	= 4/1 - 8/15	--
	Average normal	= 4/1 - 8/15	--
	Below normal	= 4/1 - 8/15	--
	Deficient	= 4/1 - 6/25	0.58
	Critical	= 4/1 - --	0.87
South Delta			
(to be implemented in 1996 unless			4/1/ - 8/31 0.70 EC
prior agreements are negotiated)			9/1 - 3/31 1.00 EC
Exports			
from Clifton Court			at all times = 1.0 EC

The D1485 basic water quality standard in effect from April 1 (beginning of an irrigation season) to August 15 (end of the irrigation season) was:

Western Delta & Interior Delta - 0.45 EC_i (dS/m)

This was based primarily on testimony of UC representatives at the D1485 hearings. Those testifying included Bob Ayers, Franz Kegel, Alan Carlton, Blaine Hanson, Jewell Meyer, and others. Testimony before the State Water Resources Control Board included many aspects of general Delta agriculture, the need for water of good quality and the effects of salinity upon crop production if salinity was allowed to accumulate to concentrations that reduced yields.

In general **for mineral soils** and our usual methods of surface irrigation, the salts in the applied water are concentrated in the root zone after a period of time to about 3 times that of the applied water. This is assuming a normal 15% leaching fraction. Then, since the method of determining the soil salinity is in the saturation extract which dilutes the soil water by a factor of about 2, the relationship between salinity of applied irrigation water (EC_i) and the resulting soil salinity of the saturation extract (EC_e) becomes $EC_e = 3/2EC_i$. For example, if $EC_i = 1$ dS/m, the saturation extract $EC_e = 3/2\ EC_i$ or $EC_e = 1.5$ dS/m and is the soil salinity (EC_e) expected to result in the root zone of a crop planted on a mineral soil and irrigated in the conventional manner with $EC_i = 1$ dS/m water.

For **subirrigated peat soils**, this relationship of $EC_e = 3/2\ EC_i$ is altered. A report on a salinity study in the Delta (Meyer, Carlton and Ayers, 1976) stated that, on average, the salinity accumulating in the soil water in the crop root zones of the organic soils during extended periods of subirrigation was about 5 to 10 times more concentrated than the salinity in the water applied during subirrigation. Since the range for the concentrating effect going from water salinity (EC_i) to soil water salinity (EC_{sw}) was reported in the testimony to be from 5 to 10 times that of the applied irrigation water, the SWRCB staff apparently picked the single concentration factor as 7.5. Thus EC_e in the crop root zone resulting from several years of subirrigation was estimated to be $EC_e = 7.5/2\ EC_i$ and reported in millimhos/cm. Thus, for a water of $EC_i = 1$ dS/m, the anticipated soil saturation extract under subirrigation would be $EC_e = 7.5/2$ or 3.75 dS/m.

After studies of the crop distribution and the range of crops being grown in the Delta, corn was selected as representative of the most sensitive, most widely grown crop in the subirrigated areas of the Delta, and the quality needs of corn were judged to be critical to the continuing agriculture of the Delta. At the time of the D1485 hearings, the salinity tolerance of corn was reported to be $EC_e = 1.7$ dS/m, as reported in FAO Paper 29, "Water Quality for Agriculture" by Ayers and Westcot (1976). This value had been obtained from a preliminary report of Dr. E.V. Maas and later published in "Crop Salt Tolerance Current Assessment" (1977).

About this same time, Maas and Hoffman released their crop yield equation relating yield, crop salinity tolerance, existing soil salinity. This appeared in the above mentioned FAO publication 29. It proposes that salinity affects yield as a straight line effect once the salinity tolerance of crop is exceeded. The equation follows:

$$Y_r = 100 - b\,(EC_e) - a$$

where:

Y_r = relative crop yield

EC_e = salinity of soil saturation extract

a = salinity threshold value for the crop representing the maximum EC_e at which a 100% yield can be obtained in (dS/m)

b = yield decrement per unit increase in salinity, or the percent yield loss per unit increase of salinity between the threshold value (a) and the EC_e value representing the 100% yield decrement.

On this basis, the following Table 2 was prepared for consideration of the SWRCB staff:

Corn Yield = $100 - b(EC_e - a)$;
Corn Tolerance (a) = 1.7 dS/m;
Loss in Yield per Unit
Increase in Salinity (b)= 12.05% (from FAO 29).

From Table 2, it is apparent that the theoretical corn yield begins to drop off as applied water salinity increases above an $EC_i = 0.45$ dS/m.

Table 2.

EC_i dS/m	$EC_e = 7.5/2\ EC_i$ dS/m	$Yield_r$ (corn) a = 1.7 dS/m; b = 12.05%
0.10	0.037	100.0%
0.20	0.75	100.0
0.30	1.125	100.0
0.40	1.50	100.0
0.45	1.687	100.0
0.50	1.875	97.9
0.60	2.25	88.5
1.00	3.75	75.3
1.50	5.625	52.7
2.00	7.5	30.1

Field Experiments on the Salt Tolerance of Corn

At the conclusion of the D1485 hearings and the issuance of the water quality standards for the Western and Interior Delta, a three-year cooperative study was authorized and supported by Department of Water Resources and the State Water Resources Control Board (later extended to a fourth year) with the objective to determine under actual Delta agricultural conditions the salinity tolerance of corn. The trial was conducted under the management of the US Salinity Laboratory, Riverside, California, and the UC Cooperative Extension.

The three-year field experiment was conducted near Terminous in the Sacramento-San Joaquin Delta from 1979 to 1982. From the trial, the tolerance of corn to salinity (a) was EC_e = 2.1 dS/m: the loss in yield of corn (b) as a result of each EC_e unit increase in soil salinity above this tolerance was b = 20.2%. The Maas-Hoffman equation for predicting the yield of corn (Y_r) = 100 - 20 (EC_e - 2.1) where EC_e is the measured mean soil salinity.

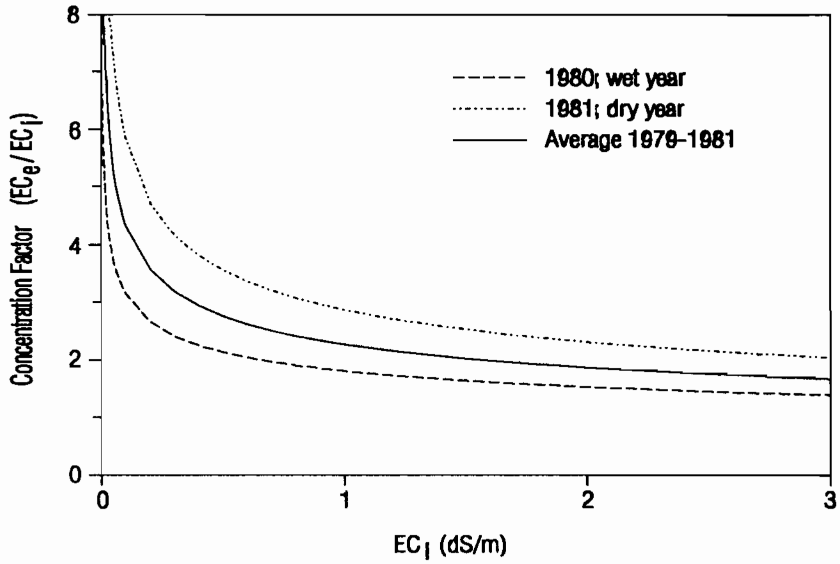
At soil salinity levels less than an EC_e = 2.1 dS/m, corn yield was equivalent to non-saline conditions. As soil salinity exceeded this threshold value of EC_e = 2.1, yield (Y_r) was reduced at the rate of 20.2% for each unit increase in soil EC_e. Neither the climate nor the organic soil in the Delta significantly altered the salt tolerance threshold from those previously published for mineral soil. The salt tolerance loss in yield per unit increases in soil salinity (b); however, as expressed for the subirrigated organic soils, was nearly twice as great as for corn grown on mineral soils--a significant difference (for surface irrigated mineral soils, b = 12%; for subirrigated organic soils, b = 20.2%). Salts in excess of crop tolerance accumulating in the root zone of the subirrigated crops reduced yield nearly twice as much as the same amounts of excessive salts accumulating in the crop root zone of mineral soils. The method of irrigation, whether sub-surface or surface sprinklers, did not affect the threshold salt tolerance of corn significantly (Hoffman, Maas, Prichard, and Meyer, 1983).

During the fourth year of the study, full corn production was achieved in soils that were saline the previous year, provided the irrigation water salinity (EC_i) applied by sprinkling was less than 2.0 dS/m and leaching was adequate from either winter rainfall or irrigation to reduce the soil salinity below the threshold. Under the same conditions for subirrigation, an EC_i up to 1.5 dS/m did not decrease yield (Hoffman, Prichard, Maas, and Meyer, 1986).

Relationship Between Irrigation Water Quality and Soil Salinity

These field trials show that unlike mineral soils, the concentration factor for applied-water salinity to soil-water salinity varied with the concentration of the applied water (Prichard, Hoffman, Meyer, 1983). This work indicates the concentration ratio is not constant as originally suspected. The ratio decreases as EC_i increases (Figure 1). Figure 1 shows the effect of winter rainfall on the concentration factor of a dry (260mm) and wet (685mm) suggesting rainfall as an important factor.

Figure 1. Concentration factor (EC_e/EC_i) as a function of applied water salinity (EC_i) for subsurface irrigated organic delta soils -- 3-year combined average (1979-1981); 1980 (wet year -- 685mm); 1981 (dry year -- 260mm).



It is interesting to note that the value of 3.75 EC_e used earlier (1978) was determined from fields supplied with waters near 0.3 dS/m. These later results show essentially the same concentration factor for the salinity of the irrigation water. Irrigation water quality has a strong influence on soil salinity of organic soils. However, winter rainfall, soil properties, leaching practices, irrigation techniques, and elevation and salt concentration of a water table can significantly influence the relationship.

Predictive Models

From the field trials, a model was developed to predict the soil salinity in organic soils of the Delta, based on the salinity of the irrigation water, a representative level of soil salinity and rainfall. Additionally, a model was developed to predict the reclamation process based on the (1) salinity of the soil initially; (2) the desired level of soil salinity; (3) the salinity of the water applied for leaching; and (4) the depth of soil to be reclaimed and the depth of water required to pass through the soil to achieve the desired level of soil salinity.

At the conclusion of the three-year field study on the salt tolerance of corn followed by a year of reclamation trials (Prichard, Hoffman and Oster, 1985), Dr. Glenn Hoffman (then with the US Salinity Laboratory, Riverside, California) proposed a series of equations that could be used to predict a following year's spring soil salinity, fall soil salinity, average irrigation season soil salinity, and relative corn yield if rainfall and irrigation water salinity were known. With such predictive capability, Dr. Hoffman concluded that a good reliable estimate of soil salinity at the time next year's crop is to be planted could be determined from soil samples taken the previous spring or the previous fall period. It then follows that it should be possible to predict from the prior year's soil samples, the need to leach or not to leach over the winter months in order to be assured that the next spring soil salinity would not exceed the tolerance of the crop to be grown. Such an equation is given in the following:

$$SEC_e = 1.2\ (FEC_e) \times (0.0012\ (FEC_e)\ (R\text{-}Rt)$$

where:

SEC_e	=	spring EC_e
FEC_e	=	fall EC_e
R	=	total rainfall
Rt	=	150mm (threshold amount of rain required to bring the soil water content to a level where leaching commences)

Based on these equations, Mr. Ed Winkler of the Department of Water Resources has developed a computer model called DELCORN salinity model. This program is able to model three water management scenarios:

- No special fall or winter irrigation management practices for salinity control. Assumes the only way salts are removed after the end of the irrigation season is by rainfall.
- A fall subirrigation is performed for purposes of soil moisture replenishment. No further leaching is done except by winter rainfall.
- An extended winter pond leaching is performed; the field is then drained and prepared for crop. Drainage and drainage pumps are presumed to be in operation throughout the leaching period.

The model has been used to predict spring soil salinities for each of years of record from 1922 to 1978. Input data to this model are the measured in-stream water salinities and the recorded winter rainfall. If spring salinity was predicted to exceed the tolerance of corn, a management decision was made to leach or not to leach. If fall irrigated (case #2), the spring salinity was reduced based on effectiveness of the winter rainfall. If leached (case #3), the salinity was reduced based on the assumptions in the model (50% reduction), and salinity was subsequently allowed to increase in the manner predicted by the appropriate equation .

A sample of the Delcorn model's output is given in Table 3 where corn yield for each year is plotted as a function of predicted soil salinity. For case #1 (no leaching), it is readily seen under the assumptions in the model and without leaching, the spring soil salinity would very soon have been too salty to support an economic yield of corn. In case #2, with a fall subirrigation to replenish soil moisture prior to the winter rains, the need for or frequency of leaching is greatly reduced. In case #3, it can be seen that with an effective winter leaching (50% salinity reduction), losses in yield due to salinity are at a very minimum.

A Gauge for Agriculture's Future?

Based on the results of the corn study, it appears that corn can be grown and maintained with saltier water than proposed in the 1978 standards (D1485); however, controlled leaching would be required. For now, the present water quality salinity objectives of the May 1991 Water Quality Control Plan for the most part continue the objectives of the D1485 plan pending the outcome of studies to address the effectiveness , practicality, and economics of Delta organic soils of salt leaching practices. This project, conducted by UC researchers, is supported by the State Department of Water Resources, the Bureau of Reclamation, the State water Resources Control Board and the Central Delta Water Agency.

In addition the Western and Interior Delta Agricultural Work Group, under the sponsorship of the Department of Water Resources, continues to meet and monitor the research findings. It is anticipated that an acceptable agreement on standards or objectives will soon be reached among these participants as to what the real management alternatives will be for various levels of salinity that might possibly be mandated for the western and interior delta.

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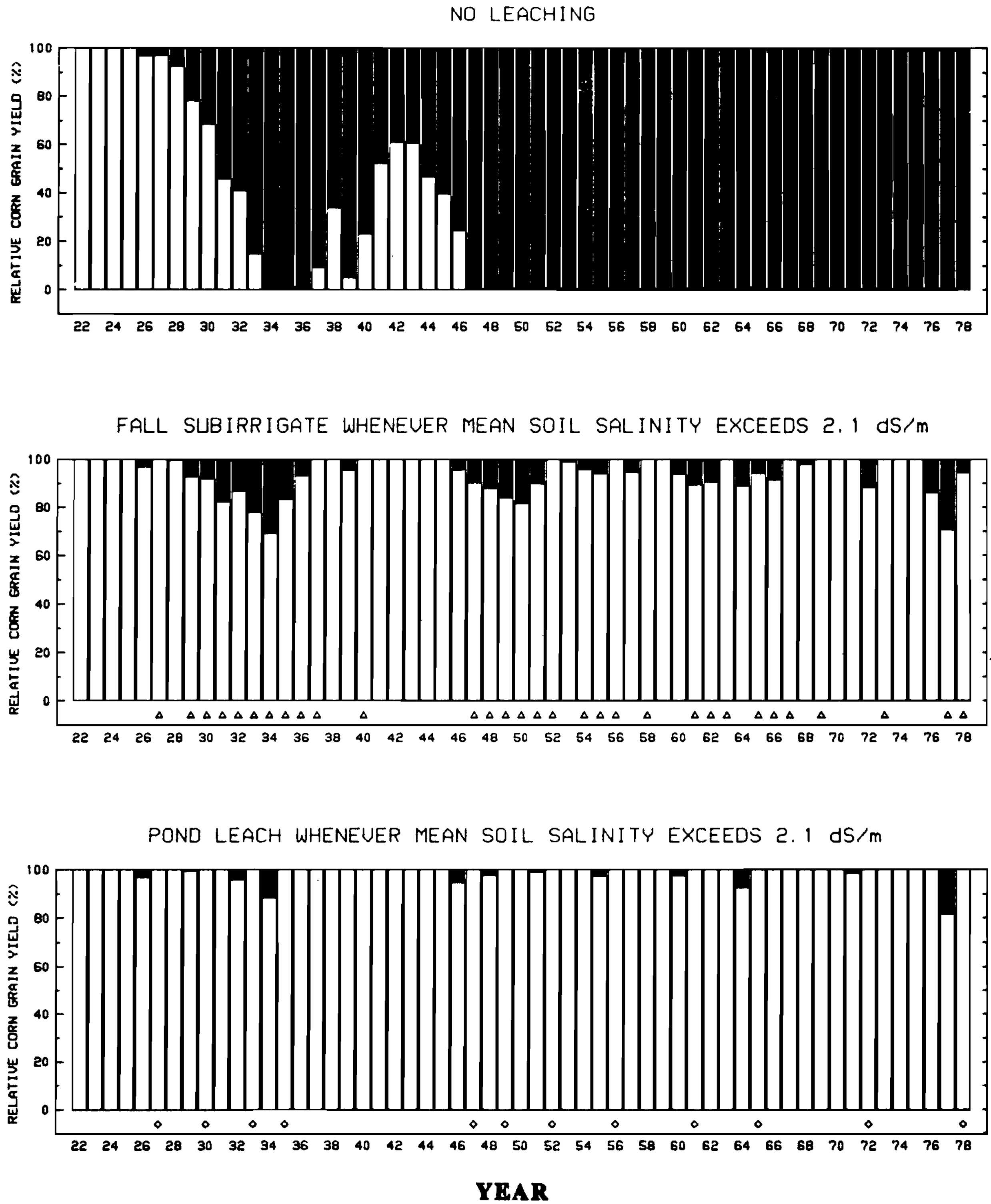
Table 3

VARIATION IN CORN YIELD WITH DIFFERENT LEACHING PRACTICES AT EMMATON

ASSUMING 1990 LEVEL OF DEVELOPMENT HYDROLOGY
MEETING D-1485 STANDARDS



LEGEND:
▲ = Fall subirrigation Performed
◇ = Pond Leaching Performed

IRRIGATION TAILWATER AND RIVER TOXICITY

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The Central Valley Regional Water Quality Control Board's Basin Plan[1] contains a narrative toxic objective stating that "all waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in ...aquatic life". In 1991 the California State Water Resources Control Board adopted an Inland Surface Water Plan stating that there shall be no chronic toxicity in receiving waters and that attainment of this objective shall be measured by conducting the EPA three species bioassay test. Furthermore, the Plan directs Regional Boards to insure that follow-up studies are conducted in waters with consistent toxicity to determine the source of pollution and that the responsible parties take all reasonable steps to eliminate it.

The Regional Board conducted periodic surveys of the San Joaquin watershed employing the EPA three species bioassay protocol from 1988 through mid 1990. The purpose of these surveys was to assess changes in San Joaquin Basin water quality throughout the hydrologic cycle. When toxicity was detected, staff attempted to conduct follow-up studies on some of the more significant events to characterize them in terms of their temporal and spatial nature and, if possible, determine the chemicals causing toxicity.

Major findings for Ceriodaphnia dubia, the invertebrate component of the EPA three species bioassay, are summarized. Forty nine incidences of toxicity were

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[1] Legal document which regulates water quality in the Central Valley.

detected which represented 24 percent of all invertebrate bioassays conducted. The average invertebrate mortality rate in these samples was 83 percent in 6 to 9 days. Toxicity was measured in water samples collected from the San Joaquin River and from all Rivers, Creeks and constructed agricultural drains tributary to the San Joaquin except the Stanislaus River. A pattern of high invertebrate mortality was measured at three San Joaquin River stations located between the confluence of the Merced and Stanislaus Rivers. Average invertebrate mortality in samples from this 43 mile River reach were at least 4 times higher than at either Mendota Pool or Mossdale, the most upstream and downstream sampling sites in the study. Similarly, the frequency of toxicity increased from no recorded incidences at Mendota Pool or Mossdale to a 40-50 percent chance of observing toxicity on any occasion in the same River section. Both the increase in average mortality and in the frequency of toxicity at all three sites was statistically greater than at either Mendota Pool or Mossdale ($P<0.05$). The primary cause of toxicity is believed to be pesticides entering the San Joaquin River in tailwater from orchard and row crops. On five occasions, pesticides commonly used in this section of the Basin were detected in San Joaquin River samples which previously had tested toxic in bioassays. Diazinon, parathion, carbaryl, and carbofuran were measured in drain and River samples at concentrations in excess of both EPA recommended criteria and of concentrations reported in the literature to be toxic to invertebrates.

EMERGING IRRIGATION TECHNOLOGY TO REDUCE RETURN FLOWS

The Department of Water Resources (DWR) and the State Water Resources Control Board are conducting a demonstration project to evaluate the amount of irrigation water applied, the volume of deep percolation produced and study the feasibility of the subsurface drip, low energy precision application (LEPA), improved furrow, and conventional furrow irrigation systems. DWR contracted with Boyle Engineering in Fresno to conduct the project. in 1988.

A 160 acre demonstration site on Harris Farm in western Fresno County was subdivided into four 40-acre plots. There was one plot for each of four irrigation technologies. Cotton was planted in all four plots during 1989 and 1990.

The objectives of this demonstration project included an evaluation of several long term characteristics, as well as yearly data. This report is based on two years of data. The study will continue until the end of 1993, and some of the initial conclusions may change. Some of the initial conclusions include:

- ❖ Irrigation scheduling should be promoted in combination with the others methods to reduce the volume of applied water and agricultural drain water with furrow irrigation.

- ❖ The majority of the deep percolation occurred during the pre-irrigation and the first irrigation of each growing season according to the individual irrigation system evaluations. Reduction in the amount of the water applied during the pre-irrigation and the first season irrigation has the greatest potential to reduce the amount of agricultural drainage.

- ❖ The average soil salinity in the subsurface drip and LEPA plots increased between the spring and the fall during both years of the project.

- ❖ The average soil salinity in the subsurface drip and LEPA plots increased between the first and the second year of the project. The average soil salinity in the improved furrow irrigation plot decreased between the first and the second year of the project.

- ❖ The average ground water salinity generally varied during the irrigation season, however the magnitude of the salinity reductions did not correspond with the deep percolation predicted by Boyle Engineering during individual irrigation system evaluation.

- ❖ The average ground water boron concentration appeared to be influenced by deep percolation, however the magnitude of the boron concentration reductions did not correspond with the deep percolation predicted by Boyle Engineering individual irrigation system evaluation.

- ❖ The average ground water selenium concentration beneath the west side of the field appeared to influenced by subsurface ground water inflow from adjacent areas containing higher concentration of selenium to the west of the field. The two plots on the east side of the field were not affected because of the small magnitude of the lateral flow.

There are a variety of ways to evaluate an irrigation system. In the fifth (sixth?) year of a drought, one measure of success is to compare the amount of water used for each system (Table 1). When this is done, the LEPA system applied the least amount of water in 1989 (1.66 acre-feet per acre), and the improved furrow system applied the least amount of water in 1990 (1.64 are-feet per acre). (The LEPA system had mechanical failure in 1989 and unintentionally applied this depth of water.) The subsurface drip system consistently applied less than or equal to 2.0 acre-feet of water per acre per year to the cotton. By this measure of success, the subsurface drip system during both years, and the improved furrow system during 1990, were better than the other systems.

Another measure of success is the volume of agricultural drain water produced by the irrigation system (Table 2). The LEPA system consumptively used water from the shallow ground water table in 1989. Because of the mechanical failure of the LEPA system, the importance of this prediction was discounted. In 1989 the deep percolation from the subsurface drip system was predicted to be 0.16 acre-feet per acre by the DWR. In the same year, deep percolation from the other systems was predicted to be at least 0.61 acre-feet per acre by the DWR. In 1990 the deep percolation from the improved furrow system was predicted to be 0.14 acre-feet per acre by the DWR. In the same year, deep percolation from the other systems was predicted to be at least 0.35 acre-feet per acre by the DWR. By this measure of success, the improved furrow system was better than other systems in 1990, and the subsurface drip system was a close second.

A final measure of success is the bottom line, or the feasibility of the system (Table 3). Boyle Engineering estimated the greatest net economic return to the grower from the subsurface drip irrigation system in 1989 ($268.58 per acre) and from the conventional furrow irrigation system in 1990 ($235.98 per acre). These values do not include costs of a subsurface drainage system, or costs of disposal or treatment of agricultural drain water. The subsurface drip, improved furrow and conventional furrow systems had a positive net economic return both years of the project. The LEPA system was estimated to have a negative net economic return during both years.

In the face of uncertain conditions, the irrigation systems can also be evaluated by the variability between years. The averages and standard deviations presented in Tables 1, 2 and 3 to illustrate this point. The subsurface drip had the smallest variation of applied water and predicted drainage volume, but the largest variation of net revenues. The improved furrow system has the largest variation in applied water, the second largest variation in drainage volume, and the smallest variation in net revenues. Which system is rated 'better' will depend on the focus of the rating (applied water, drainage volume, or net revenues), the purpose of the rating (policy, regulation or implementation) and how uncertainty is viewed.

The results after two years of study indicate that there is potential for changing irrigation technologies to reduce the volume of applied water and the volume of agricultural drain water. The change of irrigation technology requires large initial capital expenses and will probably be resisted by growers on these grounds. However, these changes appear to provide the grower with less water applied, less agricultural drain water and a positive net economic return in the long term.

The results also indicate that there is potential for better management of conventional furrow irrigation systems to reduce the volume of applied water and drain water. Management changes are also expensive because they require capital investment, monitoring of field conditions and possibly more intensive labor for irrigation. Management changes also appear to provide the grower with less applied water, less agricultural drain water and a positive net economic return in the long term.

There are a variety of ways to evaluate the four irrigation systems as noted above. The ranking of the four irrigation systems varies according to the measure used, and varies from year to year. The results do not indicate that one irrigation technology was clearly better than another in all circumstances, and that long term issues will have to be considered in the final evaluation of an individual system.

Table 1
Applied Water by Irrigation System
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Subsurface Drip (AF/Ac)	LEPA (AF/Ac)	Improved Furrow (AF/Ac)	Conventional Furrow (AF/Ac)
1989	1.92	1.68	2.46	2.54
1990	2.00	2.21	1.64	2.40
Average of Two Years	1.96	1.95	2.05	2.47
Standard Deviation	0.06	0.37	0.58	0.10

Table 2
Predicted Drainage Volume [a] by Irrigation System

Year	Subsurface Drip (AF/Ac)	LEPA (AF/Ac)	Improved Furrow (AF/Ac)	Conventional Furrow (AF/Ac)
1989	0.16	-0.16	0.61	0.74
1990	0.37	0.35	0.14	0.77
Average of Two Years	0.27	0.10	0.38	0.76
Standard Deviation	0.15	0.36	0.33	0.02

a. Estimated Drainage Volume = Leaching Requirement + Deep Percolation. This value was predicted by DWR. This is different than the deep percolation predicted by Boyle Engineering for individual irrigation system evaluations (data not shown).

Table 3
Estimated Net Revenues by Irrigation System
(data taken from the Semiannual Reports, Boyle Engineering)

Year	Subsurface Drip ($/Ac)	LEPA ($/Ac)	Improved Furrow ($/Ac)	Conventional Furrow ($/Ac)
1989	268.58	(81.63)	127.65	130.03
1990	46.04	(361.30)	165.59	235.98
Average of Two Years	157.31	(221.47)	146.62	183.01
Standard Deviation	157.36	197.76	26.83	74.92

( ) = a negative return, or loss

GROUNDWATER RECHARGE STUDIES IN A SEMI-ARID URBAN AREA: FRESNO, CA

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As population increases there is a critical need to maintain the quality and quantity of groundwater available for municipal and agricultural use. In areas such as Fresno, California, where municipal uses are entirely dependent on groundwater (sole-source aquifer), the need to maintain water quality and availability is even more critical. One method to augment the supply and improve the quality is through groundwater recharge of high quality surface water.

The City of Fresno recharges surface water through the Leaky Acres Recharge Facility (LARF) and in flood control basins as part of a cooperative program with the Metropolitan Flood Control District. The rights to the surface water are obtained by the City as agricultural land surrounding the city is developed for housing and commercial buildings. Personnel at the Water Management Research Laboratory (WMRL) cooperated with the City of Fresno during the development of LARF by analyzing the quality of the groundwater within and around the recharge facility. The results of ten years of research on the effect of groundwater recharge on water quality, ion transport and water availability will be presented.

Analysis of water quality samples taken from below and down gradient from the 80 ha LARF showed a 100% decrease in the electrical conductivity and 60 and 94% reductions in sodium and nitrates, respectively after 10 years of recharge. The average recharge rate at LARF over a 17 year period was 14 cm d^{-1} for the period which corresponded to the irrigation season, approximately 250 days a year. The average annual volume recharge was 14.9 million m^3 (12,000 ac-ft). The city uses in excess of 86 million m^3 of water a year. Additional recharge occurs in the flood control basins.

A second study was conducted as part of the National Urban Runoff Program (NURP) to evaluate the movement of heavy metals in soils during groundwater recharge in the flood control basins. Basins were selected which drain land use categories including residential, industrial and mixed. The soil, soil water and ground water were analyzed to determine the presence and movement of heavy metals such as arsenic, lead, nickel, and copper.

Statistical analysis of selected soil and aquifer properties and water quality indicated that at sites with rapid infiltration and flow there is lower salinity in the groundwater. Studies of the transport of AS, Ni, Cu and Pb under flooding basins indicted that these elements were accumulating in the first few centimeters of the soil profile and were not being transported to the groundwater. This was true for the basins which received runoff from the industrial as well as the urban land uses.

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EFFICACY TEST OF DRiWATER* A Slow Water Release Substrate

N. B. Dellavalle

DRiWATER*, a poly cellulose gel containing 97.98% water, is a moisturizing substrate made from cellulose gum, alum and aerated water. The substrate which is decomposed by micro-organisms slowly releasing water, is intended for use on house plants, other container grown plants and newly planted trees and shrubs as a substitute for frequent or costly watering. The manufacturer's label claims that the substrate will water plants for 30 days, will save time and water, and eliminate over watering. A test to determine the efficacy of the poly cellulose and to verify label claims was conducted. Four replicates of two rates of water, three rates of the substrate and an unirrigated check were applied to azaleas, Rhododendron indicum, in one gallon pots. Poly cellulose treated plants were maintained through a four week period. The gel disappeared over a 3 to 4 week period. Irrigated plants grew well. Efficacy of and claims for DRiWATER* were substantiated.

*DRiWATER is a patented product of DRiWATER, Sebastopol, California.

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ACIDIFICATION AND NUTRIENT DEFICIENCIES OF BARREN AREA SOILS IN MIXED CONIFER FORESTS, NORTHERN CALIFORNIA

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Acidification of barren area soils on mica schist in Trinity National Forest was studied and compared to adjacent soils with coniferous vegetation. Soil solution extracted by centrifugation, N mineralization and nitrification were examined to determine the source of acid production. Vegetation and forest floor samples were analyzed for nutrient concentrations and the total elemental composition of the mica schist was analyzed. Soil solution pH values ranged between 3.7 and 4.2; the dominant cations were H and Al while NO_3 was the dominant anion. Laboratory incubation showed a nitrification rate of 39 mg/Kg in the surface soil for both barren and forested soils over a two week period. The mica schist contained 2200-2800 mg/Kg of NH_4. Nitrification was the source of acid production in these soils and N was supplied from both organic matter and parent material. Coniferous trees invading the barren areas were low in Ca and Mg compared to in the adjacent forested areas. The lack of a nutrient rich forest floor in barren areas results in nutrient deficiencies and prevents reforestation.

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DEVELOPMENTAL CONTROL OF THE DIURNAL WATER BUDGET OF THE GRAPE BERRY

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The diameter of individual berries was measured continuously with electronic displacement transducers in potted 'Zinfandel' and 'Cabernet Sauvignon' vines as well as in field-grown 'Cabernet Sauvignon'. Shoot or cluster transpiration was restricted by bagging with polyethylene film both before and after veraison to determine the relative contributions of these water loss pathways to diurnal berry contraction. Restriction of shoot transpiration reduced diurnal berry contraction by approximately 70% during stage II, but had no effect post-veraison. Restriction of cluster transpiration reduced diurnal berry contraction by approximately 30% during both pre and post-veraison stages. The relative contributions of the xylem, phloem, and berry transpiration fluxes to the diurnal water budget of the fruit were measured in the potted Cabernet Sauvignon. A nearly exclusive role of the xylem was evident during pre-veraison development, whereas the phloem was clearly dominant in the post-veraison water budget.

Post-veraison diurnal measurements of leaf, stem and cluster water potentials in the field-grown Cabernet Sauvignon revealed a continual gradient favoring stem-to-cluster water flux. Nevertheless, afternoon fruit contraction was evident during this period.

The amplitude of diurnal contraction post-veraison was markedly diminished with respect to the pre-veraison contraction in both potted and field-grown vines. Additionally, the amplitude of pre-veraison diurnal contraction increased dramatically with decreasing plant water status, but the diurnal volume changes in post-veraison fruit were insensitive to low vine water status. These results indicate that diurnal volume loss in the ripening fruit may be predominantly a result of berry transpiration rather than a result of diurnally-reversing water flux from fruit to shoot. Short-term resistance of the ripening berry to low vine water status is likely due to dysfunction of the xylem vessels of the peripheral vascular bundles at veraison. Furthermore, harvested fruit size and composition are unlikely to be affected directly by vine water status effects on berry hydration during the ripening period. The impact of post-veraison vine water status on fruit composition is more likely a result of indirect physiological processes than of a dilution or concentration of solutes.

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FULL-SCALE FIELD TESTING AND NUMERICAL ANALYSIS OF THE CAPILLARY BARRIER CONCEPT

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Placing capillary barriers on top of a landfill can prevent recharging water from infiltrating into and through the landfill, thus reducing the risk of contaminating underlying groundwater. A capillary barrier generally consists of two layers of granular material with a sloping interface, and with the fine textured layer overlying the coarse textured layer. Due to capillary forces, recharging water will be stored in the fine layer and will drain laterally rather than infiltrate into the coarse layer. A full-scale capillary barrier was constructed at a field site north of Copenhagen, Denmark. Outflow from the barrier system was measured over a period of four years. Measurements showed that it is possible to laterally drain up to 70% of the water that infiltrates into the upper layer of the barrier. The USDS-model "VS2D" was modified to simulate the associated two-dimensional saturated-unsaturated water flow process. Fairly good agreement between measured and simulated values was achieved.

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PRODUCTIVITY OF LAMB GRAZING SYSTEMS ON SUBCLOVER-SEEDED ANNUAL GRASSLAND

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Information on management effects on the productivity of improved California annual grassland pastures is limited. Our objectives were to compare herbage and lamb (Ovis aries) production in subclover (Trifolium subterraneum L.)-seeded annual grassland under different intensities of continuous and rotational systems of grazing. Grazing systems at three grazing pressures were applied in a factorial arrangement to 12 0.65-ha pastures in a randomized complete block design replicated twice. Targhee lambs grazed pastures from February 28 to May 9 in 1989 and from March 5 to May 1 in 1990. Lambs occupied each of the eight paddocks in a rotation pasture for 1 to 4 days, depending on herbage growth rates. Lamb numbers were adjusted monthly to provide herbage allowances of approximately 41, 55, and 70 kg DM/lamb at high, medium, and low grazing pressures. Season-long average daily gain was unaffected by grazing system or pressure in 1989 (range 0.10-0.17 kg), and in 1990 was higher under continuous grazing (0.24 vs. 0.17 kg) but unaffected by grazing pressure (avg. 0.20 kg). Season-long gain/ha was higher under continuous grazing in both years (1989: 194 vs. 154 kg; 1990: 221 vs. 185 kg), was unaffected by grazing pressure in 1989 (range 163-194 kg), and increased with grazing pressure in 1990 (179 to 223 kg). Results were related to differences among treatment levels in pasture clover content.

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COVER CROP AFFECTS ON CRUST STRENGTH AND SEEDLING EMERGENCE

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Emergence, crust strength, organic carbon, and moisture content were measured and compared among 0, 150, 200 kg/ha N from $(NH_4)_2SO_4$ treatments and oat, oat plus vetch, and vetch winter cover crop treatments. Tomato seedling (Lycopersicon esculentum) emergence rate was delayed in the fertilizer plots relative to the legume cover crop plots. Crust strengths as measured by a soil micropenetrometer were reduced for the legume treatments, and increased with increased fertilizer application rate. Gravimetric water content of crusts did not differ significantly across plots at the time of crust strength measurements. Significant differences in Walkley-Black organic carbon between treatments were related to the nitrogen input from both biological and commercial N which influenced the preceding year's corn (Zea mays) stover yield. The efficacy of three years of leguminous cover crops in a tomato/corn rotation for improving soil physical properties at the time of emergence is shown.

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DESORPTION OF NATURALLY-OCCURRING CADMIUM FROM SOILS USING ACID AND CHLORIDE TREATMENTS

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Cadmium desorption from three South-Coastal California soils naturally high in cadmium was determined in batch experiments as a function of pH, chloride addition and various combinations of pH and chloride addition. Chloride ion increases cadmium solubility by formation of chlorocomplexes. Acidification alone and chlorocomplexation alone increase cadmium solubility but do not remove all of the sorbed cadmium. Combined treatments of lowering pH and adding chloride substantially increase cadmium solubility. Optimum combinations of chloride addition and acidification treatments determined from this study will be used in column leaching studies in order to determine potential effectiveness of the treatments for removing cadmium from the rooting zone.

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SPECIATION OF SELENIUM (Se) IN SOILS

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Methods were developed to determine total soil Se as well as inorganic and organic forms of Se by HPLC with a fluorescence detector. Total soil Se was determined by acid digestion and analysis for a Se IV - DAN complex. Inorganic and organic forms were extracted with 0.1 M NaOH into alkali-soluble and alkali-insoluble forms. Then the alkali extract was fractionated into five fractions: Se(IV, inorganic), Se(VI, inorganic), organic Se with low molecular weight, organic Se with high molecular weight and organic Se in humic acid. Se in the alkali-insoluble fraction was considered to be contained in soil mineral parts and nonextractable organic fraction. In the five Japanese soils which contained 1.6-15% organic carbon, 67% of the total soil Se was in the organic fractions. These findings suggest that organic Se is a significant pool of soil Se.

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RESPONSES OF THOMPSON SEEDLESS GRAPEVINES TRAINED TO SINGLE AND DIVIDED CANOPY TRELLIS SYSTEMS TO NITROGEN FERTILIZATION

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The response of Thompson Seedless grapevines to four levels of N-fertilization (0, 112, 224, and 448 kg N/ha) in combination with two trellis-training systems [one wire Single Curtain (SC) and two-wire Double Curtain (DC)] were studied from 1980 to 1984 at the Kearney Agricultural Center near Fresno, CA. N-fertilization at rates of 112 to 448 kg N/ha increased crop yield and pruning weights of SC vines by 23 to 38% and 42 to 72%, respectively, and of DC vines by 33 to 48% and 73 to 113%, respectively. N-fertilization significantly reduced °Brix and K, but increased titratable acidity (TA), pH, and arginine in berry juice. Averaged over five years and for all N treatments, the DC increased crop yields and pruning weights by 39 and 24%, respectively, compared to the SC. The DC usually reduced the level of sugar, pH, and arginine in fruits compared to the SC, whereas TA usually was not affected by the trellis treatments. Arginine in mature fruit was the best indicator of the N status of a vine, and gave the highest correlation with crop yield.

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EFFECTS OF WATER STRESS ON FLOWERING IN PRUNE

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Regulated deficit irrigation in drip irrigated French prune was found to allow water savings of up to 30% without significant detrimental effects on yield or quality and with some possibly beneficial effects. Plant based measurements (predawn water potentials) were used to assess the levels of stress experienced by the trees. Water deprivation at certain growth stages was found to have an enhancing effect on flowering the following year. This effect appeared to be most pronounced when the trees were stressed during the first half of fruit growth stage II. The increase in flowering was linearly related to the previous season's stress with flower density increasing from 5 blossoms/cm limb circumference, with an average predawn water potential of -0.3 MPa, to 15 blossoms/cm limb circumference, with an average predawn water potential of -0.7 MPa. The spring 1991 results (year 3 of study) will also be discussed.

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SYNCHRONIZATION OF FRUIT SET AND YIELD INCREASE IN *Citrullus lanatus* var. TIFFANY TREATED WITH SOIL-APPLIED AUXIN PRECURSORS

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Research has shown that soil microorganisms can produce secondary metabolites such as plant growth regulators (PGRs) upon application of L-tryptophan (L-TRP) to soil. This field study was conducted to determine the growth-promoting effects of L-TRP and two auxin precursors on the yield of seedless watermelon var. Tiffany. The two intermediates of auxin synthesis were identified in laboratory studies to have an extremely long soil residence time and a large percentage was converted into indole-3-acetic acid (18-24% of auxin derivative applied) in the soils tested. The watermelon seeds were planted May 6, 1991, maintained in a glasshouse and treated with concentrations of PGRs ranging from 10^{-4} to 10^{-10} $\underline{M}$ on May 29, 1991. The treated seedlings were moved into a shaded glasshouse (25°C) to reduce water needs and transplanted into the field on June 4, 1991 and maintained by drip irrigation and fertilized. Three harvests were conducted on August 21, August 27 and September 4, 1991. The best PGR treatments resulted in a total yield increase (kg) of 52, 35 and 38% for the two auxin derivatives and the L-TRP treatments. PGR applications resulted in a synchronization effect on the fruit set of the treated watermelons with 86, 92 and 86% of the seedless melons at physiological maturity at one harvest date for the auxin derivatives and L-TRP applications, respectively. The study found that optimum application rates required to obtain the yield increases were 10^{-9}, 10^{-6} and 10^{-6} $\underline{M}$ for the auxin derivatives and L-TRP, respectively. The two auxin derivatives are presently under patent consideration by the University of California, limiting disclosure of information.

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RECONNAISSANCE INVESTIGATION TO ASSESS THE CONCENTRATION OF URANIUM, MOLYBDENUM, ARSENIC, BORON, AND SELENIUM IN PROMINENT VEGETATION ON THE WESTSIDE OF THE SAN JOAQUIN VALLEY

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Since the discovery of elevated concentrations of selenium in the water, sediments, and biota at the Kesterson wildlife refuge, several studies regarding trace element distribution in the San Joaquin Valley and their potential environmental impacts have been initiated. We conducted a reconnaissance investigation to assess the concentration of boron, selenium, arsenic, molybdenum, uranium and vanadium using inductively coupled mass spectroscopy in prominent vegetation in the San Joaquin Valley. Five sites representing a range of geochemical environments with known differences in trace element concentrations in their soils or shallow ground water were selected for sampling of both cultivated and non-cultivated plants. Concentrations of boron, selenium, arsenic, molybdenum, uranium, and vanadium in soil and tissue will be presented for these geographic areas for a variety of wild species as well as for several crop plants including alfalfa, almonds, cotton, garlic, grapes, onions, tomatoes, and wheat. Interpretations of the wide range of trace element tissue concentrations that have been determined will be discussed.

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FATE OF NITROGEN IN WETLANDS OF HIDDEN VALLEY WILDLIFE AREA

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Levels of NO_3-N in the Santa Ana River, an effluent dominated stream, are near the limit of 10 mg/L established by the regional water quality control board. Before treatment plants will be allowed to increase their discharge, inorganic N levels in the effluents will have to be reduced. A study of a riverine wetland in the Hidden Valley Wildlife Area near Riverside, California was conducted to evaluate the potential of this system for cleanup of effluent from the City of Riverside treatment plant. Four ponds totaling 40 acres are connected in series and maintained with tertiary effluent. The quality and quantity of water moving through the pond system and leaching from the ponds were evaluated during 1990. Of the water entering the system, 37% flowed out of Pond 4, 3% evaporated and 60% infiltrated. Inorganic N concentrations in water leaving the pond system (mean 11.1 mg/L) were greatly reduced compared to the incoming concentrations (mean 16.3 mg/L). Concentrations of inorganic N in water leaching beneath the ponds were very low (mean 3.5 mg/L). Results of a nitrogen balance for the system indicated that 38% of the incoming inorganic N flowed out of Pond 4, 32% was taken up by algae and duckweed or denitrified in the water column and 30% was denitrified in the pond sediments. The results of this study indicate that the ponds established in this wet land ecosystem can be used effectively to reduce the N content of effluent prior to discharge into the Santa Ana River. Secondary benefits of an enhanced habitat for waterfowl are also significant.

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ADDRESSING TEMPORAL AND SPATIAL VARIABILITY OF NATURAL AND MODIFIED SOILS THROUGH MAP UNIT DESIGN

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The current method of mapping modified soils and reporting information about soil properties and interpretations does not meet the needs of soil survey users. The temporal and spatial variability of soils undergoing modification through management needs to be addressed in soil surveys. Alternatives for designing map units for modified soils were identified and compared. A new type of map unit, an undifferentiated association, is proposed. This map unit provides a categorical means of identifying areas with ongoing soil modification, thus solving a cartographic problem. It recognizes spatial variability in soil properties that are use-dependant and therefore a function of time. It consists of a natural soil component and a modified soil component, and it can address irreversible or reversible modifications. It provides useful properties and interpretations for both the natural soil and the modified soil.

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EFFECTS OF VARIOUS CROP WATER STRESS INDEX LEVELS IN GRAPEVINES ON YIELD, TIME OF FRUIT MATURITY, AND VEGETATIVE GROWTH

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For many years, grape growers have been allowing their vines to become water stressed as a means of advancing fruit maturity. However, in the past it has been difficult to stress vines effectively because of problems in quantifying water stress. In the past five years, the development of the infrared thermometer and the method of calculating the Crop Water Stress Index (CWSI) has finally produced a practical method of taking reliable, plant-based measurements of water status. A trial was begun at California State University, Fresno on drip-irrigated Thompson Seedless in 1989. The vines were held at predetermined CWSI levels after veraison by cutting off the irrigations when the daily measurement of the CWSI fell below a certain value. This procedure proved to be remarkably effective in maintaining a constant level of water stress in the vines. Results after the first year indicate that yield, berry size, and soluble solids were not significantly affected in the stressed treatments, while shoot growth was significantly decreased.

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REDUCING LETTUCE CORKY ROOT SEVERITY BY USE OF TRANSPLANTS

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Corky root (CR) of crisphead lettuce, a widespread disease in California coastal valleys, is caused by Rhizomonas suberifaciens. CR severity was reduced on roots of transplants, compared to those of directly-sown plants, in greenhouse, field microplots and production field experiments. Reduction of disease severity was associated with increased yield in lettuce crops with relatively high levels of CR but not in those with low CR severity. CR severity increased with time of exposure of plants to R. suberifaciens and decreased with plant age at time of transplanting. In some situations, CR is so severe that production of directly-sown lettuce is seriously limited. Transplants can provide lettuce growers an alternative method to reduce the impact of CR on production by reducing time of plant exposure and plant susceptibility to CR.

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WATER AND SEDIMENT QUALITY SURVEY OF SELECTED INLAND SALINE LAKES

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The accumulation of certain trace elements in agricultural drainage water evaporation basins in the San Joaquin Valley, CA is of concern. A water quality survey was conducted on 15 inland saline sink lakes in the western United States to determine if such accumulation occurs under natural conditions and to what level. The natural salt lakes varied greatly in mineral and trace element concentrations and in almost all instances showed concentrations less than those found in the evaporation basins. The inland salt lakes did not appear to show the extent of salt buildup found in the evaporation basins. Although showing a significantly lower trace element concentration, the natural salt lakes displayed a characteristic similar to the evaporation basins in that they showed trace element accumulation at concentrations higher than seawater. This accumulation was greatest for arsenic, boron, molybdenum, uranium and vanadium.

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TURF MANAGEMENT EFFECTS ON GENETIC STRUCTURE AND ADAPTATION OF GOLF COURSE *POA ANNUA* POPULATIONS

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Golf course ***poa annua*** populations located along a gradient of different intensities of turf irrigation and mowing practices were studied for characteristics of seed dormancy and seed bank, effects of light conditions and growth regulators on dry weight partitioning, and genetic differentiation and adaptation of life history traits. A large genetic component of variation of various vegetative and reproductive traits indicates rapid genetic differentiation has been taking place among the populations at the micro-ecological level. Plants from dry and low-maintenance conditions show annual characteristics, whereas plants from wet and high-maintenance conditions show perennial characteristics. Effects of light and growth regulator treatments indicate different responses between annual and perennial biotypes. This information is of value for ***Poa annua*** control and management.

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