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CALIFORNIA PLANT and SOIL CONFERENCE

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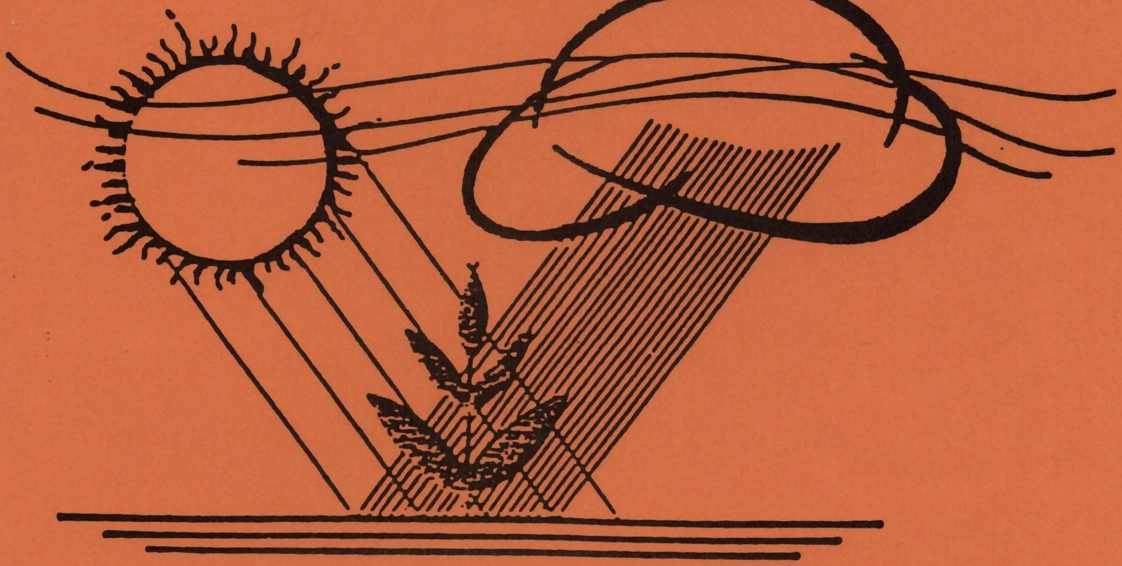

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COTTON PHYSIOLOGY EDUCATION PROGRAM
National Cotton Council

January 31 - February 1, 1990
Hilton Hotel
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ECONOMIC FACTORS RELATED TO OPTIMAL IRRIGATION

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Agricultural production is a business operation motivated by goals of producing food and fiber and generating a profit. Irrigation is a vital complement of the agricultural operation in arid and semi-arid regions of the world, particularly in California. Optimal irrigation is defined here to be irrigation that leads to maximum profit to the farmer.

Economists require quantitative relationships between various inputs and outputs in the production system in order to compute optimal irrigation. The relationship between the amount of applied irrigation water (AW) and yield is of paramount importance. In general, increasing AW results in increasing yields up to a point after which additional amounts of AW no longer increases yields and might possibly decrease yields if waterlogging or excessive nutrient leaching is caused. Unfortunately, no unique relationships between these two variables occur. The relationship may be depicted by several curves depending upon various factors.

Uniformity of irrigation significantly affects the shape of the curve. Some degree of non-uniformity occurs under any irrigation technology and/or management practice where some parts of the field receive more water than other parts of the field. Therefore, some "over irrigation" and "under irrigation" can occur in the same field at the same time. The general effect is that increasing amounts of AW are required to achieve the same yield with decreasing irrigation uniformity.

Irrigation to achieve high yields is virtually impossible without at least a small amount of water percolating below the root zone. The economic consequences of deep percolation to the farmer is dependent upon the drainage situation. If the water percolates freely through the subsoil strata, the only cost imposed on the farmer is the cost of the applied water which percolated below the root zone. For this case, the relationship between AW and yield is adequate to determine the optimal value of AW. Water is applied up to the level when the cost for additional water is not compensated by an additional increase in yield.

Many irrigated lands have water tables that are sufficiently high to impact crop yield if they are not controlled by a subsurface drainage system. Under these conditions, the economic analysis must consider the cost for drainage water disposal. This analysis requires a quantitative relationship between AW and deep percolation. As was the case for the relationship between AW and yield, there is no unique relationship between the two variables. As before, irrigation uniformity is a significant determinant on the shape of the curve. In general, the amount of deep percolation for a given AW value increases as the irrigation uniformity decreases.

The economic consequences of irrigation uniformity are two-fold. Decreasing uniformity leads to decreasing yields for a given value of AW. Since income is associated with crop yield, decreasing irrigation uniformity leads to decreasing income. Secondly, decreasing irrigation uniformity leads to increasing drainage volumes and therefore increasing cost. The effects of non-uniform irrigation on yield can be partially or completely overcome by applying more water. However, applying more water leads to more deep percolation and the effects of non-uniform irrigation on deep percolation costs become magnified by increasing water application. Drainage water disposal costs, therefore, impose a significant management constraint on the farmer.

Irrigation uniformity can be altered by changing irrigation technology and/or management. The switch in irrigation management and technology leading to improved irrigation uniformity imposes a cost to the farmer. The cost associated with improving irrigation technology must be offset by increased income from higher yields and decreased cost from drainage water disposal.

Switching irrigation technology should lead to some change in other management practices. For example, a subsurface drip irrigation may require much less weed control than furrow irrigation. In determining the economic cost of various irrigation technologies, the total management package must be considered. Considering only capital costs for the change in technology is not adequate. One must review all of the various management practices which will be altered with their associated costs and/or benefits.

The economic analysis leading to optimal irrigation is straightforward. The main shortcoming in making accurate economic analysis is inadequate and uncertain input data. For example, irrigation uniformity is a critical factor. Yet, appropriate means for characterizing or measuring irrigation uniformity in a form suitable for crop production analysis are not well developed. Irrigation uniformity for furrow irrigation systems are commonly determined by flow advance rate curves. This analysis determines the non-uniformity associated with opportunity time. Opportunity time refers to the fact that water is on the upper part of the field for a longer period of time than the lower part of the field, thus has greater time for infiltration. Non-uniformity associated with opportunity time may represent one-half or less of the non-uniformity within the field caused by spatial variability and infiltration characteristics of the soil. Soil texture and structure are not uniform across most fields and these variabilities lead to different infiltration rates.

It is beyond the scope of this presentation to outline all of the shortcomings and difficulties associated with measuring irrigation uniformity for various irrigation technologies. It must be noted, however, that this is a critical factor in the economic analysis and without it considerable uncertainty exists in the economic conclusions.

Many irrigation technologies such as subsurface drip, LEPA, linear move sprinkler, etc., have not been extensively used in the western part of the San Joaquin Valley. Thus the total management package associated with each irrigation technology has not been adequately developed. This also leads to uncertainty in the associated cost for the various technologies. Capital costs for installing systems may be fairly accurately determined but alterations in other management practices are ill-defined.

Various irrigation technologies are now being demonstrated in the western San Joaquin Valley. Crop yields are easily measured so that an evaluation of the relationship between irrigation technology and yield can rather easily be made. Unfortunately, determination of deep percolation is very difficult if not impossible to quantify. Thus, one of the significant factors in the economic analysis is still lacking from the demonstration projects. Where drainage disposal costs are high, the effects of irrigation technology on altering deep percolation may be far more significant than their effects on yields.

Water is a valuable resource which has utility for agricultural and urban uses. Generally, the water uses for urban or have a higher monetary value than for agricultural production. The cost for upgrading irrigation technology which might lead to less water application by a farmer may not be offset by the benefits achieved particularly if one only considers the value of the "conserved" water. On the other hand, a municipality may be able to afford the cost for improving irrigation which results in less water application thus making some available for the municipality. The agreement between the Metropolitan Water District of Southern California and the Imperial Irrigation District is an example whereby urban water users could afford to finance cement-line leaking irrigation ditches carrying waters to fields in exchange for the water conserved. The value of that water to the agricultural community could not justify the expenditures for cementing the ditches. This program does not affect the amount of water available to the farmer for irrigation, but raises the question as to whether similar arrangements might be advisable on the farmer field level. For example, could municipal water users afford to finance upgrading irrigation technology on the farm in exchange for the water savings for the conserved water. Letey and Dinar (1989) investigated the water marketing effects on crop-water management. The analysis suggested that a water market price somewhere between $60 and $95 per acre foot would induce a shift in irrigation technology decreasing water application and making some water available to the urban sector. At the same time, the farmers' profits would equal or exceed those without water marketing. Legal, political and implementation barriers, however, must be overcome before a water marketing system consistent with this analysis could be adopted.

The farmer faces a large array of factors affecting their optimal irrigation practice. In some cases, accurate quantitative data for the accurate economic analysis is not adequate. Research and field demonstrations presently underway hopefully will provide additional important information upon which sound economically beneficial irrigation management practices can be adopted.

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AN INCREASING BLOCK-RATE PRICING PROGRAM TO MOTIVATE WATER CONSERVATION AND REDUCE SUBSURFACE DRAIN WATER

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Dennis Wichelns, Assistant Professor, University of Rhode Island

Preparing for the 90's - Drainage Reduction through Water Conservation

Nineteen ninety begins a new era for the districts in the Grassland Basin that drain to the San Joaquin River. The California Regional Water Quality Control Board has established water quality objectives for the discharge of drainage water to the river. Broadview Water District is attempting to reduce drainage discharge through water conservation by implementing an increasing block-rate pricing program.

The Broadview Water District has recently completed its first full crop year under the increasing block-rate pricing program for irrigation water (tiered water pricing). The final irrigations on cotton, late season melons, alfalfa hay, and rice were applied in September. Irrigations on tomatoes, alfalfa seed, lima beans, and mid-season melons were concluded in July and August. Preliminary analysis of irrigation and drainage data for the 1989 crop year suggests that the tiered pricing program has been successful in motivating important reductions in applied water depths for some crops, and in reducing the volume of subsurface drain water generated by irrigations.

The tiered pricing program, implemented on October 1, 1988, included a set of crop-specific tiering levels that describe the amount of water available at $16 per acre foot. Additional water was available at the higher price of $40 per acre foot. For example, cotton and tomato fields were allowed 2.9 acre feet per acre at $16 per acre foot, while melon fields were allowed 1.9 feet and sugar beet fields were allowed 3.9

feet at the lower price (Table 1). Tiering levels for barley and wheat were 1.7 feet and 2.1 feet, respectively.

Tiering levels used in the pricing program during the 1989 crop year were determined by reducing crop-specific three-year average irrigation depths in Broadview, by 10 percent. This approach provided a historical basis for selecting the tiering levels and, therefore, incorporated crop water requirements, soil characteristics, and irrigation practices that are relevant in the Broadview Water District. Average irrigation depths for the six major crops, during 1986 through 1988 range from 2.06 feet on alfalfa seed to 4.58 feet on sugarbeets (Table 2). The three-year average for cotton and tomatoes was 3.2 feet. Tiering levels for crops not grown recently in Broadview, such as safflower, alfalfa hay, and rice, were based on irrigation data from an adjacent water district.

Irrigation Summary

Irrigation practices observed during the 1989 crop year indicated that farmers responded positively to both the spirit and the technical detail of the tiered water pricing program. Farmers displayed increased interest in irrigation volumes, throughout the season, and shared information regarding irrigation strategies and potential effects on crop yields. Several farmers worked with irrigation consultants to schedule irrigations, while they and others implemented improved irrigation practices including shortened furrow lengths, reduced set times, and alternate-furrow application, during some irrigations.

Applied water was reduced on tomato, melon, and sugarbeet fields in Broadview in 1989, while average water applications increased on cotton and wheat fields (Table 2). The average cotton and wheat irrigation depths of 3.34 feet and 3.02 feet were higher than those observed during any of the three previous years. The average applications on tomatoes (2.72 feet), melons (1.93 feet), and sugarbeets (3.73 feet) were lower than those observed during any of the three previous years. Crop-specific examination of irrigation practices and seasonal weather conditions is required to gain useful insight into the farm-level responses to tiered water pricing and the potential for motivating water conservation and reducing subsurface drain water.

Drainage Summary

The goal of Broadview's tiered water pricing program was to motivate water conservation practices that reduced farm-level generation of subsurface drain water. Preliminary analysis of drain water volumes collected in district tile drain sumps during the 1989 crop year suggests that the program has been successful in this effort. Drain water volumes were reduced below the average volume collected during 1986 through 1988 at 15 of 25 drainage systems sumps. Twelve drainage systems produced less water than the volume collected during the 1988 crop year. Reductions at individual drainage systems between 1988 and 1989 ranged from 5.3 acre feet (4.1%) to 181.0 acre feet (23.4%).

The total volume of drain water collected in Broadview sumps in crop year 1989 was 249.5 acre feet (6.3%) less than the three-year average annual volume, but 108.7 acre feet (3.0%) greater than the volume collected in 1988. Four drainage systems were expanded in size between 1988 and 1989. A fifth system displayed an unexplained 55% increase in drain water, following a 128% increase between 1987 and 1988. The Broadview cropping pattern in 1989 included more acres of crops that tend to produce large volumes of drain water and fewer acres of crops that tend to produce smaller volumes of drain water, than were grown in

1988. For example, the area planted in cotton, tomato, and rice increased by 300, 170, and 178 acres, respectively, between 1988 and 1989. Sugarbeet and melon planting declined by 304 acres and 256 acres. The total volume of drain water collected in Broadview sumps increased by only 108.7 acre feet (3.0%) in 1989, despite this change in the district's cropping pattern and the increased size of four drainage systems.

Further evidence of reduced drain water generation is provided by examining drain water volumes collected by a subset of Broadview sumps. The subset is formed by eliminating from calculations the four drainage systems that were expanded between 1988 and 1989 and the one that has shown exceptional increases in volumes for the past three years. The remaining 20 drainage systems collected a total volume of 3,057.9 acre feet in 1988 and 2,706.8 acre feet in 1989. The three-year average annual volume for this subset is 3,520.7 acre feet. The volume of drain water collected by these 20 sumps in 1989 was 813.9 acre feet (23.1%) less than the average annual volume and 351.1 acre feet (11.5%) less than the volume collected in 1988.

Tiered Pricing Summary

The unexpectedly large irrigations on cotton and wheat fields generated concern among farmers and district personnel that the tiered pricing program had created excessively large surcharges, despite legitimate efforts to improve irrigation practices. It was suggested that irrigations on cotton and wheat were driven above averages observed in the three previous years by reductions in winter rainfall and high evapotranspiration (ET) rates in spring and summer. These conditions did not appear to affect melons and tomatoes in the same way, as irrigations on these crops did not exhibit a similar across-the-board increase in irrigation depths.

One of the concerns regarding equity of the tiered pricing program was that farmers with light-textured soils would pay larger surcharges than farmers with heavy-textured soils, because it is difficult to reduce applied water volumes on the lighter soils, when using furrow irrigation methods. Soil-related differences in irrigation depths may be even more pronounced during high ET years, as lighter soil have less water holding capacity than heavier soils. An adjustment in the tiered pricing program was desired to account for soil-related differences in the farm-level costs of reducing applied water volumes and the unusual growing seasons for cotton and wheat.

The median irrigation depth on cotton fields was 3.45 feet in 1989, or 0.55 feet above the tiering level. Inspection of field-specific irrigation depths revealed that fields above and below the median included both light soils and heavy soils. This suggested that farmers with lighter soils were able to reduce applied water volumes to the median observed for the district, on fields where some effort was made to improve irrigation practices. At the same time, many farmers with light and heavy soils remained above the median irrigation depth for cotton.

It appears as if the tiered water pricing program was successful in reducing subsurface drainage. As a result, the Board of Directors has voted to renew the tiered water pricing program for the 1990 crop year, retaining the orginal tiering levels for all crops. Field-specific irrigation, drainage and yield data will be collected throughout the year.

Table 1. Crop-specific tiering levels in Broadview Water District's tiered water pricing program, 1989

Crop Type	Tiering Level
	(Feet)
Cotton	2.90
Tomatoes	2.90
Melons	1.90
Wheat	2.10
Barley	1.70
Sugarbeets	3.90
Seed Alfalfa (New)	2.70
Seed Alfalfa (Established)	1.90
Dry Beans	2.20
Safflower	2.90
Alfalfa Hay	4.50
Rice	5.10

Table 2. Crop-specific average irrigation depths for major crops in the Broadview Water District, 1986 through 1989

Crop	1986	1987	1988	86-88 Average	1989	1989 vs Average
			(Feet)			
Cotton	3.21	3.13	3.27	3.20	3.34	+
Tomatoes	3.21	3.29	3.15	3.22	2.72	-
Melons	2.15	1.99	2.20	2.11	1.93	-
Wheat	2.01	2.55	2.35	2.30	3.02	+
Sugarbeets	5.01	3.81	4.92	4.58	3.73	-
Alfalfa Seed	2.13	2.24	1.80	2.06	1.84	-
Rice	5.72	5.24	5.99	5.65	5.40	-

Note: Rice irrigation data for 1986 through 1988 are from Firebaugh Canal Water District.

ECONOMIC RESPONSE OF WALNUTS TO IMPROVED WATER MANAGEMENT

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Robert H. Beede, U.C. Farm Advisor, Kings County

INTRODUCTION

Research has established the average water requirement (ET) of mature, healthy walnuts at 42 inches per season under clean cultivated conditions. Seasonal climatic conditions can affect this actual water use by about 10 percent. A cover crop increases seasonal water use by as much as 25 percent. Failure to apply the correct amount of water at the proper time adversely affects orchard health, production and longevity.

Goldhamer et.al. showed several adverse effects of sustained underirrigation on walnuts. After one season, trees supplied with only 66 percent of ET had reduced canopy and trunk growth; yield was slightly reduced the first year due to smaller nut size. After the second year, the trees showed a 16 percent yield reduction due to lost growth and nut size. Yield was further reduced by 34 percent the third year of sustained stress. This reduction was attributed to reduced vegetative growth that resulted in fewer fruiting positions per tree. Other undersirable effects associated with underirrigation include increased mite susceptibility, sunburn and kernel discoloration, premature postharvest tree defoliation that interupts carbohydrate storage and increased incidence of shallow and deep bark canker in susceptible varieties.

Overirrigation is of concern, on orchard soils characterized by slow water infiltration. Applying too much water per irrigation or irrigating too frequently causes standing water and low soil oxygen. Three to four days of standing water can kill feeder roots and increase disease potential; the sudden collapse of otherwise healthy walnuts has been associated with low soil oxygen in hot weather. Overirrigation can also restrict orchard access at critical pest management periods, thus reducing yield and quality due to disease or insect damage. Lastly, excess irrigation contributes to unnecessary energy and labor costs.

This study was designed to demonstrate sound irrigation practices already developed and validated under more controlled research conditions. The objectives of this study were three-fold: 1) to document existing on-farm irrigation management practices in walnuts 2) to implement changes in irrigation practices if appropriate and 3) to document orchard responses to changes in water management.

STUDY PROCEDURES

A 27 acre Serr walnut orchard (30 x 30 foot spacing) was selected in 1983 as a long term study site. The orchard had been established for eleven years on the Nord Complex fine sandy loam soil series. A border check flood irrigation system with one valve per check was used. Check length was 600 feet with a dead level slope across the borders and 0.03 percent grade down the check. Surface irrigation water was provided from the Kings River with supplemental water from shallow wells. Annual grass and broadleaf weeds were controlled by mechanical mowing.

Data collection during the 6 year study included irrigation dates, assessment of the soil water holding capacity and an evaluation of irrigation application rates. Percent soil moisture depletion prior to each irrigation was estimated using neutron probe sites and the water balance method. Cultural practices such as fertilization and pruning were recorded to assist in isolating the impact of future irrigation practices on orchard performance. Orchard performance was assessed on a per acre basis using overall yield and nut quality records. Production and quality parameters were then compared to average regional production records for each year of the study. During 1983, the existing irrigation program was unchanged to establish a baseline. In 1984, modifications were implemented and maintained through the 1988 season.

RESULTS

ORIGINAL IRRIGATION MANAGEMENT

The unchanged irrigation management practices for 1983 are presented in table 1. Net water supplied to the orchard in 1983 from stored soil moisture, spring rainfall and 5 irrigations during the growing season was 26.65 inches. Estimated ET for the same period was 45.54 inches indicating that only 58 percent of the water requirement was met. Figure 1 shows the estimated soil moisture depletion throughout the 1983 season. The 54 day interval between leafout and the first irrigation reduced the available soil moisture to 25 percent of field capacity. The slow water infiltration characteristics of the orchard soil and infrequent irrigation scheduling created sustained dry soil moisture conditions in the orchard from early June to the end of the season.

OTHER CULTURAL PRACTICES

Other important cultural practices impacting orchard health and performance were monitored over the six year study. Nitrogen fertilization ranged from 132 to 155 pounds per acre. Insect damage was consistently low throughout the study. Pruning costs increased when irrigation practices were changed. Actual hours invested in pruning ranged from 0.0 hours per acre in 1983 to 6.5 and 6.0 hours per acre in 1986 and 1987, respectively.

MODIFICATIONS TO ORIGINAL IRRIGATION PRACTICES

Irrigation Scheduling

The primary changes focused on improved irrigation scheduling thoughout the season. Irrigations were scheduled by using real time grass reference evapotranspiration (ETo) in conjunction with specific crop coefficients for walnuts to estimate weekly water use. Water was applied when the accumulative evapotranspiration approached 4.0 inches since the last irrigation (about 50 percent depletion of the available soil moisture). Table 2 compares the unchanged irrigation schedule used in 1983 to the irrigation schedules used in 1984 - 1988. One irrigation was applied before leafout in four out of five years of modified irrigation scheduling. Winter rainfall appeared insufficient to refill the root zone, particularly during consecutive winters of low rainfall. Irrigation scheduling was also compromised in mid August to allow adequate drying and preparation of the orchard floor for harvest. A post harvest irrigation was routinely practiced.

System Operation

Operation of the irrigation system was not changed as significantly as the scheduling. Application times were reduced from about 10 hours to 2.5 hours per set and inflow rates were higher to increase advance time and improve control over the amount of water applied. Prompt shut-off of inflow was the most important operational concern to avoid applying excess water and prolonging standing water.

RESPONSES TO CHANGES IN IRRIGATION MANAGEMENT

Soil Moisture Regime

Figure 2 compares the effect of increased irrigation frequency in 1987 to the original management in 1983. In 1987, soil moisture was maintained more consistently near 50 percent of field capacity than in 1983 until the irrigation schedule was compromised for harvest preparation. Fluctuations in soil water content were not as extreme under 1987 management compared to 1983. Prompt postharvest irrigation improved the soil moisture regime compared to the 1983 season. In general, 1987 management practices provided more consistent and abundant water to the orchard. Similar soil moisture regimes were observed for the other seasons when modified irrigation schedules were used.

Orchard Response

Figure 3 shows that from 1982 through 1984 the dry in-shell yield for the orchard ranged from 1.1 to 1.7 tons per acre; this was about 2 to 27 percent less than the Kings-Tulare regional average for the Serr variety. In 1985, after two years of improved irrigation management, dry in-shell yields ranged from 1.85 to 2.25 tons per acre, a 31 to 75 percent increase above the regional average. The nut quality indices of edible yield, reflected light index (RLI), and percent offgrade were also monitored. Figure 4 shows that edible yield was 1.0 to 4.0 percent below average from 1982-1984. After modifying the irrigation practices, edible yield improved slightly to nearly equal the regional average. Figure 5 compares reflected light index, a measure of walnut meat color; it ranged from 1.0 to 3.0 percent below average before changes in irrigation and was equal or slightly above the average afterwards. Offgrade for the commercial orchard was below average irrespective of irrigation practices. Overall, nut quality showed only a slight increase as irrigation practices changed, but more importantly good nut quality was maintained while production increased substantially.

Profitability

Total water applied in the orchard under modified management increased an average of 2.4 acre-feet per acre over previous seasonal applications. Labor for irrigation approximately doubled due to more frequent scheduling. Assuming a water cost of $25.00 per acre and an increase from 6 hours labor to 12 hours labor per acre ($6.50 per hour), increased costs of improving irrigation management was estimated at $100.00 per acre. Pruning costs increased about $120.00 per acre due to increased tree growth. Total added costs related to modifying the irrigation practices from 1984-1988 were about $220 per acre.

Nut quality was sufficient to qualify for in-shell market prices. Assuming a market price of $0.45 per pound, added value from improved yields for the period of 1985 -1988 averaged $650.00 per acre above that for 1982 - 1984. Net return to improved water management averaged about $430 per acre. It appears that it was therefore profitable to modify the original irrigation practices.

FURTHER STUDIES

ADDITIONAL FIELD MONITORING

Recognizing the site specific nature of the findings from this long term study, two more commercial walnut orchards were monitored during the 1989 season. The purpose was to determine if the irrigation practices used in other commercial orchards were similar to the original practices observed at the first site. The same methodology used in the long term study was applied to monitor the irrigation practices at the new site.

One site (#2) was a 15 acre mature Hartley walnut orchard located on a Grangeville fine sandy loam, partially drained saline soil. The other site (#3) was a 9 acre mature, Hartley orchard located on the Grangeville fine sandy loam soil series with good drainage. Both orchards were planted on a 30 by 30 foot tree spacing. A border check flood system was used at both sites. At site #2, one valve per check was used to irrigate the trees, whereas, at site #3 one valve supplied water to two checks. Border length was 600 feet with near level slope across the checks and an average of 0.025 percent slope down the checks at both sites. Site #2 was irrigated with good quality shallow well water. The primary source of water at site #3 was from the Kings

River supplemented with shallow well water. Both sites were grown under clean cultivated orchard floor conditions.

Original Irrigation Schedules

Table 3 provides the observed irrigation schedules during the 1989 season Site #2 received 1 irrigation before leafout and 5 in-season irrigations before harvest. Total irrigation water applied per acre was 27.70 inches. Site #3 received 7 irrigations, 6 before harvest and 1 irrigation postharvest. Total irrigation water applied was 22.6 inches per acre. Estimated ET for mature, healthy walnuts grown under clean cultivated conditions was 38.3 inches in 1989 from leafout to leaf drop. Therefore, sites #2 and #3 were only supplied about 72 and 59 percent, respectively, of their full water requirements. The irrigation schedules and levels of underirrigation observed at these sites were similar to the original practices observed at site #1.

Soil Moisture Regimes

Figure 6 shows measured soil moisture depletion patterns in 1989 for orchard site #2. The effective root zone was estimated to be 4.0 feet. Neutron probe readings taken between 5 and 9 feet were not included in the calculation of soil moisture depletion because a perched, saline water table was present at 6.0 feet; root activity appeared minimal in the 4-5 foot zone because of low oxygen and ECe values in excess of 6.0 ds/m. Four of the six irrigations were applied between March 10 and June 14 resulting in relatively good early-season soil moisture for shoot growth and nut size. However, the two remaining irrigations in July and August represent severe deficit irrigation during the period of maximum water use. Figure 7 shows measured soil moisture depletion patterns for site #3 in 1989. Soil moisture depletion was much greater than 50 percent at the onset of the season. Slow water infiltration and infrequent irrigation subjected this orchard to highly depleted soil moisture conditions throughout the season. The soil moisture depletion patterns at both orchard sites in 1989 resembled the pattern observed at the Serr orchard before modification of irrigation management.

CONCLUSIONS

ON-FARM APPLICATIONS

The long term study conducted from 1983-1988 demonstrates opportunity to improve on-farm irrigation practices in walnuts and realize a profitable production response. Improved irrigation scheduling in conjunction with better application techniques provided a consistent and abundant supply of soil moisture for walnut growth and production. The additional studies in 1989 show the opportunity to improve irrigation management was not unique. It is likely this opportunity to improve ongoing irrigation practices exists in many walnut orchards.

Research Needs

This study demonstrates that irrigation research can have on-farm applications. However, adaptability is very site specific. The likelihood of an economic response to improved irrigation management in walnuts is complicated by the following factors that are not presently and clearly understood: 1) stage of orchard health which recovery from improper irrigation is probable; 2) strategy for phasing in improved irrigation practices on declining orchards that may not be using water at a rate comparable to a healthy, well watered orchard; 3) interaction between improving irrigation practices and pruning to stimulate tree growth; and 4) improving irrigation practices for different walnut varieties.

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Table 1. Records of stored soil moisture, rainfall, and irrigations in 1983 for Kings County Serr Orchard (site #1).

	Applied Water (inches)			
Date	Stored Winter Rainfall	Spring Rainfall	Net * Irrigation	Cumulative
3/30	6.10			6.10
4/18-4/30		0.55		6.65
5/24			4.60	11.25
6/26			3.44	14.69
7/15			2.92	17.61
8/4			3.52	21.13
8/27			2.88	24.01
9/21-9/30		2.29		26.30
10/5		0.35		26.65

* Net irrigation calculated based on 70 percent uniformity of applied water.

Table 2. Comparison between 1983 irrigation schedule and modified schedules used from 1984-88 at Serr walnut orchard site in Kings County.

Irrigation #	1983	1984	1985	1986	1987	1988
1	5/24	3/21	3/13	5/1	3/3	2/16
2	6/26	4/24	4/19	5/23	4/10	4/2
3	7/15	5/18	5/14	6/7	4/30	5/7
4	8/4	6/3	6/6	6/13	5/17	5/28
5	8/27	6/21	6/25	6/27	5/31	6/15
6		7/3	7/2	7/11	6/13	6/28
7		7/24	7/25	7/28	6/26	7/13
8		8/11	8/11	8/15	7/10	7/26
9		10/3	8/26	9/13	7/23	8/8
10			9/28		7/29	9/12
11					8/13	10/10
12					9/29	
Total Irrigation Water Applied (inches)	21.70	41.0	56.4	45.9	62.8	50.6

Table 3. Irrigation schedules observed in two Hartley walnut orchards during 1989 in Kings County.

Irrigation #	Site #2	Site #3
1	3/15	4/10
2	4/23	5/8
3	5/17	6/4
4	6/13	6/24
5	7/9	7/15
6	8/14	8/13
7	---	11/1

FIGURE 1. Average soil moisture depletion for the 1983 season under grower management (estimated using water balance method).

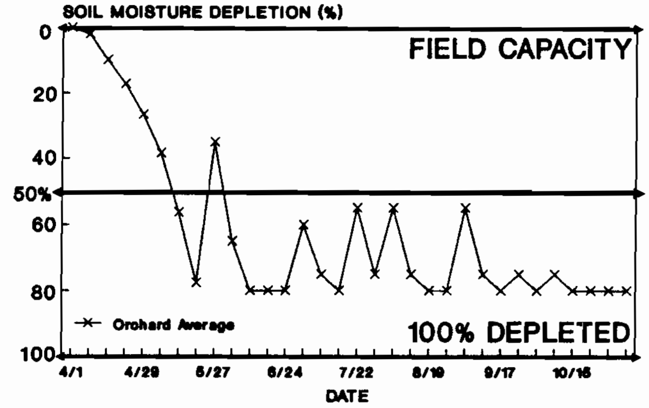


Figure 2. Comparison seasonal soil moisture patterns for 1983 versus 1987 at site #1.

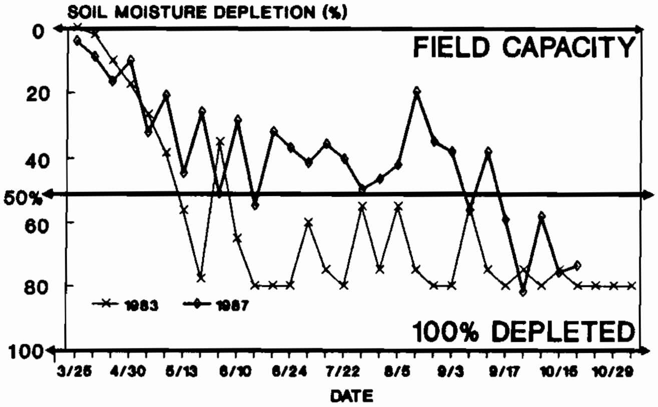


Figure 3. Yield Response: regional Serr average versus commercial orchard.

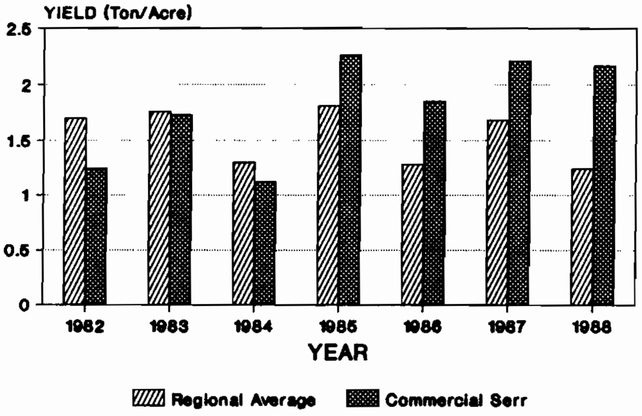


Figure 4. Edible Yield: regional Serr average versus commercial orchard.

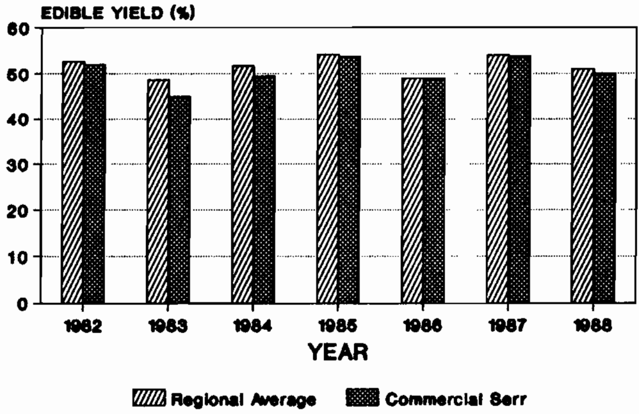


Figure 5. Reflected Light Index: regional Serr average versus commercial orchard.

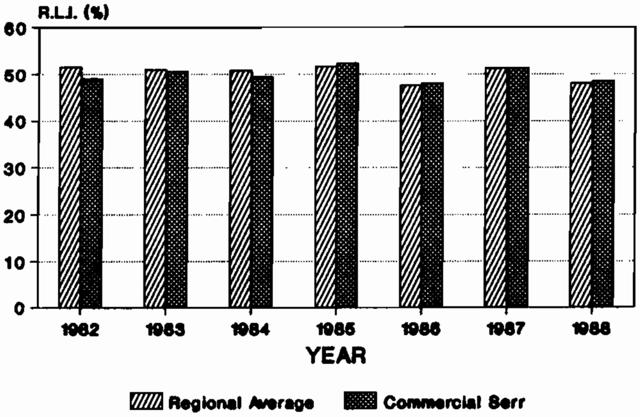


Figure 6. Average soil moisture depletion for the 1989 season under grower management at site #2 (measured to four foot depth).

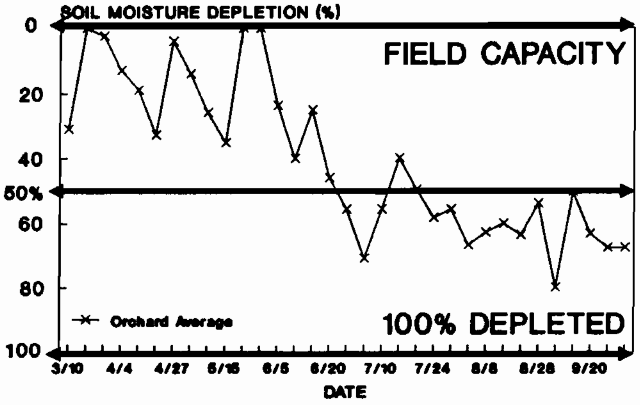
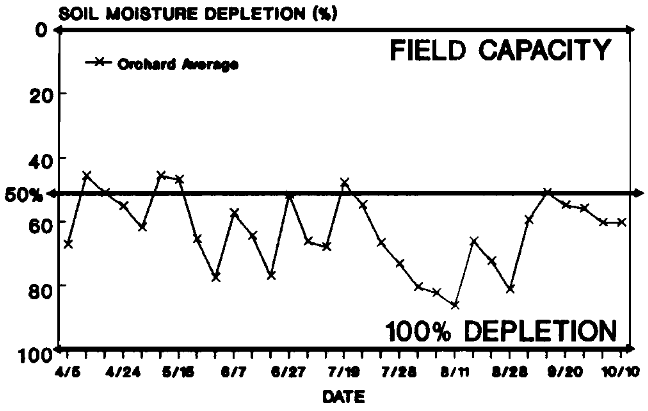


Figure 7. Average soil moisture depletion for the 1989 season under grower management at site #3 (measured to nine foot depth).



IMPROVING IRRIGATION EFFICIENCY OF BORDER IRRIGATION

Larry J. Schwankl, Irrigation Specialist, UC Davis

Efficiency of water use, which is a measure of the beneficially-used portion of total water used, has been given increased attention. This attention has been focused both on the urban and agricultural sectors, but because of its major role in the state's water use agricultural has received the predominance of the attention. Three factors which have centered this attention on agricultural water use include: the drainage problem in the San Joaquin Valley, limited water supplies and increased demand by urban sectors, and the Bay/Delta hearings held by the State Water Resources Control Board. Increasing agricultural water use efficiency is frequently put forth as a major step to solving California's water problems. The basic contention to this argument is that there is water to be "saved" in the agricultural sector through increased efficiency. It is not the purpose of this article to discuss whether such savings can be made within the agricultural sector, but if agricultural water use efficiency is to be improved, it must begin at the field level and that <u>is</u> the subject of this report.

Border irrigation is commonly practiced on a wide variety of annual and permanent crops in California. To achieve high water use efficiency in border irrigation both good design and proper management need to be practiced. Physical characteristics, such as run length, slope, and flow rate, of existing border irrigation systems are frequently difficult and costly to change. Improved management of existing border systems, along with minor physical modifications, are therefore an excellent first step in improving border irrigation efficiency.

While irrigation efficiency is most frequently talked about, uniformity of irrigation is also critical to improved water management. An article by Hanson (<u>California Agriculture</u>, September-October 1987) presents the interrelationship between irrigation efficiency and uniformity. The basic message is that in an adequately watered field, high irrigation efficiency can only be achieved with a highly uniform system.

There have been a number of techniques which have been recommended to improve the uniformity of border irrigation. They include:

1. <u>Increasing the flow rate per foot of border width</u>. With increased flow rate, water advances across the border more quickly, and infiltration times at all points along the border are more equal. This results in more uniform irrigation.

A major constraint may be the flow capacity of the delivery system. The maximum delivery rate will establish a limit to the border flow rate. Increasing the flow rate also requires more careful management since running the system longer than necessary could result in greater over-irrigation.

2. Decreasing the length of the border. This again results in more equal infiltration times along the border and therefore more uniform irrigation.

   While this is the most effective method of increasing uniformity, it is also the most difficult to do with existing systems. Supply systems have usually been installed based on an established field size, and reducing border length can frequently require costly changes to the supply system. Reduced border lengths also requires increased attention to irrigation to avoid over-irrigation.

3. Increasing the slope of the border. Increased slope results in faster movement of water across the border, and more uniform irrigation.

   Border slope is frequently constrained by existing infrastructure surrounding the field. Slope changes to the field will also result in increased leveling costs. Increasing slope by 0.1% in a 1000-foot border results in only an additional 1-foot decrease in elevation at the tail of the field. Except in those cases where low infiltration rates are already a problem, increasing the field slope will generally have a positive impact on application uniformity and efficiency.

Even with a border system which is designed and operated to apply water uniformly, efficient irrigation cannot be accomplished unless good irrigation scheduling is practiced. Irrigation scheduling provides information on **when** and **how much** to irrigate. High efficiency border irrigation is impossible unless the amount of water necessary to refill the crop's root zone is known. It is therefore important to have both the when and how much questions answered by whatever irrigation scheduling technique is used.

An additional factor which is frequently overlooked, but is the most critical, is determining the delivery flow rate. Particularly in open channel situations this is difficult, but unless the flow rate to the border is determined, the proper amount of water cannot be applied.

Case Study

During the winter of 1988-89, the University of California was approached by the Turlock Irrigation District (TID) to discuss ways in which irrigation at the field level could be improved. Due to the drought conditions experienced in the previous years as well as the District's commitment to investigate methods of improving the efficiency of both the delivery system and field applications, a field study to demonstrate improved IWM was a major topic of discussion. TID has a significant portion of its delivery area currently irrigated using border irrigation. In addition, many of these border systems are located on sandy soils which makes efficient irrigation with surface systems a challenge.

It was decided that a grower-scale demonstration of improved irrigation water management would be an effective means of gaining grower interest in improved IWM. In addition, a large-scale demonstration would allow determination of constraints and considerations as well as documentation of the costs of improving border irrigation systems.

There were a number of factors and constraints to implementing a project which were considered. They included:

1. Finding a grower who would cooperate with the project. It was decided that TID personnel would do the actual irrigation of the field.
2. Physical changes to the field and irrigation system needed to be realistic in terms of cost and convenience. The objective was to demonstrate the effects on irrigation water management of physical and management changes which other growers could reasonably be expected to adopt.
3. Both water costs and crop value were low on many of the border irrigated lands. This leads to a lack of incentive for adoption of improved IWM. It was therefore hoped that yield increases would result from the improved irrigation practices.

Once a cooperating grower was located, realistic irrigation system modifications were developed. The grower's original irrigation system was borders on sandy soil, each of 8 borders 300 feet wide by 850 feet long, with a slope of approximately 0.1%. A 36-inch concrete pipeline ran along the head of the field with two 24-inch valves delivering water to each check. Corn silage was to be grown on the field. To irrigate each check, the two valves were opened to deliver a total flow of approximately 14 cfs.

Of the three "conventional wisdom" improvements listed earlier, only two--increased flow rate and slope change--showed promise. While shortening the run length was felt to hold the greatest potential, cost of an extra pipeline for this 45-acre field was $40,000.

Since the concrete pipeline servicing the field was already operating near capacity, substantially increasing flow rate to the existing border configuration was not feasible. It was decided that decreasing border width from 300 feet to 150 feet through addition of levees would be attempted. Each smaller check (150' x 850') would be irrigated with the full pipeline delivery rate (16 cfs) being delivered through the single valve now servicing each check. This effectively results in a significant increase in flow rate per foot of border width.

Field slope would also be increased to 0.2%. This slope increase was not significant enough to cause cultural problems, but was hoped to have a noticeable impact on irrigation performance.

Finally, improved irrigation scheduling techniques including CIMIS-based ET information and neutron probe soil moisture monitoring would be utilized. It was determined that, due to the low waterholding capacity of the sandy soils, irrigation frequency should be approximately every 5 days. Standard grower practice was to irrigate every 7 to 10 days.

The "new" 16 check field was randomized into four replications of the following four treatments:

Table 1. Flow rate, slope, and irrigation scheduling used in each of the four treatments.

Treatment No.	**Flow Rate (cfs)**	**Slope**	**Irrigation Frequency**
1	8	0.1%	Grower: 7-10 days
2	8	0.2%	Grower: 7-10 days
3	16	0.1%	ET: approx. 5 days
4	16	0.2%	ET: approx. 5 days

Pre-irrigation occurred on May 3, 1989 with corn planted on May 16. Through the course of the season, the ET scheduled plots received 12 irrigations while the checks irrigated according to the grower's normal schedule received eight irrigations. The seasonal applied water for each treatment are summarized in table 2.

Table 2. Seasonal applied water and number of seasonal irrigation for the four treatments.

Treatment No.	**Flow Rate**	**Slope**	**Schedule**	**Seasonal Applied Water (in.)**	**No. of Seasonal Irrigations**
1	8	0.1%	Grower	52.5	8
2	8	0.2%	Grower	49.1	8
3	16	0.1%	ET	61.9	12
4	16	0.2%	ET	52.5	12

The later seasonal irrigations exemplified the impact which various physical modifications in the irrigation system had on the minimum irrigation depth which could be applied. Table 3 summarizes these typical depths.

Table 3. Typical irrigation depths applied during later season irrigations for the four treatments.

Treatment No.	**Flow Rate (cfs)**	**Slope**	**Schedule**	**Irrigation Depth* (in.)**	
1	8	0.1%	Grower	5.1	8/7/89
2	8	0.2%	Grower	5.0	8/7/89
3	16	0.1%	ET	4.3	8/8/89
4	16	0.2%	ET	3.8	8/8/89

*Average applied depth of the four replications of the respective treatment.

The major irrigation criteria was to ensure full field coverage. Irrigations were managed excellently by the TID personnel. Thus, the over-irrigations which occurred were the result of application system limitations and not poor management. It is evident that both increased flow rate and increased field slope allowed a reduced irrigation depth to be applied. Increased flow rate was the more effective in improving irrigation performance.

It is very important to note that while no water was "saved" by increasing the flow rate and slope plus following the ET schedule (treatment 4) as compared to the treatment with lower flow rate, normal (0.1%) slope, and the grower schedule (treatment 1), it was possible to irrigate more frequently during the season. Due to the limited waterholding capacity of the sandy soil, more frequent irrigations were desireable to maintain a soil water status more conducive to plant growth.

The average yields at 70% moisture for the four treatments are shown in table 4.

Table 4. Average yields at 70% moisture for the four treatments.

Treatment No.	**Flow Rate (cfs)**	**Slope**	**Schedule**	**Avg. Yield at 70% Moisture (tons/ac)**
1	8	0.1%	Grower	24.8
2	8	0.2%	Grower	19.5
3	16	0.1%	ET	23.7
4	16	0.2%	ET	23.5

There was a large variability of corn yield of plots within each treatments. These plot yield differences within treatments were due primarily to substantial variability in soil conditions. Much of the field was underlain with hardpan. This hardpan ranged in depth from 6 inches to greater than 5 feet. This affected the waterholding capacity of the crop's root zone thereby impacting yield. The variability of corn height was very evident and data gathered showed a direct correlation between plant appearance and hardpan depth.

An additional explanation of the lack of yield increase in the more frequently irrigated treatments (ET schedule) may lie in nutritional problems encountered early in the season. Crop appearance and tissue samples indicated that the ET scheduled plots experienced a nitrogen deficiency early in the season. This was a result of the timing of the first post-plant irrigation. It was felt that the earlier, first irrigation in the ET scheduled plots (9 days earlier than on the grower scheduled plots) resulted in the pre-plant fertilizer being leached from the root zone. Water run fertilizer was not applied during the first irrigation. Subsequent irrigations contained fertilizer (injected anhydrous ammonia). Solution to this early seasonal nitrogen deficiency may be to apply a smaller pre-plant fertilizer application and initiate "water-run" fertilization with the first irrigation.

In summary, the project was successful in demonstrating that physical changes could be made to the borders which were effective in allowing smaller irrigation amounts to be applied. These physical changes required no significant delivery system modifications. Due to increased irrigation frequency, the ET scheduled plots with increased flow rate and increased slope had the same seasonal water application as did the treatment following the grower's normal practices. Yield improvements resulting from increased frequency of irrigation were not evident. Probable explanations for this include substantial field variability of rooting depth due to hardpan and nutritional problems encountered early in the season.

IMPROVED FURROW IRRIGATION TECHNOLOGY DEMONSTRATION

Steven Haugen, Irrigation Specialist, Dellavalle Laboratory,Inc.

This presentation is based on a project funded by the Department of Water Resources Water Conservation Office to Demonstrate Improved Furrow Irrigation Technology to reduce drain water discharge volumes.

This project is intended to demonstrate irrigation technology on a production scale that is readily available. There are several criteria that this project must meet before any large scale adoption of these techniques is going to happen. The first criteria is yields and soil quality must be maintained and/or improved. The second criteria is that the "new" technology must be relatively risk free while not significantly increasing the hassles involved in the operation of the system. The third and most important criteria is the technology must be economically justifiable.

With these criteria in mind the systems that were selected to be demonstrated consisted of existing technology that is often used singularly but are seldom intergrated into a single irrigation package. The systems selected for this demonstration included a surge irrigation system as well as a continuous flow system with the use of furrow torpedoes.

The components that were common to both systems were, short furrow run lengths (880 feet), high furrow flow rates, tailwater reuse, improved irrigation scheduling and timing, and alternate row irrigations for the first seasonal irrigation of the crop. The additional components of the surge system were surge valves and the use of surge irrigation techniques. The additional component required with the continuous flow system is the use of furrow torpedoes used prior to irrigating and after any cultivation work occurs. The hardware layout of both systems were the same with the only differences being in the management techniques.

The irrigation hardware layout consisted of three gated pipe lines which broke the half-mile furrows into 880 foot run lengths, thus allowing irrigation water to be applied at three points in a half-mile furrow simultaneously. The generated tail water was allowed to run under the lower pipe lines in the field, and into the lower portion of the set. A single tail water ditch was pulled along the lower end of the field with all tail water being collected and measured using a Parshall flume and a totalizing ultrasonic flow meter. A surge valve was placed in the middle of each gated pipe line for a total of three valves per field. With this layout, surges could be made between the left and right hand sides of the field or sets could be switched on the continuous flow regime at optimum set times when labor was not available. A flow meter and line gate were installed in each gated pipe line so that flow rates could be balanced between the three gated pipe lines. A booster pump was needed so that gated pipe could be used. The district water that supplied this field is a surface source and sufficient head is not available to operate gated pipe. A diagram of the system lay out can be found in figure 4. Each system was installed in one half of the same quarter section in order to directly compare each management scheme. This resulted in each system irrigating 80 acres.

Results

The results of the 1989 irrigation season can be found in table 1. Typically, 34 inches of water was infiltrated for a cotton crop in the area surrounding the study field where as only 18 to 20 inches of water was infilrated in the study field. With the careful attention paid to the scheduling of irrigations, one to two irrigations less than normal practice was required. These results show that a significant reduction can be obtained in drainage volumes. A cotton crop in the study area generally requires 24 to 26 inches of water to satisfy evapotranspiration. The balance of the evapotranspiration was contributed by a high water table of relatively good quality. The electical conductivity of the water table averaged 7.0 through the season with Boron levels at 6.9 ppm. The water table in the study fields varied from 19 inches on June 19, 1989 to 100 inches at the end of the season as shown in figures 2 and 3. This final water table elevation is below the level of the tile drains, which are place at 84 inches. The electrical conductivity of the soil surface composite samples have not shown any significant change during the last irrigation season as shown in figure 1. The yield on each field is estimated at 3 bales per acre based on a module count. This yield compared favorably with the historical yield on this field.

Because of tighter and tighter constraints that are being placed on all of agriculture, the reduction in drain water flows is the present primary concern with this project. To reduce drain water flows, an increase in the irrigation efficiencies and distribution uniformities is needed. The techniques discussed in this paper are applicable in many more situations than that of the immediate study. Any place there is a concern about deep perculated irrigation water is a prime candidate for these techniques.

Table 1. Summary of Irrigations.

Date of Irrigation	Applied Inches	Runoff Inches	Infiltrated Inches	DU	IE
Surge					
2/24/89	8.40	0.43	7.96	85.0%	50.0%
6/14/89	4.30	0.80	3.50	85.0%	71.0%
7/11/89	7.66	2.43	5.23	90.0%	86.0%
7/29/89	5.22	1.71	3.51	90.0%	92.0%
	Season totals		20.20	87.2%	70.3%
Continuous					
3/2/89	9.08	2.52	6.56	85.0%	61.0%
6/17/89	4.58	1.61	2.98	91.0%	80.0%
7/18/89	8.29	2.93	5.36	90.0%	88.0%
8/4/89	4.88	1.78	3.05	90.0%	96.0%
	Season totals		17.94	88.4%	78.2%

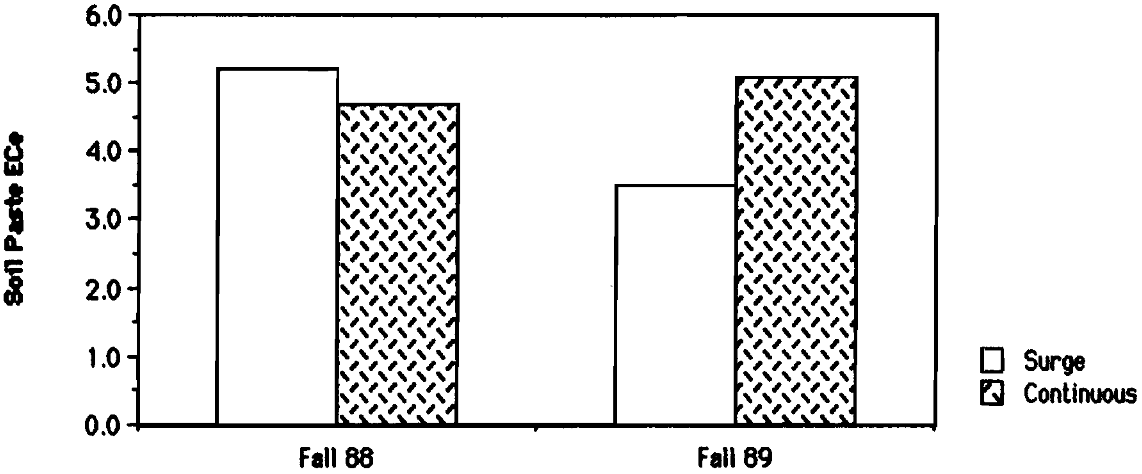


Figure 1. Soil ECe change over the irrigation season.

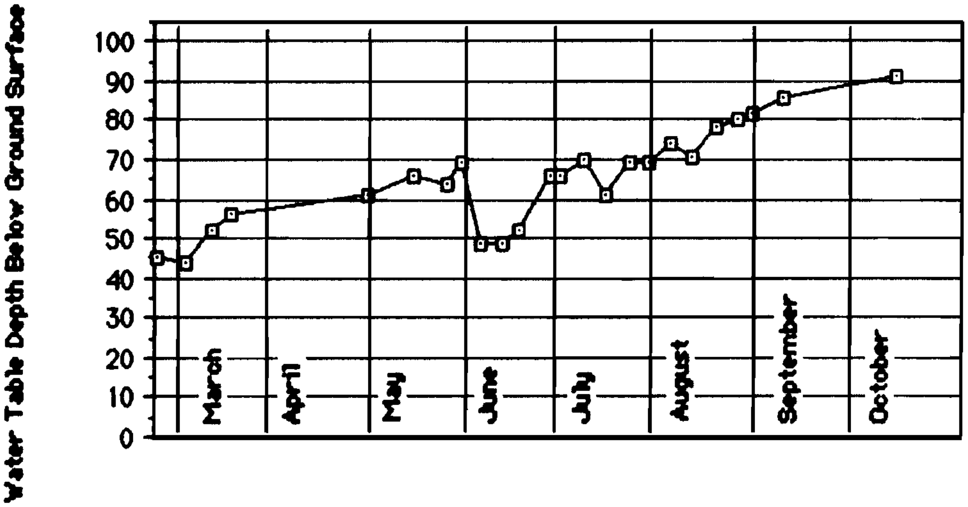


Figure 2. Water table response under the surge irrigation regime.

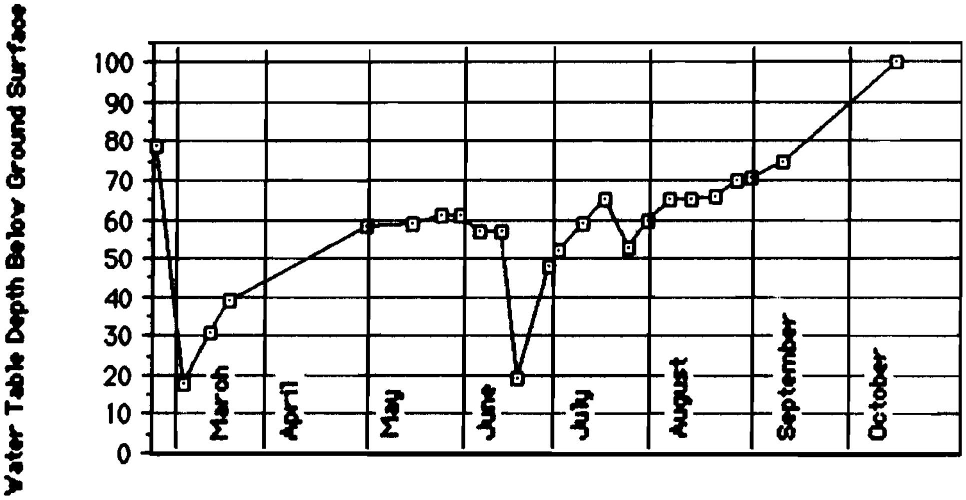


Figure 3. Water table response under the continuous flow regime.

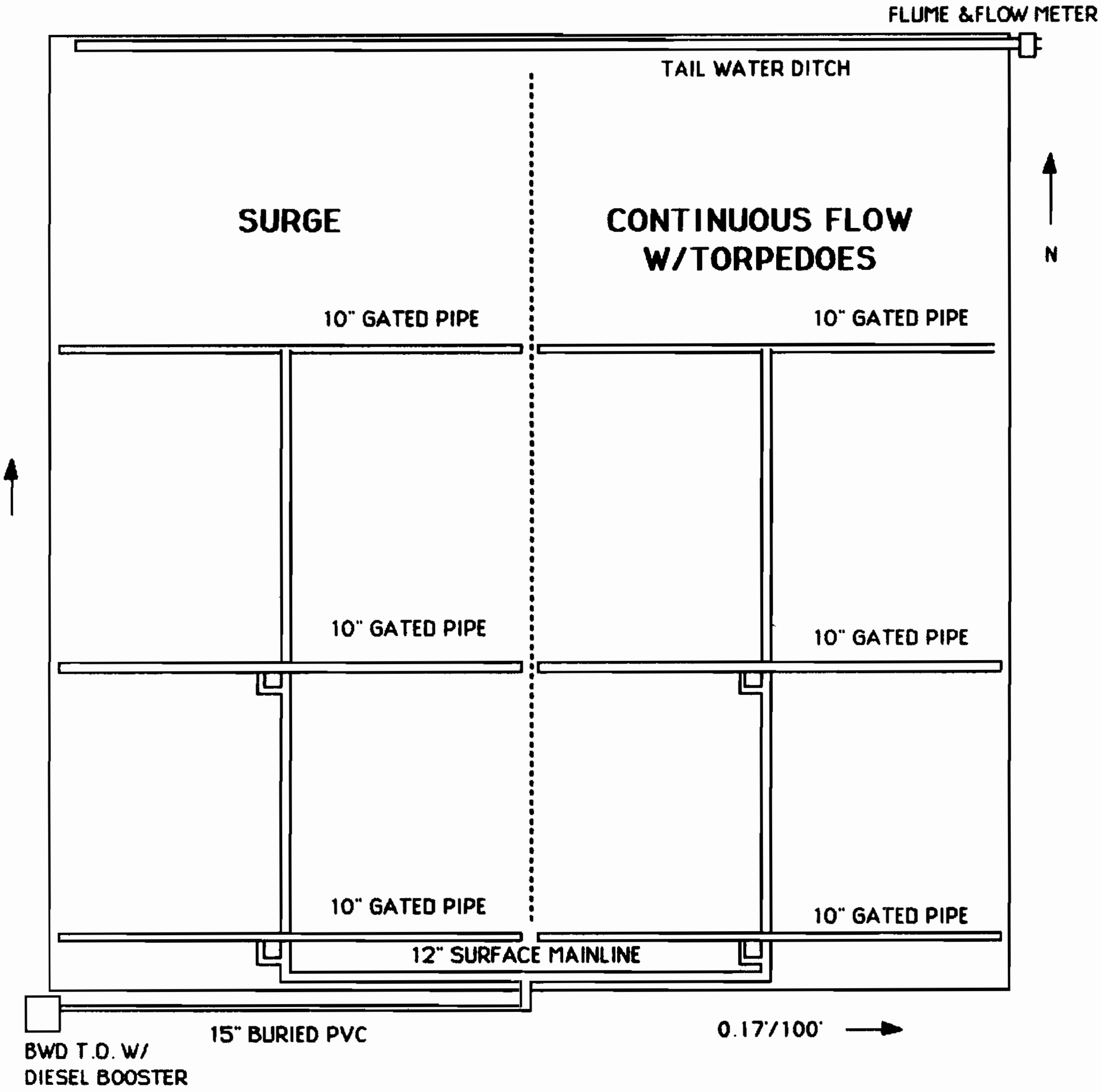


Figure 4. System layout.

ECONOMIC COMPARISON OF SUBSURFACE DRIP, LEPA, AND FURROW IRRIGATION SYSTEMS

Richard B. Smith, Senior Agronomist, Boyle Engineering Corporation, Fresno
James D. Oster, Extension Soils and Water Specialist, UC Riverside
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As a result of irrigation on the west side of the San Joaquin Valley, water additions to the shallow groundwater occur due to deep percolation losses from irrigation and seepage from conveyance facilities. The result is a gradually rising shallow water table that impacts productive agricultural lands in large areas of the western San Joaquin Valley. Agricultural areas with existing (1986) shallow water tables less than 5 feet deep that may require subsurface drainage in the western San Joaquin Valley (Kern, Kings, and Fresno Counties) are estimated at 405,000 acres.

A number of potential solutions have been postulated to correct existing shallow groundwater conditions in the western San Joaquin Valley. These approaches can generally be categorized as follows:

- On-farm water conservation, crop use of shallow groundwater, and reuse of drainage water to reduce volume of drainage effluent. A disposal site, either in the valley or ocean, is needed to sustain this option.
- Treatment of subsurface drainage water to reduce the concentrations of selenium and other potentially toxic constituents to acceptable levels and discharge into the delta/ocean.
- Discharge of untreated subsurface drainage water into an existing saline water body, e.g., deep well injection or ocean.
- Discharge of treated or untreated drainage water into evaporation ponds/basins or into subsurface geologic strata.

Treatment and discharge options that have been studied thus far are expensive and, in some cases, controversial. Regardless of the option ultimately selected, there is an opportunity to reduce the cost by decreasing drainage effluent volumes by on-farm irrigation water conservation. The development of on-farm water conservation, treatment, and discharge-related solutions revolve around a set of complex technical, economic, environmental, legal/institutional, and social factors. A recent editorial distributed by the National Academy of Sciences points out the obvious about irrigation-induced water quality problems, "but the laws of nature cannot be waived. When agriculture and the environment collide, something has to give."

The University of California Committee of Consultants on Drainage Water Reduction recently evaluated farm profitability as a function of drainage water treatment and disposal costs. This evaluation concluded that with no costs or restrictions on drainage water disposal, maximum profits from agricultural production in the western San Joaquin Valley are achieved with furrow irrigation systems. Profitability from agricultural crop production will decrease as the cost of irrigation water and drainage water treatment and/or disposal increase. The rate of decreased profitability is strongly dependent on the uniformity of water infiltration achievable for each different type of irrigation system. The lower the infiltration uniformity, the greater the rate of decrease. Whereas furrow irrigation is presently the most profitable irrigation system, it could become economically justifiable to implement other systems if costs for drainage water treatment and/or disposal were foregone or water conservation occurred as a result of such a change.

The decision to install pressurized irrigation systems by farmers currently using furrow irrigation will not be based on calculated, untested economic analyses. Innovative irrigation technologies, such as subsurface drip and LEPA (low-energy precision application) irrigation systems, have not been adequately studied under commercial conditions in the valley to determine if irrigation water usage and drainage water production can effectively be decreased while maintaining acceptable profitability and salinity control. Further, it needs to be determined if equal results can be obtained with improved management of furrow irrigation systems.

Boyle Engineering Corporation is under contract with the California Department of Water Resources Water Conservation Office to perform a two-year demonstration project to evaluate emerging irrigation technologies. The objective is to evaluate the effectiveness of these technologies on reducing deep percolation and on grower profitability. Each irrigation treatment comprises a 40-acre commercially managed/operated field. The data presented herein summarizes the irrigation system cost estimates based on the first year of the study.

IRRIGATION SYSTEMS

Subsurface Drip

The subsurface drip system uses Netafim's 0.4-gph in-line emitter spaced at 40 inches along 0.520 I.D. x 0.620 O.D. polyethylene hose. Spacing between hoses is 80 inches. Hoses were buried 18 inches deep (±2 inches) in nonwheel rows to minimize compaction problems.

Two buried PVC submains supply irrigation water to the hoses. Each submain is regulated by a 4-inch Hardie irrigation pressure-regulating valve. The ends of each hose are connected to a PVC pipe flush manifold. Each manifold has two manually operated flush valves. The drip hose is connected to the buried PVC pipe with a polyethylene hose riser connected to an Ag Products saddle glued onto the PVC pipe. Hose runs are approximately 450 feet.

A 30-horsepower booster pump supplies water to the system from a small reservoir. Filtration is performed by a set of Lakos Pro 4806-3A media filters filled with No. 20 crushed silica media. The media has an approximate filtration capability of 200 to 250 mesh. The filtered water is metered before going into the PVC mainline. The backflush water is recirculated by being discharged into a tailwater ditch, which feeds back into the reservoir. Backflush is controlled by an electronic/mechanical controller.

A venturi-type injector is connected across the discharge and inlet of the booster pump to inject necessary chemicals. The injector was used to apply nitrogen and phosphorous fertilizers and sulfuric acid to combat root intrusion/biological growth within the system.

The pressure-regulating valves at the submain inlets are set to regulate pressure at 25 psi. This corresponds to a system average discharge of 0.56 gph per emitter. The average application rate is 0.04 inches per hour. Overall calculated emission uniformity is 93 percent. The system runs approximately 8.5 hours per day to meet the average peak cotton evapotranspiration of 0.32 inches. Preirrigation was applied using hand-move sprinklers.

LEPA

The LEPA system is a Lindsey Manufacturing linear system converted to a hose drag system. It is approximately 0.25 miles long. It is constructed of 6 5/8-inch piping. There are seven spans of 178 feet each with a 40-foot overhang at the end. There are 43 booms attached to the main linear pipe. Most of the booms have nine outlets spaced 40 inches apart. At each outlet there is a 3/4-inch, 15-psi Nelson pressure regulator, 15/128-inch brass nozzle, 5/8-inch by 7-foot drop tube, and a furrow bubbler.

Water is pumped from a small reservoir using a diesel engine driven pump. The water is filtered by a Plum Creek suction screen. This screen has interior water jets that rotate the screen and remove exterior debris from the 18-mesh screen. Pressure and water for the jets is supplied by the pump discharge. The pump feeds a surface aluminum pipe mainline going to the LEPA system. Riser valves (6-inch) are located about 340 feet from each end of the field providing an attachment point for the drag hose. The 4-inch flexible drag hose is approximately 360 feet long.

The approximate discharge rate of each drop tube is 1.6 gpm. Overall system capacity is about 610 gpm. Assuming 85 to 90 percent uniformity, it is necessary to operate the system 10.5 to 11 hours per day to meet the average peak cotton evapotranspiration of 0.32 inches. Preirrigation was applied using a hand-move sprinkler system. The preirrigation for the 1990 crop year will be applied using the LEPA system.

Furrow

The furrow irrigation system consists of 10-inch gated pipe used on 40-inch beds. Furrow length is approximately 1,190 feet. Energy dissipation socks are placed on the gates to prevent soil erosion. Water supply is provided through a buried PVC pipeline connected to Westlands Water District facilities. A 10-inch flow meter is connected at the pipeline discharge to record the volume of irrigation water applied. Preirrigation was applied using all furrows. Alternate furrows were used for crop irrigations. The field was irrigated using blocked ends since tailwater collection/reuse facilities were not available. Set times were determined based on soil water depletion and estimated soil intake rates.

IRRIGATION SCHEDULING

Soil water content was monitored with a neutron probe at three locations in each irrigation treatment with two access tubes per location. Access tubes were monitored weekly. Irrigation scheduling was based on measured soil water content, predicted weather, and predicted plant evapotranspiration. The CIMIS weather station located at the University of California Westside Field Station was used to obtain climate data, and a computer program was used to model plant evapotranspiration.

For the subsurface drip and LEPA irrigation systems, the computer program was used to predict the total number of operating hours needed to satisfy plant evapotranspiration for the next seven days. This value was provided as a daily run time to the operator. A water balance for the previous week was used to check the accuracy of the irrigation schedule.

For the furrow irrigation system, the computer program was used to predict frequency and duration of irrigation. The prediction limits were set by inputting the allowable soil depletion. The allowable soil depletion was based on root zone depth, soil water-holding capacity, estimated soil intake rate, and applying a reasonable depth of irrigation water.

IRRIGATION SYSTEM COST

The system design criteria and actual experience gained from operating each different irrigation system during the first year of the demonstration project were used to develop cost estimates for each irrigation system. The acreage assumed for each system was based on using the area that would constitute a economic sized installation.

The summary of irrigation system cost estimates is shown on Table 1, while the comparison of annual irrigation costs for each system is summarized on Table 2. Pressurized systems (subsurface drip and LEPA) are more expensive when compared to the more widely used furrow irrigation systems. The capital cost for the subsurface drip irrigation system is estimated at $1,350/acre, while the LEPA system cost is $584/acre. The annual cost for the furrow system was estimated at $57.94/acre compared to $136.41/acre for the LEPA and $275.18/acre for the subsurface drip irrigation systems.

SUMMARY/CONCLUSIONS

Design criteria and actual operating/management experience gained from the first year of the two-year demonstration project was used to develop estimates of annual costs for subsurface drip, LEPA, and furrow irrigation systems. The pressurized systems are more expensive to install and operate annually when compared with furrow irrigation. There are different design approaches and materials that can be used in these pressurized installations. However, the annual cost estimates presented herein provide a reasonable order of magnitude.

Based on limited experience, net returns from cotton production have not been sufficient to repay the annual costs for installing/operating subsurface drip irrigation systems. With

TABLE 1

SUMMARY OF IRRIGATION SYSTEM COST ESTIMATES

A. SUBSURFACE DRIP

			Annual Cost ($ per acre)
Assumptions:	Netafim inline emitters 0.50 gph		
	Emitter spacing @ 40"		
	Tubing spacing @ 80" - alternate furrows		
	Tubing buried 18" ±2" deep		
	0.43"/day maximum water application		
	Application rate @ 0.036"/hr (average)		
	15 weeks of operation		
	40-hp centrifugal pump		
	Sand media filtration (No. 20 crushed silica)		
	155 net crop acres		
	2 irrigation sets		
	10% interest		
System Capital Cost:	Pump/filtration	$17,500	
	Buried PVC	99,500	
	Tubing/emitters	92,250	
	Total	$209,250	
		(1,350/ac)	
	Annualized capital cost		
	Pump/filtration, 15 yrs = 0.13147 x $17,500	$ 2,301	
	Buried PVC, 40 yrs = 0.10226 x $99,500	10,175	
	Tubing/emitters, 10 yrs = 0.16275 x $92,250	15,014	
	Total	$27,490	
	Annual cost/ac ($27,490/155)		$177.35
Maintenance Cost:	Maintenance and repair cost based on percentage of first costs		
	Pump/filtration facilities $17,500 @ 6%	$1,050	
	Buried PVC $99,500 @ 0.5%	498	
	Tubing/emitters $92,250 @ 5%	4,613	
	Total	$6,161	
	Annual cost/ac ($6,161/155)		$ 39.75

			Annual Cost ($ per acre)
Operating Cost:	Operating labor, foreman 3 hrs/week @ $12.00/hr, 15 weeks	$ 540	
	Flushing, irrigator 4 hours/flush @ $6.00/hour, 4 times	96	
	Irrigation scheduling $8/ac x 155 ac	1,240	
	Total	$1,876	
	Annual cost/ac ($1,876/155)		$ 12.10
Energy Cost:	40 hp x 0.7455 = 29.8 kwh PG&E estimated @ $0.10/kwh 29.8 kwh x $0.10/kwh = $2.98/hr of operation Total water applied @ 1.44 ac-ft/ac (17.28 ai/ac) 17.28 ai/ac ÷ 0.036"/hr = 480 hrs operation 480 hrs x $2.98/hr x 2 sets = $2,861		
	Annual cost/ac ($2,861/155)		$ 18.46
Preirrigation Cost: (hand-move sprinklers)	Sprinkler lines	$52,900	
	Booster pump	15,000	
	Total	$67,900	
	Annualized capital cost - 15 years $67,900 x 0.13147 = $8,927 Annual cost ($8,927/960) = $9.30/ac		
	Maintenance		
	Sprinkler lines $52,900 x 2.5%	$1,323	
	Booster pump $15,000 x 5%	750	
	Total	$2,073	
	Annual cost ($2,073/1,240) = $1.67/ac		
	Operation		
	Labor to install/remove	$ 200	
	Move laterals ($14/move/line)	840	
	Total	$1,040	
	Annual cost ($1,040/155) = $6.71/ac		
	Energy (diesel fuel @ $0.80/gal) @ $20.50/ac-ft and 0.48 ac-ft/ac Annual cost/ac ($20.50 x 0.48) = $9.84		
	Preirrigation annual cost ($9.30 + $1.67 + $6.71 + $9.84)		$ 27.52
TOTAL ANNUAL DRIP IRRIGATION SYSTEM COST			**$275.18**

B. LEPA

Assumptions:
1/2 mile LEPA system
320 gross acres - 310 net
Concrete ditch fed
40" drop tube spacing
Distribution system fed by district pressure
Application rate @ 0.428 ai/ac/day
24-hour irrigation sets
10% interest

			Annual Cost ($ per acre)
System Capital Cost:	LEPA system	$130,000	
	Delivery system and controls	50,920	
	Total	$180,920 ($584/ac)	
	Annualized capital costs		
	LEPA system, 15 yrs = 0.13147 x $130,000	$17,091	
	Delivery system and controls, 25 yrs = 0.11017 x $50,920	5,610	
	Total	$22,701	
	Annual cost/ac ($22,701/310)		$ 73.23
Maintenance Cost:	Maintenance and repair cost based on percentage of first costs		
	LEPA system = $130,000 @ 6%	$7,800	
	Delivery facilities = $40,920 @ 3%	1,228	
	Controls = $10,000 @ 1%	100	
	Total	$9,128	
	Annual cost/acre ($9,128/310)		$ 29.45
Operating Cost:	Operating labor, foreman 3 hrs/day of operation $12.00/hr and 48 operating days	$1,728	
	Irrigation scheduling $8/ac x 310 ac	2,480	
	Total	$4,208	
	Annual cost/ac ($4,208/310)		$ 13.57
Energy Cost:	Diesel fuel @ $12.00/ac-ft and 1.68 ac-ft/ac		
	Annual cost/ac ($12.00 x 1.72)		$ 20.16
TOTAL ANNUAL LEPA SYSTEM COST			$136.41

C. FURROW

			Annual Cost ($ per acre)
Assumptions:	Land leveling @ 800 yds/ac		
	320 gross ac = 310 net		
	1/4 mile irrigation run length		
	Aluminum gated pipe		
	System pressure from district		
	10% interest		
	5 irrigations/season		
System Capital Cost:	Land leveling 320 ac @ 800 yds^3/ac at $0.50/yd^3	$128,000	
	12" aluminum gated pipe and appurtenances 6,600 ft @ $7.15/ft and 200 socks and snaps @ $4.75 each	48,140	
	Total	$176,140 ($568/ac)	
	Annualized capital costs		
	Aluminum gated pipe, 15 yrs - 0.13147 x $48,140	$6,329	
	Total	$6,329	
	Annual cost/ac ($6,329/310)		$ 20.42
Maintenance Cost:	Maintenance and repair costs based on percentage of first costs		
	Land leveling $128,000 @ 3%	$3,840	
	Aluminum gated pipe $48,140 @ 2%	963	
	Total	$4,803	
	Annual cost/ac ($4,803/310)		$ 15.49
Operating Cost:	Install/remove gated pipe		
	5 irrigations @ $150/irrigation	$ 750	
	Irrigation labor 10 days @ 12 hrs/day and $6.00/hr x 5 irrigations	3,600	
	Irrigation scheduling 310 ac @ $8.00	2,480	
	Total	$6,830	
	Annual cost/ac ($6,830/310)		$ 22.03
TOTAL ANNUAL FURROW SYSTEM COST			$ 57.94

TABLE 2
SUMMARY OF IRRIGATION
ANNUAL COST ESTIMATES ($/ACRE)

Cost Element	Drip	LEPA	Furrow
System	177.35	73.23	20.42
Maintenance	39.75	29.45	15.49
Operating	12.10	13.57	22.03
Energy	18.46	20.16	0.00
Preirrigation (sprinkler)	27.52	0.00	0.00
TOTAL	275.18	136.41	57.94

consideration for subsurface drainage collection/disposal costs or increased irrigation water costs, the economics of subsurface drip and other pressurized irrigation systems may become more favorable.

Long-term environmental impacts and hazards of drain water disposal in the valley provide a strong incentive to investigate irrigation strategies that could minimize drainage volumes required to sustain crop production. Pressurized irrigation systems may offer the flexibility and control necessary to significantly limit unnecessary water additions to the shallow groundwater table. The potential may exist to substantially reduce the extent of the drainage water problem in the valley, assuming large-scale usage of these types of irrigation systems. Additional work needs to be performed to study the long-term costs/benefits of these pressurized irrigation systems. These future studies should address design/operating alternatives based on the requirements of a diversified cropping pattern and consider various long-term environmental problems.

GREENHOUSE EFFECT: A CALIFORNIA PERSPECTIVE

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By now everyone has heard about the "Greenhouse Effect." Popular science magazines, television, and almost every newspaper have featured stories about it. The question confronting plant and soil scientists is how much change will occur in California within the next several decades. This presentation will discuss what changes have definitely occurred, what the rates of change are, how well we can project future change, and the likely implications in California.

The evidence of change is apparent in several atmospheric properties. There is no doubt that global surface air temperature is gradually increasing, although the deviations from one year to the next are large. One cannot say that any drought sequence or warming period is significantly different. It is only when the data are smoothed over a period of decades that a warming trend of about 0.5°C over the last century is evident. Another indication of the warming trend is that the montane glaciers have been receding during this period; their extent has been carefully observed in recent history. The last century has also been marked by gradual sea-level rise. At a rate of 2.5 cm/decade, the increase has been almost imperceptible, but wave and tidal actions certainly pose a threat of salt-water intrusion into the estuaries and dikes of the California delta. Moreover, the atmospheric CO_2 concentration has been monitored very precisely by IR absorption techniques since the mid-fifties, and we have seen an increase from 320 ppm in the mid-sixties to nearly 350 ppm now. In addition, investigation of CO_2 concentrations in air bubbles trapped in ice cores, has shown that before industrialization the CO_2 concentration was 280 ppm in the 18th Century. Isotopic analysis of ancient ice cores shows that the CO_2 concentration has not been this high since 120,000 years ago. Between 120,000 years ago and now the air temperature was cooler by 5 to 10°C.

We cannot say yet that the increasing concentration of CO_2 has caused a perceptible change in climate; perhaps it would have been cooler without the CO_2 present, but this is speculation. Over the same period that CO_2 was observed to increase, there has been a geometric increase in the carbon released by fossil fuel combustion. In the mid-fifties the carbon-release rate was $2x10^9$ T/y, by mid-sixties $3x10^9$ T/y, and by mid-seventies $5x10^9$ T/y. While it is true that North America contributes much of the carbon, our share has been declining steadily from about half in the mid-fifties to about one-fourth at present. The largest share of annual carbon is contributed by emerging economies; so it is not a simple matter of self-imposed control but rather an international problem for delicate negotiation. The seriousness of the problem can be judged by the simplest economic projections. If the growth rate of the international economy continues at 3% to 4% per year, the present CO_2 concentration (350 ppm) should double (700 ppm) in 40 to 80 years.

To make matters worse, CO_2 is not the only "greenhouse gas." Other trace gases, taken together, would absorb as much IR energy as CO_2. The other trace gases are methane (a component of natural gas), carbon monoxide (a product of combustion), nitrous oxide (released by decomposition), and man-made compounds called chlorofluorocarbons (CFC). The CFC gases are the "freons" and cleaning solvents, which are not yet replaceable by our present technology. All the trace gases are increasing at a much greater rate than CO_2 and consequently will contribute to an increasing share of the greenhouse effect.

Projections of greenhouse warming are presently done somewhat crudely, using the same equations of motion and conservation that serve in weather forecasting. But in the numerical models, the scale of resolution is about 500 km (800 miles), ocean circulation of heat is oversimplified, and cloud layers are poorly represented. Each of the most prominent scientific institutions have been asked to compute the resulting change in global air temperature should the CO_2 concentration double. One result is a consensus that annual temperature should increase by about 4°C. Another result is that the major warming would be over the polar regions, especially the Antarctic. All the numerical models differ in detail, but it can be safely argued that changes in temperate regions will be spotty and variable, and precipitation will be decreased in some areas and increased in others. The relationship between the variance of precipitation and the mean precipitation has been tested from existing weather records. Lowering the mean precipitation by 10% will increase the probability of one-half "normal" precipitation by 30% and one-fourth "normal" precipitation by nearly 50%. Thus drought frequencies will be increased with only slight decreases in mean precipitation.

In California, we depend on winter precipitation for our irrigation water and for most of our electricity. The Central Valley is protected from salt water intrusion by a maintenance of fresh water outflow from the Sacramento and San Joaquin Rivers. Estimates have been made that global warming of 4°C, projected to occur perhaps 40 to 80 years from now, should cause the maximum winter precipitation to peak several months earlier so that runoff would be earlier in the winter with flow nearly exhausted by springtime. This generally means a shorter season for distribution of the available water and may tax our water reservoir capacities.

Carbon dioxide is required for photosynthesis, and elevated CO_2 stimulates the growth of many crop plants. Research has shown that doubling the CO_2 concentration will increase yields of annual species by up to 40%. While this may be a boon for 90-120 day crops it does not seem to help plants in California that grow over many seasons, such as alfalfa. It also seems that plants with longer maturity in California have a tendency to accumulate starch in their leaves rather than translocate it to storage organs. The effect of elevated CO_2 on water use is to reduce water loss per unit area of leaf, but this is usually counteracted by increased growth and expanded leaf area. The net effect for most crops will be more growth for about the same amount of water required; that is, the water use efficiency will increase. When the transpiration rate of leaves decreases, the leaf temperature increases. Leaves of crops and trees will be 3 to 5°C warmer at double the present CO_2 concentration. This will help balance the global radiation budget as a feedback mechanism, but it could push plants past their thermal limits on hot, sunlit days. Increased growth of plants means increased demand for nutrients, and the perennial plants growing in unmanaged soils might become nutrient limited.

There are many complex issues regarding the response of ecosystems to the greenhouse effect. The interaction of increased growth and demand for nutrients, altered carbon allocation, starch accumulation, and increased leaf temperatures would be further complicated by different competitive advantage, pathology, insect predation, and reproduction. None of these complex issues have been adequately studied to date. Fundamental studies of long-term elevated CO_2 and the ecosystem responses to temperature and drought extremes are needed. There have been studies in California, but most of the effort at present can be categorized as preliminary or at the stage of methods development.

OZONE AND CROP PRODUCTIVITY

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Ozone

This paper discusses the effects of ozone (the main phytotoxic pollutant in "smog") on crop productivity, emphasizing the impacts in the San Joaquin Valley. The root cause of the ozone pollution problem in the Valley is the action of high levels of summer sunlight on nitrogen oxides and hydrocarbons which are primarily emitted by vehicles and industries. These pollutant sources occur both in the San Francisco Bay area- contributing to ozone downwind from the Bay, and in the Valley itself. Because of inversions which often occur in the valley during the summer and trapping of the air by the surrounding mountains high ozone concentrations accumulate in the Valley.

Ozone air monitoring is a critical aspect of the assessment of ozone effects on crops. Most of the monitoring sites in the San Joaquin Valley are on the east side, in the major cities; with only a few sites on the west side. Based on the data that are available, ozone concentrations are highest southeast of the major cities of Fresno and Bakersfield.

Ozone and Crop Productivity

Leaf injury symptoms of ozone have been observed on susceptible crops (including cotton, grapes, tomatoes, and lettuce) in the San Joaquin Valley for many years. However, to quantify any ozone impacts on yield controlled experiments are required to related plant responses to measured ozone concentrations. Experiments to assess ozone impacts on yield have been conducted at a number of sites in the San Joaquin Valley and at Riverside using large open-top chambers. These experiments have produced ozone exposure-yield loss equations for a number of crops, such as cotton, grapes, alfalfa, and lettuce.

The loss equations were used to estimate the potential yield losses from current ozone concentrations for major crops in each county of California. Yield losses were estimated relative, to the potential yield for each crop in "air clean" (unaffected by human activities) in each county. "Clean air" is difficult to define, but for the purpose of the assessment it was defined as a 12-hour (daylight) growing-season ozone concentration of 0.025 ppm averaged over the growing season for each crop in each county (2,3). This average ozone concentration is similar to the concentrations in the San Francisco Bay and Delta areas where persistent sea breezes blow pollutants to the east.

Estimated ozone-caused yield losses were greatest for cotton, dry beans, grapes, and potatoes (Table 1). Losses were highest in the southern and eastern regions of the San Joaquin Valley, corresponding to the areas of highest ozone concentrations. However, some crops exhibited little or no ozone-caused yield losses (Table 2). In addition, there were a number of crops (primarily tree fruit and nut crops, i.e. almonds, peaches, and walnuts) for which there are no yield loss equations available (because of a deficiency or absence of experimental data) consequently no loss estimates were available.

The economic significance of these ozone-induced yield losses is difficult to assess. However, estimates been made by economists at the University of California at Davis and Air Resources Board (1) indicate that the losses are substantial. The loss estimates consider the direct impact of ozone but do not take consider the indirect losses due to increased inputs (water, pesticides etc.) which may be required to maintain crop productivity in spite of ozone stress.

Conclusions

1. Ambient ozone concentrations are causing serious yield losses in susceptible crops in the San Joaquin Valley.

2. Some crops are tolerant to ozone, with no measurable yield loss.

Acknowledgements

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Table 1. Yield loss (% vs. "clean air") for ozone susceptible crops in the San Joaquin Valley in 1986[a]

CROP	LOSS (%)
Alfalfa Hay	11.4
Beans, Dry	26.0
Cotton	15.6
Grapes, Raisin	26.5
Grapes, Wine	22.9
Lemons	9.4
Oranges	9.3
Potatoes	32.1

[a]12 hour growing season average of 0.025 ppm O_3.

Table 2. Yield loss (% vs. "clean air") for ozone tolerant crops in the San Joaquin Valley in 1986[a]

CROP	LOSS (%)
Broccoli	0
Corn, Field	2.6
Lettuce	0
Onions, Dry-Dehydrated	1.0
Rice	2.7
Spinach	0.4
Sugar Beets	0
Tomatoes	2.1
Wheat, Irrigated	1.1

[a]12 hour growing season average of 0.025 ppm O_3.

INTERACTION OF AIR POLLUTANTS WITH CROP MANAGEMENT PRACTICES

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Management of agricultural crops requires the integration of a wide variety of environmental and biological factors in order to maximize yield potentials and economic benefit. Optimization of irrigation, fertilization, agronomic practices and pest control are all an important part of successful management programs. However, many times environmental factors will alter the normal course of these integrated management programs and require changes be made to accommodate the influence of these confounding factors. One such interacting factor is air pollution.

Although there are many individual components in air pollution, the primary pollutant of concern with respect to agriculture is ozone. Ozone is highly toxic to plants and accounts for over 90% of the agricultural losses in California from all air pollutants. Although ozone levels are usually higher near urban sources of pollutants, injurious levels often occur in agricultural areas of the state, often later in the day indicating long range transport from urban areas. Other pollutants, although not considered primary air contaminants, may cause problems in specific regions of California. For example, acidic precipitation in the form of acidic fog may impact many agricultural areas in the state during winter months. Because these air pollutants have been shown to interact with both biotic and abiotic factors influencing crop growth, crop management decisions may be altered.

Biotic Interactions

Incidence of disease or insect infestation may be modified by presence of pollutants. Ozone has been shown to increase or decrease incidence of disease of fungal pathogens, depending on the host-parasite combination. Obligate pathogens (biotrophs) require healthy plant tissue for success. However, tissue necrosis by ozone may reduce the potential sites for infection. In contrast, necrotrophs (saprophytic organisms) usually require injured or dead tissue as infection sites and pollutants may provide the necessary injury for increased pathogen success. Bacterial pathogens also respond to ozone-injured plants, but the response can be negative or positive depending on the pollutant dose and timing relative to pathogen inoculation. Recent evidence also indicates that acidic fog may influence the success of pathogens by eliciting lesions which act as entry points for certain disease organisms.

Insects are also influenced by pollutants. Mexican bean beetle and gypsy moth exhibited feeding preferences for ozone-exposed and sulphur dioxide-exposed foliage over non-exposed foliage. Growth rate of aphids was higher on roses grown in polluted air as compared to filtered air.

Beneficial organisms may be affected by air pollutants as well. Symbiotic root-inhabiting mycorrhizal fungi have been shown to be affected by exposure to ozone and sulphur dioxide. Pollutant impact reduces the effectiveness of these fungi to aid in nutrient uptake and, under severe pollutant stress, may change the beneficial nature of these fungi to a pathogenic regime. The nitrogen fixing bacterium, Rhizobium, also has been shown to be negatively affected by pollutant exposure by reducing the number of nodules per plant and the amount of leghemoglobin produced within each nodule.

Abiotic Interactions

Many abiotic factors influence plant growth. Primarily, most management programs attempt to control fertilization, water availability and pesticide application. All of these factors have been shown to interact with air pollutants.

The nutrient status of a crop plant can profoundly affect its response to air pollutant stress. Generally, increased nutrient levels predispose plants to pollutant injury. Increased levels of both macro- and micronutrients have demonstrated increases in injury symptoms on a variety of crop plants. Presumably, the more vigorous plant growth, greater sensitivity to pollutants. However, this injury is offset somewhat by increased growth and yield and would not be considered a control strategy to limit pollutant impact.

Water availability is also an interacting factor with respect to pollutants. Crops under water stress will exhibit decreased stomatal conductance with concomitant reductions in gas exchange.

Because the primary point of entry for gaseous pollutants is through the stomata, drought conditions usually result in reduced pollutant injury. Again, as in nutrient availability, optimization of water is usually the goal in most crop management programs and determining irrigation thresholds for adequate growth and minimal pollutant damage would be difficult.

Finally, a major component of crop management is pesticide application. Pesticides utilized to control insects and disease, or herbicides and growth regulators to increase productivity are a major economic expense in California agriculture. Increases in pesticide phytotoxicity have been reported under conditions of ozone exposure and the occurrence of phytotoxicity would certainly alter recommendations of application rates or frequency. In contrast, some fungicides have shown to have antioxidant abilities and actually decrease ozone injury. Therefore, a dual benefit may be obtained from the use of these specific chemicals.

Conclusions

Crop management strategies attempt to maximize all interacting factors to improve growth and yield. However, air pollutants may interact with biological and nonbiological factors to change normal agricultural practices. For example, increases or decreases in disease or insect incidence as a result of pollutant impact would require changes in pesticide application rates. Additionally, interactions of pollutants with plant nutrition, drought stress and pesticides might also necessitate changes in traditional agricultural practices. The extent of these changes would depend on the type of pollutant and the total pollutant impact during the crop growing season. Because of the apparent interactions between air pollutants and a wide variety of biotic and abiotic factors, these relationships should be considered carefully when evaluating and designing crop management programs.

SAN JOAQUIN VALLEY AIR POLLUTION STUDY

Pauline Larwood, Kern County Supervisor
Chairman - San Joaquin Valley Air Pollution Study Agency

Good science is the basis of good policy. The San Joaquin Valley Air Pollution Study Agency is on the leading edge of a new local, state, and federal partnership. it's called cooperative environmental management.

Kern, Fresno, Kings, Madera, Mariposa, Merced, San Joaquin, Stanislaus, and Tulare counties have formed a joint powers agency to provide an administrative structure to design, plan, and implement an ozone and air pollution study encompassing the whole San Joaquin Valley. Kern County Supervisor Pauline Larwood has served as chairman since its formation in 1986.

Chairman of the California Air Resources Board acts as chairman of the policy committee established to provide the direction and the decision-making necessary for the study. Representatives from the EPA, Department of Defense, National Park Service, industry, agriculture, and local and state government fill out the membership.

This $14 million study, including $9 million in cash contributions with $5 million provided by in-kind contributions of services and equipment is a shared effort by federal, state and local, and private sources. One-third funding is to be provided by each entity to bring this important cooperative environmental project to a successful end.

Nine technical support studies have been completed in 1989. The data gained has been used to design the field study which will determine the sources and the windflows of air pollution in the San Joaquin Valley.

During a nine week period in the summer of 1990, fifty different locations are planned for monitoring equipment throughout the air basin. Seven aircraft will be collecting information aloft. The operation will be directed by a project manager from headquarters based in Fresno and involve fifty employees. In addition, fifty college students will be in the field gathering the data and transmitting it to the center where it will be entered into a computer.

During the study period, the emissions from forest fires, agricultural burning, pesticide use and biogenic emissions from crops will be surveyed and added to the data bank. In 1991 a computer simulation model will be developed to be used as a reliable planning tool that will predict various outcomes when control measures are instituted. Decision-makers can then institute emission controls that will be effective in achieving improved air quality.

In August 1989, the study was expanded to include the Bay area, the Coast Range, the Sierra and an aerosol monitoring component. AUSPEX is a $6 million program which is jointly sponsored by P.G.& E., the Electric Research Institute and the Bay Area Air Quality Management District. This collaboration will allow improved understanding of the transport of pollutants by inclusion of both source and receptor areas within the study.

Major emission controls for stationery sources continue to be instituted throughout the valley. The study was never intended to delay implementation of future controls.

Automobile inspection and maintenance programs have now been adopted by six San Joaquin air basin counties. Future mobile source reductions are needed. Scientific data from this study concerning mobile source emissions will provide decision-makers with the knowledge to institute further regulations on mobile sources working cooperatively with federal and state policy makers.

FERTILIZER
"THE FOUNDATION OF CROP PRODUCTION"
AN ENVIRONMENTAL RISK?

DR. R.D. Johnson[1]

As we enter the last decade of the 20th Century many issues will surface questioning the impact of Agriculture and its effect on the Environment. As these issues are opened they will have to be addressed by Production Agriculture utilizing scientific facts rather than unfounded emotions. Many of these issues will be concerns about Risk Management and of current chemicals and practices use, however, there will be issues resulting from past practices and the chemical use, that were considered safe. Even as we evaluate today's fertilizers and chemicals, utilizing the scientific community, there will still exist the close scrutiny of the non-scientific environmental community.

The major issue to be faced by the fertilizers industry is Risk Management and the concerns of exposure to heavy metals in the work place, and the potential of exposure to nitrate-N in drinking water sources. As new legislation is passed there will always be the need to evaluate old and new materials to see if they pose a real risk to exposure or just a potential of a risk as either a reproductive toxicant or as a carcinogen.

To date **six heavy metals** have been recognized under the guides of California's Prop-65 as posing significant risk to both occupational exposure and potential drinking water contamination. Five elements; **Arsenic, Cadmium, Beryllium, Chromium(hexivalent) and Nickel** are classified as being suspect in causing cancer. The sixth element, **Lead** is listed as being suspect as a reproductive toxicant. Arsenic is being re-evaluated as a potential reproductive toxicant. **Nitrate nitrogen has not been listed** under the guides of Prop-65 but it is an issue as an suspect in causing Blue Baby syndrome (methemoglobinemia) in infants.

Heavy Metals originating from N-P-K commercial fertilizers have been determined to pose little if any risk to the environment as a direct result of fertilizer use, however, there still remains a concern from an occupational standpoint and their effect on long term health. Nitrate-N poses a concern to the fertilizer industry as a emotional sensitive issue, similar to the impact of Alar, the plant growth regulator, registered for use on fruit(apples) in the Pacific NW.

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[1] Agronomist, Chevron Chemical, Fresno, Ca.

There is no easy solution to either the issue of heavy metals and nitrates. The first step is recognizing that both **Heavy Metals and Nitrate-N are natural constituents of the Environment**. Heavy Metals, unlike nitrate-N are relatively non-mobil in the environment due to their chemistry. They become of an concern when they exist in a soluble form and can enter into drinking water sources and remain mobil. Fortunately heavy metals react quickly in the environment losing their solubility or mobility and thus losing their risk to exposure. Nitrate-N on the other hand is very mobile in the environment. Even when nitrate-N reacts in the environment to form natural salts, many of these salts have high solubility and thus retain their mobility.

It is essential that we establish reasonable Safe Harbors for each element or chemical in respect to the no effect level and the level we find naturally as background levels of the environment. When a element exceed the no effect level as natural background or as hot spots it needs to be identified and Best Management criteria developed. If the element is above the safe harbor level, then a priority of use needs to be established and if a point source can be identified than a priority of control be established.

Cooperation between Federal, State, Local Agencies and the Agricultural community is critical. Environmental issues become emotional issues when not properly addressed. Communication and corporation within the local community is essential so that Best Management Policies and Practices can be developed for the benefit of the community.

Best Use Guidelines and Best Management Practices are currently they most logical approaches we have in addressing the environmental risk issues of fertilizers. With proper recommendations and application of fertilizers, that have been developed at the local level and with the proper management skills utilized by the grower, many of the environmental issues can be overcome with the grower continuing to produce crops and generate profit at the farm level.

A very important part of this whole process is the continued education, development and demonstrate that fertilizers can have a minimal impact on the environment. Research and demonstration projects need to be continued evaluating fertilizer type(both commercial and natural), including organic(whether animal or municipal), in relationship with water management (whether non-irrigated or irrigated) showing that the benefits of fertilizer use overshadow the risks. **Best Management Practices are in essence Management Options essential to the decision making process** as to selections of fertilizer materials, selection of rates, timing of material application, method of application and placement of application.

Development of BMPs from a fertilizer prospective for heavy metals management is to recognize that many of the heavy metals associated with fertilizer are natural background constituents and are present because of origin in the raw material (organic or inorganic) used in the production of many fertilizer materials. The development of BMPs for Nitrates take on a different prospective because Nitrate can be the results of processing and manufacturing of fertilizers, as a natural constituent of natural fertilizers, or unlike heavy metals is often the resultant by-product of natural biological conversions of organic and inorganic nitrogen in the soil, a process called nitrification, which results in the natural formation of Nitrates.

Nitrates become an issue when soluble nitrate salts enter sources of drinking water. These salts can originate from many areas of the environment. Although, production Agriculture does in fact apply nitrogen fertilizer directly to the soil environment for crop production, it is not the sole contributor of nitrate-N to the Environment. The presence of natural salts, seepage from active and closed sewage fields and the direct and indirect contribution of Confined Agriculture, whether dairy, feedlot and greenhouse are all contributing to the nitrate background in our Environment. It can be stated simply, **"NITRATES HAPPEN!!"**

Water Use and its management is the key to many of the environmental issues facing Production Agriculture. Water Use decisions are as much an emotional issue as the quality of the water that is available. **The issue of Water Use Policy will be solved by Politics. The issue of water quality with respect to heavy metals and nitrates stemming from Production Agriculture will have to be solved by facts originating from understanding the environment, geology, soils, climate, crops and management ability and developing programs and practices as determined by research and field demonstrations.** The movement of soluble salts (metals or nitrates) with water is a natural process. Many of the conditions that influence water movement control soluble salt movement. As a result one of the keys in the control of salts resulting from the production of crop is understanding the presence of water either naturally through rainfall and/or soil storage or by irrigation. In either case if the water applied or rainfall exceeds the soils ability to hold water than drainage takes place. If a soluble salt is present and moves with the water then we have the potential of a environmental risk. When the happens without the influence of man then we call it our natural environment, when it because of the action of man, then its pollution and posses an environmental risk.

The conflicting issue of Nitrate as an environmental risk or as plant nutrients involve the presence at known quantities. In evaluating risk assessment we are concerned with both concentrations and volumes. Often we are asked to evaluate acute dosage and long term effects. In affect risk assessment are based on daily dosage over long term life spans. The issue of nitrate involves that addition of nitrogen at a rate sufficient to reaches or maintain an adequate concentration of nitrate in the active roots zone. Nitrogen fertilizers are applied at rate per acre and often involved applying at rates in excess of that needed for crop production. Cropping systems inefficiencies of use and/or the inability of get proper conversion of the fertilizer to a plant available form have to be programmed in developing efficient crop production programs. Even with the development of a Best Management Practices that involves using smaller, more frequent application, for short term crop response, there remains an potential for residual carryover that can have long term impact on the environment.

Even, with this in mind, the requirement of society will continue to place pressure on Production Agriculture to do a better job of understanding its production systems and the total environment in which these systems operate. The issue of heavy metals will solved by reducing where possible the amount of question elements found in fertilizers. The issue of Nitrates will be a little more complex. It involves Field Level Management and understanding Geology, the nature of soils, the requirement of the crops for specific nutrient input and the ability of the grower to manage. This is where Best Management Programs will play a important role at the grower level.

BEST MANAGEMENT PRACTICES TO ACCOMPLISH MAXIMUM ECONOMIC YIELD AND SUSTAINABLE AGRICULTURE

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Introduction

Progressive crop management systems are the result of research, extension, agribusiness, and farmers working together to develop, adapt, and apply new and improved technology and production practices. Site-specific management is becoming increasingly important to ensure sustained profitability and maintain responsible stewardship of natural resources. Research, extension, and industry specialists, in cooperation with farmers, are working to develop lists of recommended best management practices (BMPs) for individual crop-soil-climate-management systems. These will provide farmers with management guidelines for making their crop production decisions to help maintain productivity and protect the environment.

Perspective: LISA versus BMPs

Interest in low-input agriculture was generated in the mid-1980's as a result of increasing public concern about severe financial stress in farming and agribusiness, increasing sensitivity to environmental issues, and concerns over erosion under intensive row-crop management systems in highly erodible areas. Many people associated these concerns with capital-intensive farming and concluded that a return to less intensive management with a reduction in the use of purchased inputs --- especially pesticides and fertilizers --- would lead to a more economically viable and environmentally acceptable agriculture.

Legislation mandating USDA support for low-input systems was enacted by Congress in 1988 under the Agricultural Productivity Act. The acronym **LISA**, for **L**ow-**I**nput, **S**ustainable **A**griculture, was adapted with stated objectives of preserving the family farm, conserving natural resources, and improving environmental quality. LISA has become a rallying point for individuals and groups supporting the general concepts of organic farming and employing terms such as "alternative agriculture" and "regenerative agriculture".

The problem with LISA is that it focuses on lowering inputs with the assumption that the stated objectives will be met. Scientific evidence does not support this.

The long history of agronomic research that forms the basis of today's progressive production practices is scientifically sound and has withstood the test of fluctuating economic conditions. It provides for the maintenance or improvement of productivity through balanced fertility management and sound soil conservation practices. The modern system of **b**est **m**anagement **p**ractices (**BMPs**) is agronomically sound, economically efficient, and environmentally responsible. This is the real sustainable agriculture.

BMPs Lead to MEY

The **m**aximum **e**conomic **y**ield (**MEY**) approach to crop production employs best management practices (BMPs). The approach is to optimize each input factor with the goal of maximizing profits. This may require reducing or eliminating certain inputs and increasing or adding others. Inputs are tools to achieve the goal. It is important to understand that cutting needed inputs below optimum levels will reduce production efficiency and profits, and reduce the sustainability of the management system.

MEY is not all-out production. But rather, it sets yield goals that are perhaps slightly lower than the maximum potential yield, but approaching the point of maximum profits. Since crop production is a complex biological system, greatly influenced by weather patterns, the MEY point cannot be determined precisely, but the goal is still sound.

MEY management has a proven track record. It is agronomically sound and addresses the environmental, resource efficiency, and economic concerns facing today's farmers and agribusiness.

MEY management includes:

- **Paying attention to details** of agronomic management of every acre farmed. Inefficient farmers will continue to drop out, but they will be replaced by farmers who are better skilled in the technology and business principles of modern agriculture.

- **Establishing realistic yield goals.** New technology continues to offer opportunities for increasing yields and profits. Maximum yield research shows a large window of potential increase for most crops.

- **Employing best management practices (BMPs)** on all fields, to conserve soil and water resources and improve production efficiency.

- **Fertility management based on soil tests**, plant analysis, and crop removal estimates to match realistic yield goals. More precise fertilizer placement and timing offer opportunities to increase profitability and reduce environmental hazards.

- **Building and maintaining soil fertility** to the most efficient and profitable levels to guard against environmental stresses and take advantage of seasons when weather is favorable.

- **Integrated pest management (IPM)** to control pest damage to yield, quality and profitability, utilizing best available combinations of chemical, biological, and cultural methods.

- **Use of adapted crop rotations** to spread risk, reduce fertility and pest management costs, and take advantage of yield enhancement found in crop rotations.

- **Improved soil tilth and organic matter** through increased amounts of crop residue incorporated into the soil profile.

Summary

<u>MEY management</u> enhances soil productivity and balances all necessary production inputs for most efficient use. Profitability is increased by elimination of unnecessary inputs. The environment and natural resources are protected by avoiding unnecessary use of fertilizers and chemicals and by reducing erosion and leaching losses. Profits are increased by focusing not on LISA's low-input approach, but rather on <u>reducing per-unit costs of production</u>. MEY focuses not on low-input alone, or on high yield alone, but on increasing yields to reduce inputs per unit of production. Best management practices are integral to this goal.

All production inputs should be evaluated on the basis of sound research data and on-farm experience. Good managers attempt to optimize each input factor with the goal of maximizing profits. Cutting needed inputs below these levels will reduce profits and reduce potential sustainability of the management system.

BUILDING A SYSTEM OF BEST MANAGEMENT PRACTICES

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INTRODUCTION

According to the latest estimates, the earth will soon be inhabited by some 5.2 billion people. Concurrently, arable land will only increase 4 percent. Therefore, we are faced with the challenge to continue to increase yields per acre with the same magnitude that has occurred during the last 50 years. While advances in biotechnology will be significant, fertilizer, as it has in the past, will continue to have a major role in meeting this most important challenge.

We stand on the threshold of a new decade wherein the operative word will be "compliance". Best Management Practices (BMPs) will be the means by which compliance will be accomplished. "The cutting edge in farming is at this agricultural-environmental boundary," cites Bill Liebhardt, director, UC Sustainable Agricultural Research and Education Program. The totality of people involved in farming must now concentrate their individual and collective efforts on total input management---including fertilizer management. However, as we increase our agricultural productivity so does the concern for its effects on the environment. This is made evident by the growing and increasingly vocal segment of our population that believes modern agricultural production is being achieved at the cost of environmental degradation and food safety. As evidence of this, the number of bills to legislate the implementation of Best Management Practices (BMPs), particularly the management of agricultural nitrogen, continues to grow.

BMPs DEFINED

While certainly not new to farming, BMPs have become agriculture's latest acronym. A crop production system which utilizes Best Management Practices is a management system that uses inputs (those available as natural resources on the farm and those purchased externally) in the most efficient manner possible to optimize productivity and profitability from the farming operation, while minimizing adverse effects on the environment. BMPs, as they relate to fertilizers, can be defined as agricultural practices which allow the continued production of crops by using fertilizer with or with out irrigation in a manner that minimizes the impact of such operations on the environment.

BMPs include both crop and land management practices which help to reduce or prevent non-point pollution. Therefore, the major question for agriculture is how to achieve increased food production, in which fertilizer-use will assume an ever-increasing role, and at the same time maintain, or even increase, environmental quality.

THE OBJECTIVE OF FERTILIZER APPLICATION

Plant uptake of fertilizer is the main objective of fertilizer application. Nitrogen and phosphorus that are absorbed and utilized by the crop to provide yield does not cause environmental pollution. Therefore, the best nutrient management strategy from an agronomic and environmental standpoint is to apply enough fertilizer to produce maximum economic yield. This implies application of the right ratio or balance of nutrients, in the right amount, at the right time, and in the right place. These "4-Rs" have been collectively called the Fertilizer Bill of Rights.

NITROGEN MOVEMENT BELOW CROPS

Utilization of applied nitrogen as measured by crop recovery is seldom greater than 65-75 percent. The average, however, is closer to 50 percent. In sugar beet field trials, the range of uptake efficiency of fertilizer nitrogen varied from 0 to 50 percent. Agricultural Extension and Experimental Station investigators studied nitrogen movements below the root zone of sugar beets in an actual field trial with sprinkler irrigation and 5 rates of nitrogen. Maximum yield of sugar beets, reported in hundred weights of sugar per acre, occurred with 120 lbs of N per acre. Soil water moving below the roots was approximately 4 ppm N. Yields were depressed by additional nitrogen, and N in soil water increased to about 12 ppm. While the values of N moving below the root zone were lower than expected, the data showed an increase in leaching losses of N at high rates of application. With potatoes, maximum yield of No. 1 potatoes resulted from 100 lbs of N per acre. Nitrogen in soil water was near 20 ppm. At the 300 lbs of N per acre, yields of No. 1 potatoes decreased and N in the soil water increased to nearly 40 ppm. Here again, the pollution potential is relatively low at the rate of nitrogen needed to produce near maximum yield and it increases at an accelerated rate as the rate of N applied goes up.

Data from a 5-year field study with labelled N fertilizer applied to corn, supports the relationships between yield, amount of fertilizer applied, and N recovered in grain or remaining as leachable N in the soil. High levels of fertilizer N (196 lb/A), coupled with high levels of yield (143 bu/A), showed very low potential for pollution. Fertilization in excess of that needed for maximum yield sharply increased the amount of leachable N in the soil.

BMPs MUST BE SITE SPECIFIC

When considering the diversity of crops, the complexity of soils, the multiplicity of cultural practices and irrigation schemes, and the diverse characteristics of fertilizer materials, the implementation of BMPs must be individualized to the local situation. Therefore, BMPs are site specific and should include the following considerations:

<u>Cultural Practices</u>

- Careful variety/hybrid selection for the system
- Crop rotation including deep-rooted and shallow-rooted crop
- Intercropping
- Conservation tillage and crop residue management

<u>Soil Fertility Programs</u>

- Precision-calibrated soil tests, plant tissue analyses, and irrigation water testing
- Allowing N credit for legumes, crop residues, and for nitrate in irrigation water
- Fertilizer placement, rate, and timing using split multiple or application techniques
- Use of available manures, sludges, and wastes

<u>Pest Management</u>

- Selecting pest-resistant cultivars
- Use of pest management dynamics, damage thresholds, and decision aids
- Integration of cultural, mechanical, and chemical control methods
- Use of bio-control agents, when available

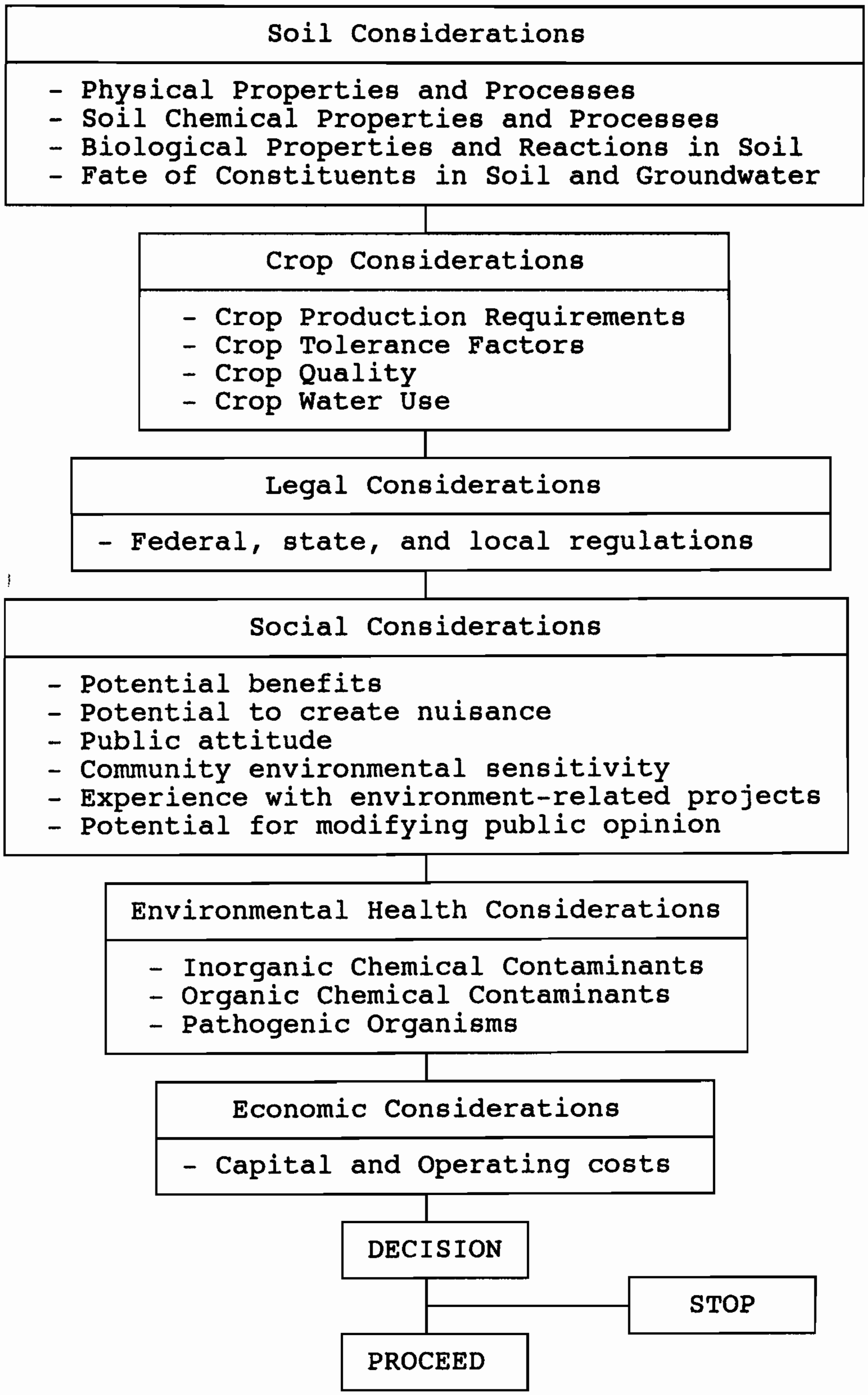
<u>Water Conservation</u>

- Use of the irrigation scheduling and limited irrigation
- Use of ecofarming and other moisture-harvesting systems in semi-arid areas
- Crop selection based on the efficiency of water use

BUILDING A BMP SYSTEM

The development of a management system which will optimize productivity and profitability, while minimizing adverse effects on the environment, will be a system which uses BMPs that are site-specific to the problems that exist and the potential for solutions to those problems. A decision tree can assist in the development of such a management system. It is suggested that planning occur in six more-or-less well defined stages as follows:

SITE SPECIFIC PLANNING CONSIDERATIONS



SUMMARY OF OBJECTIVES

Pollution potential and cost of production significantly increase as application rates of fertilizer exceed the true crop requirement for maximum economic yield. At rates of fertilizer needed to produce optimum yields, the measured pollution is relatively low.

Therefore, the primary objectives of any crop production system is to develop site-specific Best Management Practices that: 1) reduce or prevent erosion and surface runoff, 2) reduce or prevent excessive movement of contaminants into groundwater, and 3) maximize crop recovery of soil or applied plant nutrients to achieve the greatest agricultural production which has the least adverse impact on the environment.

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VIABLE CROP PRODUCTION UTILIZING BMP'S

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It is upon us to achieve the objectives of Proposition 65 to minimize the impact of a farming operation on the environment. Initially the concern is to minimize the trace element contaminates (non-point pollution) from entering the "Drinking Water" of California. The second major objective is to reduce or prevent excessive downward movement of contaminates through the soil into underground waters. The third objective is to maximize the crop uptake of soil or applied plant nutrients to achieve the greatest agricultural production while having the least adverse environmental impact.

I have been employed by Vaquero Farms, Inc. since 1979 as support staff to the farm managers to integrate into the overall crop production management agronomic and water management skills. In reviewing the guidelines for "Best Management Practices" I have realized that most of the guidelines are not new perspectives to our farm management practices. The limitations or constraints to utilizing the majority of the BMP'S involves capital expenditures and a conscientious decision process of maximizing yield potential with a cost benefit related profitability.

To utilize many of the BMP'S a working technical knowledge must be incorporated into the management process to not only evaluated warranted improvements but to also understand the objective function and the relevance to the potential outcome.

Any farm organization, large or small, must develop a management philosophy that their farming operation be managed as a business to remain viable during the 1990's. The risk of losing the farm has been very real during the early 80's with depressed commodity prices and agricultural land values. Farm managers or owners must continue to relate all of the farming decisions to profitability. We are all interested in short term viability so that there will be a long term possibility. With this in mind we must also understand that the motivation for most acting farm managers is that they like to farm. When farm managers are forced to comply to legislation, the transition of implementation has been the development of utilizing new external expertise. For example, out of the 3500 registered Pest Control Advisors in the state, how many are on-farm managers making PCA decisions for the ranch. It has traditionally been left to the chemical reps and PCA services. But the bottom line to these decisions include qualifications, time management, and, most important cost effective means of compliance.

It has been a long road paved by the type of actions similar to that of the WWD and the RCD Water Conservation Program during 1987-1990 which has encouraged growers to realize the concepts, tools and benefits of water management and related crop productivity.

These actions for growers all take time and skills to implement which compete with organizing and maintaining field operations. As managers responsibilities increase, either external or internal, personnel with expertise must be developed and incorporated into the management process which will allow all decisions to be better cost effective decisions. It is of utmost importance for our farming operation to continue exploring avenues of improvement. This should include on the farm utilization of trials comparing costs and benefits of various treatments of management inputs. Profitability is a process of producing and selling more at a lower production cost than the competition. Consequently, by becoming better (mandated or encouraged) managers with tighter constraints on available resources, the farm operation must remain viable. Through improved decision making processes limited and judicial use of resources will result with conservation and environmental impacts minimized.

The trend of Sustainable Agriculture and LISA must be developed and incorporated into the overall farm management strategy with a trial and error approach. The long term effects on productivity must be carefully managed and assessed. The utilization of these techniques warrants the technical skills and education of why and how various cultural operations benefit productivity. The cost benefits must be tested, evaluated and modified to maintain overall short and long-term farm profitability.

Not only must Researchers and Educators continue to be the leaders for agriculture in research, as equally important is the conscious efforts to educate and harmonize the public, the politicians and the growers. Without profitability agriculture will not maintain the high standard of food quality, the abundant supply, or an environmental sound use of the natural resources for this country or for export.

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The Case for Regulation in the Agricultural Environment

Most of this discussion focuses upon the prima facie case to regulate pesticide manufacture and use, and groundwater protection. Failure to have some rules with respect to pesticide use or pesticide application exposure procedures is likely to produce harm to other human beings (who live next to agricultural land or who apply the substances or who work in the fields after the pesticides are applied) or to the land or to the groundwater or to all three. Whenever human activities produce substantial harm or pose the risk of producing substantial harm to other human beings, this is cause for prima facie moral concern and typically for some form of legal control.

There are also economic concerns. If pesticides were not controlled in some fashion as to the effect on human beings or the environment, then the manufacturers and users of pesticides might well impose costs on others (because they, their land or their drinking water was harmed) which the manufacturers and users would not pay for--an <u>externality</u> or <u>external</u> cost imposed on others. These costs unpaid <u>underrepresents</u> to the public and to the markets the cost of having such products and producing other goods from them. It would also result in a <u>maldistribution</u> of resources, for the costs of harm (e.g., in the form of disease, land and water cleanup) would be borne, not by the producers and users of the products, but by those adversely affected by them.

There is also a related moral point about the maldistribution of the costs of the product apart from harm to others; it is prima facie <u>unfair</u>: those who benefit and who benefit most from using the products do not bear the burden or at least the full burden of the total social costs imposed by the products. This unfairness is not the end of the moral or economic discussion, only the beginning, for there may be justifiable institutional, social and moral reasons for such allocations, but these must be argued for in the face of unfairness.

Some harms, such as contamination of the groundwater, are "collective bads" (the obverse of "collective goods"). These are generated as byproducts of other activities and are bad states because they may use up resources (by degrading them), capital (eg. by corroding metal through air pollution), and labor (eg. by imposing disamenities or harms on others). The presence of collective bads also produces a misallocation of resources because some might pay to avoid them, the contributor of such bad states receives an implicit subsidy, <u>for it doesn't have to pay for the full costs of them</u> and too many social resources might be spent on activities which cause such degradation.

From the above there is a prima facie case for institutional mechanisms are needed to ensure that the full social costs are incorporated into the product (so there is no market failure), to ensure that risky activities or harms are not unjustifiably imposed on others and to ensure that the community does not bear an unfair distribution of benefits and burdens.

Several different legal institutions are available for controlling these potentially harmful activities. The criminal law aims to protect our rights by <u>penalizing</u> with harsh treatment, loss of liberty and social condemnation the agents who would violate them. Because of the nature of criminal punishment the state must establish <u>individualized</u> responsibility of the offender and it must overcome especially high burdens of proof to do. Both these requirements are designed to protect criminal defendants against unjust punishment, for as the slogan has it " it is better that 10 guilty men go free than that one innocent man be wrongly punished." However, the nature of environmental harms make the criminal law particularly inappropriate as a means of preventing such harms. 1) Typically environmental toxins such carcinogens do not cause palpable injuries (at least immediately), thus the injury is not easily detected. 2) Because of the latency of diseases such as cancer, palpable injury may be long delayed. 3) The resulting disease may be difficult to distinguish from background diseases, unless it is particularly rare, such as vinyl chloride induced liver cancer, or the substance leaves a unique signature as do asbestos fibers. 4) Thus, the responsible parties may be difficult to identify. 5) This is even more true where the harms caused may be the collective result of the actions of many individuals (eg., the contamination of groundwater).

The above are obvious limitations to using the criminal law. However, even in those cases in which one can identify both a harm and a responsible perpetrator, (eg., the President, Vice President and Manager of Film Recovery Systems in Chicago were found accountable of first degree murder), the criminal law is essentially retrospective: the criminal is punished because the law has been violated and in most cases a victim harmed. Such laws do nothing for the victim, and where there has been a violation, by hypothesis, do not prevent the harm. Any prevention of harm or deterrence of criminal behavior is produced indirectly from a law prohibiting certain conduct, backed by the threat of punishment. For these reasons the criminal law will rarely serve to protect us from environmental harms except in the most extreme cases, where the behavior of an individual is so outrageous as to justify imposition of criminal liability and where the threat of punishment is so severe as to discourage criminal conduct.

The tort, or personal injury, law aims to secure our rights and the rightful borders of our possessions and ourselves by making us whole again when we suffer damages by someone violating our rights or crossing the "rightful borders" of our possessions or our selves. A defendant who loses a case must pay compensation to the plaintiff sufficient, in the judgment of a court, to make the plaintiff whole again. Tort actions are easier to bring against individuals and groups; there is somewhat less attention on individualized responsibility, because of the tort law sanction. The tort law also achieves any deterrence effect indirectly: successful tort suits might force sufficiently high compensation payments to plaintiffs that neither the present defendant nor other potential defendants in similar circumstances will be tempted to cause harm similar to that caused to the plaintiff.

There are shortcomings to the tort law. 1) The plaintiff prove that the defendant's violation of the law caused the plaintiff's injuries, and this is a particularly difficult requirement in many environmental harm cases, for e.g., polluted aquifers, or elevated childhood leukemia rates among the children of farmworkers, there will be considerable difficulty identifying whether there has been harm, identifying the perpetrator of the harm, and identifying the mechanism and the environmental path of the harm. 2) The tort law, like the criminal law is essentially retrospective: the aim is to provide compensation to victims in order to make them whole again. 3) There is no prospective feature to the tort law, except for indirect deterrence, enough successful suits against tortfeasors to deter others from causing similar harms.

Prospective regulations via the institution of administrative agencies aim to remedy the shortcomings of (or gaps in) the criminal and tort law. The regulatory law is essentially preventive; it seeks to protect our rights and infringements of our rightful possessions by specifying in advance how certain activities must be done - it provides prospective guidance (with various criminal or tort law sanctions) verses retrospective compensation or punishment. A homey example of regulations concerns building regulations. The building department does not care what kind of houses we build, but requires that they be built in accordance with certain rules and regulations so that they don't fall down, and prior approval is required at each step of the building process. Similar features characterize federal regulatory institutions.

There are a number of reasons for preferring the regulatory law to either tort law or criminal law protection of our rights against environmental harms. 1) An obvious one concerns causation. For the tort and criminal law it is necessary to establish a causal connection between an individual's wrongdoing and a particular person's injury (if causation is required in the criminal case), which may be often difficult. For regulatory purposes, it is sufficient to establish a generalized causal connection between group exposure to a toxic substance and an elevated disease rate in that particular group. If one knows the source of the toxicity one can implement regulations designed to reduce the group exposure to a level which is not problematic. 2) The use of a regulatory law is appropriate when a centralized agency (eg., the Environmental Protection Agency, the Occupational Safety and Health Administration or the Food and Drug Administration) is in a better position than an individual defendant, to have the relevant information to identify the harms in question. 3) The regulatory law is preferable to the tort law when defendants are likely to be judgement proof, (i.e., when they are likely to run out of money sufficient to pay tort law damage suits should they lose). The regulatory law tends to avoid this problem, for persons wishing to engage in a potentially harmful activity may choose not to if they lack the funds to do it right. 4) Prevention of harm may in many cases be less costly than remedial tort suits once the damages have occurred. 5) The regulatory law is in a much better position to take into account the latency problems associated with toxic substances and to design regulations in accordance with those problems. From a moral point view there is prima facie reason to prefer prospective regulation to retrospective remedies for the aim is to design rules in advance so that the harms do not arise for as many people. Finally, there is a practical side: the community as a whole and the regulated industry or the purchasers of its products pay the costs of providing for the preventive measures, rather than individual plaintiffs who suffer should harms materialize.

The above review of available legal mechanisms to controlling potentially harmful activities merely sketches some of the reasons bearing on choice of institution. The particular institutional option, if any, depends upon the potentially harmful activity, the total social and moral costs and benefits of using one strategy versus others, including a no legal interference option.

OF MARKETS PUBLIC & PRIVATE: THE CASE FOR "THE HAND"

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I. *Introduction: The Debate Over Rights*

It is customary to approach the question of "How Much Regulation Do We Need?" by selecting one position and then firing mercilessly at the opposition. These two warring sides are generally classified as "private sector" versus "public sector," and a proregulation position implies a ringing defense of the latter via a devastating attack upon the former. (Reverse armies for the free market position.) Yet this battleline may be drawn along somewhat different dimensions.

Often, it is the private sector which openly encourages public control of markets; indeed, in a constitutional democracy such as ours political power must originate with private initiative. On the other hand, perhaps the most fundamental function of the state is its key role in enforcing private property rights. The Constitution, for instance, makes quite a point out of this, going so far as to codify the enforceability of private contracts in the Bill of Rights.

The essential point is that to demarcate the world into public and private spheres may confuse the policy debate to follow. Allow me, then, to redefine the conflict as between economic institutions which evolve as a result of private choice-making, where property rights are respected and enforced by governmental authority, versus those which owe their genesis to political decision-making where collective rights to property are enforced by governmental authority. It is the actual likely operation of a private market vs. that of a political market upon which I will focus.

Whereas the idea of a private marketplace is well understood, the political marketplace is somewhat more subtle. The fact is that, as the private entrepreneur must maximize profit subject to the economic realities which surround him, so must the political entrepreneur (i.e., the politician or bureaucrat) adjust to the political realities of his market. The competition to gain control over government resources and the ability to regulate private activity is intense, and operates with many of the same predictabilities available for observation in the purely economic (i.e., private) sphere. It makes no more sense to speak of idealized government allocations, with results simply *assumed* to be in the public interest, than it does to speak of altruistic and omnisicient *private* transactors. In that modern economic analysis offers the rational self-interest postulate as a basic tenet of private behavior, it is only consistent -- and realistic -- to carry this over to the political world. So, the governmental bodies I discuss herein will look precisely as the private maximizers of the private sector.

II. *Efficiency of Decentralized Choice-making.*

The central economic case for private marketplace allocation of goods and services rests upon the incredible complexity of a modern economy. With the extreme specialization which operates to truncate production into very fine sub-sets across, quite literally, the globe, our economic machine weaves a very complicated web. It was once discovered that there exists no single human being who knows fully how to create a *pencil.* An economic good, a very simple economic good, comes to market via a network of workers, capitalists, and managers, stretching all around the world. The co-ordination for this far-flung group activity is provided for by.... no one. The metaphor is, of course, "the market," by which we mean that buyers and sellers are linked together (and with them a virtually countless array of intermediaries who provide the seller with the inputs necessary to deliver the output) simply via mutually beneficial trading. The adhesive cementing this co-ordination is not applied consciously by a planning agency, but created spontaneously by the force of self-interest. It is the "invisible hand" of Adam Smith's famous tome.

The alternative method of satisfying consumer wants is well-known, and involves the conscious planning and directing of resources. Rather than depend upon the private, unregulated owners of inputs (including, most importantly, human capital inputs such as labor and entrepreneurship) to follow their respective interests towards a mutually agreeable outcome, the planning solution is to imbue some agency with a superior number of rights so as to direct others to an economic solution. The agency must determine the relative values (i.e., the priorities of the economic world), for in commanding resources from above, it cannot rely upon the motivations of the individuals directly involved in the production process. Indeed, the entire concept is to move the choice-making to a higher level; to plan for the Big Picture, as it were.

Where individuals are myopic, or foolish, or mean-spirited, this shifting of responsibility may be theoretically appealing. Hence, the arguments for government allocation of resources (whether by ownership -- socialism -- or regulation) have generally been attached to the back end of attacks upon the greed or stupidity (or both) of private decision-makers. The solution seen is one where the public agency can better direct resources precisely because it is not *self-interested,* and can promote broader concerns of long-run importance to society.

Unhappily, so far as this analysis goes, it is simply false. Not in the scientifically testable sense (although we will come to that), but in the sense of being logically unconnected. That is, the shifting of responsibility for choice-making from private owners to government administrators does not change people, their time-preferences, their intelligence, or their spirits. It simply gives them a new game with new rules. This creates a different set of incentives for action, but to assume that these incentives will produce the salubrious results advertised as the rationale for central planning is not an argument but a hope. In fact, the more consistent assumption is that the *homo economicus* who gets his hands on a government agency will care *less* about preserving government property for future generations than his own, care less about productive efficiency, and invest greater resources in selfish vendettas than his private counterpart simply because the budgets (and resources) he controls are public property. He does not directly internalize the benefits of efficiency, nor the costs of waste.

What does the central planning agency bureaucrat know that the private owner/allocator does not? He will know many things that most private agents will not, and these may include technical pieces of information as to productive efficiencies. But any such expertise can be hired in competitive markets; those private agents who need to know such information will be available. What knowledge is special to the bureaucrat is only of a political nature. That is the special market in which he has expertise (as proven by his success in scaling the ladder; the market test of survivorship applied to the bureaucracy itself). So decisions as to economic allocation are liable to reflect the political goals of the agency, and its bureaucrats, who compete for resources and power within the government.

There is nothing inherently evil in this; one way in which government agencies might compete is in attempting to reduce pollution in the rival markets which they regulate. Hence, contributing to the public weal may be a competitive advantage. But there is no particular reason to suspect that it will be, in that those who consume the products and pay the bills of such agencies have no freedom to choose between bureaus. This deprives the competitive process governing political markets of feedback from consumers, workers, and other private agents. The feedback which is felt is *political,* and the interests of ordinary citizens (who actually bear the costs and reap the benefits of economic allocations made) must travel a very circuitous route to be felt here. What dominates, certainly, are the interests of the political incumbents themselves, who attempt to maximize utility just as do actors everywhere. But within the public sector, they have easy access to other people's money. Hence, efficiency will be regularly compromised by the ready availability of deals which enhance the power, influence, or prestige of politically influential groups at the expense of the unorganized and relatively powerless. That these trades become the primary business of government programs is unsurprising, in that government decision-makers act essentially as brokers for such deals. Brokers like transactions.

If the public allocator knows more politics than the private allocator, the latter knows more that is special about particular economic realities. The vast amounts of information which are important to the operation of our economy include far more than technical information regarding, e.g., the temperature at which the walls of an electrical generating station will melt. Purely scientific or engineering sorts of data are relatively straightforward to collect; it is the idiosyncratic information about resource availability and use that is damnably confusing to collect. It is the meticulous gathering of the "special information of time and place" which F.A. Hayek identified as the *sine qua non* of the entrepreneur, an agent who sees opportunities for matching economic resources with consumer demands in ways missed by others. Most crucially, this sort of information is known only to those closest to the process itself, so radically dispersed is it. Moreover, it is not possible to conceive of centrally discovering it for the knowledge which is most important is not revealed outside the context of actual economic trade; the supplier who can best provide the shipping service for the particular input does not emerge until the offer to pay for such an input is made at a particular place for a specific amount. Only then does the agent step forth, accepting this opportunity as the best of those available at that time and place.

It takes the active co-operation of thousands or millions to achieve efficiency. These varied economic agents have unpredictable tastes, unquantifiable skills, and unknown alternatives. Only by giving them ownership and control of their own personal stock of resources, be it merely their labor and its income flow, can we entice them to perform the very consuming task of optimization. Yet, without their co-operation, our central plan has simply lost its data bank. In truth, it is a data bank which it never possessed, and never will. Only the decentralized market process, wherein individual resource owners make themselves better off by making the efficient choice, by doing the efficient thing, creates and builds upon such vast sources of knowledge. The beauty of the economic marketplace is that it does just that, and does it spontaneously -- without explicit co-ordination.

III. *The Moral Case for Decentralization.*

The case for government ownership of resources has often been crafted in the moral dimension. In a one classic case, Sidney and Beatrice Webb wrote in 1942 that, in replacing profit-seeking with socialism,

> *there is no distinction between the code professed on Sundays and that practised on weekdays... [T]he only good life at which [the citizen] aims is a life that is good for all his fellow men irrespective of age or sex, religion or race.*

But surely such hypothesizing is sheer fantasy, born of fanciful predictions on the order of New Soviet Man (indeed, the Webbs were writing in their tome, *The Truth About Soviet Russia,* an incredible paean to a Stalinist U.S.S.R.). What would make government allocation for "the public good" more moral than private allocation for self-interest, when the same sort of human staffs either system, is a change in personal incentives. Yet, the shift in incentives is one away from personal responsibility for efficient social outcomes and towards political competition. It does not appear that this change in incentives will lead man to a higher plane, or pave the way for a nobler set of economic outcomes.

Indeed, when the moral dimension is expanded to encompass civil rights and the sorts of liberties which citizens of democratic regimes have come to expect (and even to take for granted), the case for decentralization becomes overwhelming. Why government choices should take precedence over individual decisions seems far easier to answer in the affirmative when ignoring morality. Allowing the fullest and freest reign to individual sovereignty is the reflex reaction of the most enduring liberal societies; even a cursory examination of current history reveals the correlation between economic and political liberty to be very close to unity over the long-run. Indeed, economic liberalization mandates political freedom, as seen in the Soviet block decommunization program, while the pressures of economic freedom so seriously undermine authoritarian political structures that resort to raw terror (and a reversal of economic decentralization) may be the only way to save a dictatorship, as seen in post-Tienanmen Chinese communism.

IV. *Agricultural Markets.*

The politicization of policymaking has been demonstrated quite nicely in the agricultural policies of the U.S. and other developed nations. The basic program pursued is this: Government assumes responsibility for the overall health of farmers, with various sub-goals such as "saving the family farm." All such announced rationales are crafted for maximum political popularity, but farm groups are much better organized than consumer groups and easily manipulate policies to transfer huge amounts of consumer/taxpayer money their way. These funds are delivered to ostensibly relieve various "unique" problems in the sector, but the payments go on decade after decade, and exacerbate the very problem of low farm incomes by encouraging producers to stay in farming. Indeed, the government subsidizes exploitation of new cultivation through under-priced water projects, favorable tax treatment, low-interest development loans, and outright subsidies. The total cost to consumers and taxpayers in the U.S., 1980-88, has been put at $260 billion, while the annual budgetary costs alone are in the $25 billion range.

One recent book on U.S. farm policy summed up the efficiency and distributional effects of current programs in the following way:

> *Farm subsidies.... are the equivalent of giving every full-tinme subsidized farmer two new Mercedes Benz automobiles each year. Annual subsidies for each dairy cow in the United States exceed the per capita income for half the population of the world... Each year, the USDA's marketing orders force farmers to abandon or squander roughly 500 million lemons, 1 billion oranges, 100 million pounds of raisins, 70 million pounds of almonds, and millions of plums and nectarines... The USDA is paying eleven-year-old children $50,000 a year not to plant corn... Since 1980, the federal sugar policy has cost the equivalent of over $2 million for each sugar grower, and the USDA has spent over $1 million for each full-time rice grower since 1985. (James Bovard, The Farm Fiasco, 1989.)*

It is very difficult to argue that the vast schemes for transferring income to the farm sector result in a net efficiency for the U.S. economy, or that they are justified as help to the poor. Indeed, our farm policies raise food prices, hurting low income consumers the most, while awarding vast sums to owners of prime farmland. (Note that it is not the farmer, but the landlowner, who is, strictly speaking, the benificiary of our policies.) Conservative and liberal economists oppose such programs as wasteful and unfair. It is a classic example of the capture of resource allocation for political entrepreneurship, and a resulting economic allocation very far from the public interest -- an apt demonstration of precisely what our general theory of market competition would predict.

FARMING IN A REGULATED ENVIRONMENT

Marc Faye, Vice President, Faye Properties, Inc.
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"The impact of Regulation on the Farming Enterprise or How Can I Pick the Walnuts When the Orchard is Full of Squirrels?"

The essence of the speaker's message will be that regulations have gotten out of hand and have entered the realm of overkill. The results have been higher costs and lower productivity. Rather than seek solutions to problems through regulations, society should put its efforts into identifying problems, achieving understanding by its members and expecting them to keep the structure sound.

The Impact of Regulation on Integrated Pest Management

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In any society or enterprise, tradeoffs must be made when imposing rules. In an ideal world, these tradeoffs should be rationally evaluated, and the decisions thus arrived would provide the 'most good' for the most people. However, ours is an imperfect world and unintended side effects often result when rules are imposed. In agriculture, pesticide regulation is usually thought of as the only source of regulation. However, regulation occurs very broadly in agriculture and its impact on integrated pest management (IPM) is broad as well.

Regulation can occur at various levels of the socioeconomic system. They can be imposed by governmental or industrial sources, can arise voluntarily or involuntarily, and can be obvious or inconspicuous. I wish to present a series of examples to highlight the complexity of the regulatory environment and the resulting influences on the complex system we call agricultural pest management. I hope that through these examples, the case can be made that as larger picture must be viewed when regulating an industry as complex as agriculture.

But first, what do I mean by IPM. IPM is recognized as a set of tools which can help bring rationality to pest management. It emphasizes a system approach to agriculture and recognizes that agricultural fields occur within an ecosystem. It stresses the concept of economic thresholds which implies that pest populations can exist within the field and not be damaging. IPM recognizes that such populations can require management and that control strategies are needed. Such strategies include cultural, biological, chemical, and regulatory (i.e. exclusion, inspection, quarantine).

Regulation of Chemicals

When EPA was created in the late 1960's, it assumed the role of regulating agrichemicals which USDA previously had done. FIFRA (Federal Insecticide, Fungicide and Rodenticide Act) originally was established to protect farmers from ineffective chemical products. It now serves as the foundation for the enforcement of pesticide regulations. Registration of pesticides is one of the primary functions of EPA. In addition, the California Department of Food and Agriculture requires registration of a products before they can be used in California. Information required by CFDA include exposure information, residue data, effects on pest management, and volatile organic compounds. When a compound is registered, a label for the product is issued. This label details how, where, on what site, and how much of the product can be used. Additionally, it contains information concerning how soon workers can reenter and how long before the crop can be harvested.

While these regulations have done much to reduce environmental deterioration and increase the safety of the agricultural working environment, they have also resulted in indirect and negative influences on IPM. For example:

Rates: Only recently was a ruling made by EPA to allow rates below those listed on the labelled. The use of reduced rates of propargite in **almonds** allows management of spider mites without interfering with existing predatory mites.

Preharvest interval: Last year the reentry for propargite in **grapes** was shifted from 7 days to 21 days. This effectively replaced effective preharvest mite monitoring with scheduled preventative treatments timed 21 days before harvest. Potential results are increased pressure towards resistance and an increase in unnecessary applications.

Increased data requirements for registration: Increased data requirements fill gaps in our knowledge of the toxicology, human health risks and environmental fate of compounds, but result in fewer products making it to the marketplace. As a result, selection pressure toward resistance continues to increase to the existing arsenal of compounds. As tolerance increases to the compounds, more applications are required to control or less environmental compatible compounds are called into service.

California's separate review process for registration: California Department of Food and Agriculture requires an additional registration process after the Federal label is given to a pesticide. This delays the entrance of new compounds into the marketplace years. In about 30% of the **cotton** acreage in the San Joaquin Valley, spider mite resistance is a major problem. Because of this resistance to selective miticides, less selective chemicals are being used more frequently and greater losses in yield are occurring. A product which utilizes new toxicological pathways is stuck in the CDFA, even though it is selective, environmentally compatible, could be placed into pesticide rotation for management of resistance, is registered for cotton everywhere in the US, and has temporary registration in California on several food crops.

Other Regulations

Endangered Species Act

When people think of endangered species they usually think of some furry animal or at an extreme, a reptile. However, there are insects on the endangered species list. If you happen to share the same landscape as one, your chemical options will extremely limited. There are two cases I know where this could be a major problem. Along the riparian areas of the Sacramento Valley elderberry grows. Some growers have encouraged the reintroduction of this bush for the habitat it provides wildlife. On elderberry is found the elderberry longhorn beetle, an endangered species. The management options for insect control are limited for those people on whose land this occurs. The same situation would occur for those whose production area falls within the range of the Mojave sphinx moth.

Pest Exclusion Policies

Regulation of movements of produce across state and national borders can have positive and negative impacts. The US in general and California in particular have strict quarantine laws concerning organisms defined as noxious pests. An incomplete but familiar list contains Med fly, boll weevil, apple maggot, and citrus canker. The accidental introduction and establishment of any of these can cause major upsets to existing pest management systems. One need look no further than the southern deserts to see the impact on pest management when this system of exclusion fails, as it did with pink bollworm. Cotton production went from 100,000 acres in the 1960's to less than 30,000 by 1985. Chemical control measures upset other pests including whitefly which threaten valuable fall lettuce crops. Within the San Joaquin Valley grape **vineyards**, the introduction of the variegated leafhopper has caused major adjustments in the existing pest management program for western leafhopper. Finally, the full impact of the introduction of Russian wheat aphid is yet to be determined. Yield loss and increased pesticide costs are certainly predictable.

However, this exclusion of produce to prevent introduction of unwanted organisms works in both directions. Fuller rose beetle is a minor pest in California **citrus**. However, the Japanese consider it a pest which they do not want introduced into their country. Therefore strict inspection procedures are in effect and whole loads of citrus can be refused if one box of fruit is found with the beetle or its egg mass. Fumigation is possible for some citrus, but not for all. Recommendations are being made for spraying and certifying groves. This pest spends most of its life cycle in the soil and emerges only as an adult. The emergence period can be spread over a long period of time, requiring repeated pesticide applications. These applications only add to the over treated system in citrus.

Food Quality Standards

Food and Drug Administration

The FDA deals with processed food products and its purity. Some of its rules are often referred to as the 'filth laws'. It regulates the amount of foreign material which a product can contain. Foreign material includes dirt, rodent hair, and insect parts. With respect to the latter, the law can make no distinction between pieces of aphid (bad bugs) and pieces of ladybird beetles (good bugs). As the lady says 'part is parts'. I know of one example in which a field of **spinach** destined for the freezer had to sprayed for ladybird beetles after many unsuccessful attempts to lure them out. This will be a major obstacle for anyone trying to implement long term biological control in the processing vegetables.

Quality Standards

Much discussion has ensued over the years concerning the role of regulators in determining quality and cosmetic standards for fresh produce. Often USDA is recognized as the agency responsible for enforcing standards. However, USDA is responsible for establishing national grading standards but has little authority to require that these be met. Usually it is a buyer who requests that produce be certified meeting these standards.

Within CDFA, minimum quality standards exist most commodities. Unless otherwise covered by a specific section in the California Agriculture Code, the minimum quality standard for produce requires that *90 percent by weight ..... be free from insect injury which has penetrated or damaged the edible portion, worms, mold or decay*. These standards are do not make any mention of superficial cosmetic damage.

Marketing orders which are established voluntarily by producers through the authority of the California Agriculture Code can develop a more rigid set of standards. These are developed by the industry and reflect a desire to maintain areputation for quality produce. Maturity factors, appearance, and ripeness are a few of the factors considered. Cosmetic damage can be a major consideration. An example is **nectarines** where superficial scarring caused by thrips feeding requires close monitoring and control.

In some commodities, standards are unofficially maintained by the industry. In navel oranges for example, only the minimum California standards are officially in place. Unless a export buyer requests a specific USDA grade, standards for appearance, color, ripeness, and cosmetic imperfections are set by individual packing houses. Internal competition between houses coupled with the supply/demand for product quickly sets the standard for that year.

A case in point is **navel oranges.** The major pests are worms, citrus thrips and red scale. The latter can actually reduce yield and eventually kill a tree. Worms can cause direct damage by feeding. Thrips cause a superficial scarring which can result in a downgrade of fruit. The problem is that even a low population of thrips can be of concern. While there is an action threshold of 10% of the fruit with thrips, this level is reach every year in every grove within a few weeks of each other.

Since the population level which triggers a treatment is low, there is little room for mistakes. The amount of acceptable scarring varies depending on the supply but is unrealistically low. Because sprays must be applied yearly, introduction of biological control agents for red scale is limited. Resistance to existing synthetic insecticides is growing and control is getting more difficult. Use of environmentally soft botanicals like sabadilla or ryania requires closer monitoring and better management of these insecticides. These compounds preserve beneficial insects for mite as well as thrips management.

As long as the thrips population which triggers chemical treatment is low, pest managers will have too little time to maneuver. Much effort is being placed into developing strategies for thrips management when perhaps the most logic solution is to simply redefine the amount of scarring which first quality fruit can have. However, such an action is difficult under the current system. Only a focussed effort by producers, packers, brokers, grocers, and consumers to reach common ground can solve this problem.

Conclusions

Regulation occurs at all levels of agricultural production. It is imposed from the outside as well as internally. Regulations are rarely developed which take into account their impact on existing regulations or pest management systems. It could be suggested that before new regulations are imposed, an 'impact' report be produced. Taking this thought further, some sort of ombudsman should be created in Sacramento to monitor and evaluate new legislation.

The people of California are demanding that fewer pesticides be used. Yet the side effects of many of those rules designed to achieve this goal are encouraging increased use. The ultimate goal we desire should be clearly identified and we should work toward achieving it. A major step toward accomplishing this goal of fewer pesticides is an appreciation of the complexity of the agroecosystem including social and economic forces. Imposing regulation in the haphazard manner in which it has recently will only complicate and push further the realization of that goal.

LIVING WITH REGULATIONS: THE SEARCH FOR ALTERNATIVES

Jack Pandol, Jr., Pandol Bros., Inc., Delano, California

The search for alternatives to chemical dependency in our business began in the mid 1970's. At that time Jerry Brown, Jr. was governor and it became obvious to us that in the future it would be more difficult to obtain new product registration, that we would begin to lose products currently registered and that regulations and restrictions would be increasing substantially. Most people will agree that, in fact, these things have happened.

Our first attempts at these reductions took the form of beneficial insect releases, better timing of releases, use of narrow spectrum, quick knockdown materials that were easy on beneficials. We also focused on cover crops at the same time. We worked at refining these approaches for at least ten years.

From about 1985 to the present our motivation has changed somewhat, as well as our approach. We like to think of ourselves as a customer oriented company. What we were hearing from our end users through personal contact, as well as national surveys, was that people were fearful of chemical residues. Our whole country is into an environmental/chemical phobia. Our mission was not to question, but to meet our customers needs. In 1987 we set a "bold goal" of a 50% reduction in the use of synthetic agricultural pesticides without sustaining quality or yield decreases. By 1989 we accomplished a 65% reduction and produced some of our best quality.

This reduction was accomplished by some traditional methods, we just became very serious about it. With pests that were difficult to control we experimented with timing and rates. We paid close attention to degree-days and trap counts to time our applications better. We changed to alternative control methods, using materials that were naturally derived.

In less traditional ways we ventured into organic methods, doing 10% of our acreage in grapes under these methods in 1989.

In order to assure our customers of our product's safety we began an extensive program of laboratory testing for pesticide residues. Our 1989 goal has been 100% no residues detected. At the time of this writing we are on goal. This information has been used in our marketing program.

It is important to note that our motivation has changed from government and political pressure to a customer oriented desire to change. Our methods have evolved and improved over time and our results are accelerating. This is an evolution, not a revolution.

In the future we will continue to reduce our use of synthetic pesticides. We will continue to keep our consumers aware of the safety of our product. A new motivation is coming to the forefront as we see that some of the methods we are experimenting with now are making us better producers with better bottom line results.

Some say that the chemical phobia of today is fading, that it was just a fad fueled by the scare tactics of wild-eyed environmentalists and consumer groups. Our belief is that strong pressure will continue. Our goals must be to reduce chemical inputs and produce cleaner, more nutritious food. That is our challenge for the 1990's.

FARMING IN A REGULATED ENVIRONMENT: THE PROMISE OF ALTERNATIVE AGRICULTURE

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The real theme of this conference is preparing for the 90's. Farming in the 90's is going to be very different from farming in the 70's and 80's. To prepare for the 90's we are going to have to develop plant and animal production systems that are substantially different from those which have been developed in the past 40 to 50 years. The need for change is being brought about by the carrot and stick of our marketing and regulatory process. Increasingly the market is demanding food and fiber that is healthy, nutritious and grown with limited or no pesticides, and which contains no detectable residues. If the market is the carrot for agricultural change, legislators are providing the stick. Starting in California, state lawmakers across the country are taking a hard look at products being put in our soil, air and water that might end up in our mouths. Pressure caused by consumer concerns and legislative action is helping find a wider audience for the message that humans must be held accountable for what they do to the resources shared with other creatures. Erosion, drainage problems, and the accumulation of toxic materials in our water, soil and air pass from study reports to laws or initiatives. Numerous pieces of legislation, both at state and federal levels, are affecting the way agriculture will conduct business from now on.

Specifically, food safety, groundwater contamination, worker safety concerns and chemical company action are removing chemicals from the marketplace. And that is just the beginning. We may also have legislation that may deal with pesticide risks to children. This legislation, if passed, will have a profound effect on the way pesticides are regulated or remain on the market.

The question for agriculture is: how do we deal with all these changes? The first thing we need to be is open-minded and flexible. It will take creativity and ingenuity to develop farming systems in the next few years that are environmentally sound. Just as producers in the field are reframing their issues and needs to respond to a changing environment, those of us in research and development too must frame our questions and responses to develop an agricultural system that is less dependent on the use or management of toxic materials.

In the past, the agriculture research and development establishment has had a major role in shaping agricultural change. We must move beyond the narrow scope of our own disciplines and address the interconnected problems of modern agriculture. Today's agricultural problems cannot be laid at the door of any one discipline. They are a result of what we all do together. We must learn to value the broad and general truths as much as we value the narrow and specific. One such way to do that is to develop farming systems research. Systems research is a philosophic and scientific way to deal with large, complex issues, using researchers from many fields. Because it relies on many disciplines and specialists, systems research is more difficult to develop and coordinate. But looking at an agricultural problem from many angles and disciplines is likely to produce long-term results because it takes the entire agricultural vista into consideration. Information gathered from the entire system leads to realistic management tools for the practitioner, who seeks high profits from high yielding, safe, nutritious crops.

The second part of the title of my talk, 'The Promise of Alternative Agriculture,' suggests that there are alternatives to our present predicament. Since other speakers have talked or discussed the implications of regulations from a farming or ranching perspective, I would like to concentrate on the research and extension opportunities that exist. Right now there are about 250 plant systems in California. Additionally, there are numerous animal products produced in California which are fed on plant products. If the regulatory environment changes rapidly with the passage of the proposed 1990 "safe food" initiative, the major changes that it will bring must be addressed very quickly. Those growers who are not making the transition to more environmentally sound farming practices will be forced to do so very rapidly. This suggests that those developing information or advising growers of new information will be under tremendous pressure to help the state's agricultural community adjust to the realities of the 90's. How do we accomplish this? I think we should suggest that growers begin the transition process now on small sections of their own operations using revised or new production practices. This move to the transition is a topic by itself and requires much thought and ingenuity, but it is clearly a process that should be started as soon as possible. From this kind of experience growers will find out what the limiting factors of their own land, crops and climate are. With that knowledge they can begin to deal with their own particular environmental and management problems.

The research and development community needs to move rapidly to address the changes that are coming. We need to take a look at the issue of soil health. This may be a way to address many of the cropping systems problems we face. We need to understand the physics, chemistry, and biology of soils in an integrated sense rather than deal with each of these subjects in an isolated manner. Many of our pest management problems may be related to the way we manage the soil. Instead of focusing on the cures we need to focus on preventative strategies. We may need to find ways of incorporating diversity into our cropping systems. These are all fairly general principles that must be addressed. I would like to briefly discuss these particular principles using examples of current research and extension activities that are underway at the University of California that involve both component and systems research and extension activity.

ALTERNATIVES TO PESTICIDES FOR STRAWBERRY ARTHROPOD PEST MANAGEMENT: A PROGRESS REPORT

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The BugVac was developed by Driscoll Strawberry Associates, Inc. as a novel way to control the lygus bug, a key insect pest of locally grown strawberries.

Through the use of the BugVac in 1988, Driscoll growers were able to manage lygus populations below damaging levels. Although some beneficial insects are removed by BugVac treatments, enough remain to provide effective biological control of other strawberry pests such as aphids, flower thrips and spider mites.

Driscoll's prototype BugVac was first tested in 1987 on 3 acres of winter plated strawberries (cv Heidi) in Watsonville, CA. Use of the BugVac expanded to 4 machines operating on 500 acres in 1988 and to 17 machines in operating on the majority of Driscoll's 1,300 acres in the Watsonville, Salinas and Santa Maria areas at the start of the 1989 season.

The encouragement of a healthy, natural balance of beneficial and pest species through the use of the BugVac has helped to greatly reduce, and in some cases, eliminate the need for conventional pesticides which greatly disrupt the ecology of the strawberry field.

Designing alternative cropping systems for California farmers

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Most agricultural regions of California enjoy long growing seasons, fertile soils and irrigation, all conditions that favor a highly diversified cropping. In addition the wide variety of vegetables, field and tree crops determine a high diversity and flexibility of agricultural enterprises. Despite these factors, California agroecosystems are dominated by monocultural cropping systems. Although productive, these systems lack the ecological features to ensure efficient nutrient cycling, water and soil conservation and biotic regulation. Productivity is subsidized with chemical inputs such as pesticides and fertilizers some of which cause undesirable environmental and public health hazards. Large-scale monocultures are also highly susceptible to wind erosion, and dependent on groundwater for irrigation leading in some areas to a considerable "overdraft." In other regions poor field drainage and rising water tables are leading to unacceptable soil salinity levels. In summary, California agriculture is very productive, but the environmental cost of such productivity is threatening the sustainability of agriculture.

The search for self-sustaining, low-input, diversified and energy efficient agricultural systems is now a major concern of researchers, farmers, policy makers and the public in California. A key strategy in sustainable agriculture is to restore agricultural diversity of the agricultural landscape. Diversity can be enhanced in time through crop rotations, sequences and in space in the form of cover crops, intercropping, agroforestry crop/livestock mixtures, etc. As shown in Figure 1, different options to diversify dominant cropping systems are available, depending on whether the current monoculture systems to be modified are based on annual or perennial crops.

Table 1 assembles a number of examples of alternative diversification strategies tested in California, summarizing the beneficial effects on soil fertility, crop protection and crop yields. If two or more of the these alternative technologies are used, the possibilities of complementing interactions between agroecosystems components are enhanced (Figure 2) resulting in one or more of the following effects:

a. continuous vegetation cover for soil protection
b. constant production of food, ensuring a varied diet and several marketing items

c. closing of nutrient cycles and effective use of local resources
d. soil and water conservation through mulching and wind protection
e. enhanced biological pest control through diversification
f. increased multiple use capacity of the landscape
g. sustained crop production without use of environmentally degrading chemical inputs

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Table 1. Examples of alternative cropping systems tested in California that emphasize diversification strategies and their ecological effects

DIVERSIFICATION STRATEGY	CROPPING SYSTEM	MAIN EFFECTS	REFERENCE
Crop rotation	Rhodegrass, Timothy grass - sour orange seedlings	increased seedling growth	Martin and Ervin 1954
	Sugarbeets - nonhost crops	reduced incidence of cyst nematode	Roberts et al 1981
	Vetch - rice	increased N and enhanced rice yield	Williams and Dawson 1980
	Barley-onions or potatoes	decreased root-knot nematode, enhanced barley yield	Allen et al 1970
	Cotton-paddy rice or perennial rye grass	reduction in *Verticillium* wilt	Butterfield et al 1978
	Cotton-barley, corn or sorghum	reduction in *Verticillium* wilt	Wilhelm et al 1966
Cover cropping	Alfalfa and hubam clover in pears	improved water infiltration in orchard soil	Werenfels et al 1963
	Vetch and fava beans in apple orchards	decreased incidence of codling moth, rosy apple aphids and leafhoppers, enhanced apple yields	Altieri and Schmidt 1986a
	Oleander under citrus	insectary for the production of	Flanders 1949

		the black scale parasite <u>Metaphycus helvolus</u>	
	Several cover crops in orange	long term increase in orange yields	Parker and Jones 1951
	Ground cover of Johnson or sudan grass in vineyards	enhanced predation of Willamette mite	Flaherty et al 1971
Integration of animals into farming system	Use of geese in cotton, vineyards and orchards	control of grass weeds such as Johnson grass, Bermuda and nutgrass	Conley and Peterson 1957
	Chicken manure in alfalfa	higher yield than alfalfa treated with superphosphate	May and Martin 1966
	Dairy manure in citrus and avocado orchards	efficient source of N, P and K	Embleton and Jones 1956
Multiple cropping	Cotton-alfalfa strip cropping	enhanced control of the Lygus bug	Stern 1969
	Broccoli-fava bean or wild mustard intercropping	reduced incidence of cabbage aphids and leo beetles	Altieri and Schmidt unpub. data
	Asparagus-barley interplanting	reduced wind erosion and enhanced asparagus yields	Schultz et al 1963
	Cotton-sudan grass or german millet grown in furrows	increased water infiltration rates improving irrigation efficiency	Yamada et al 1963
	Collard-bean intercropping	reduced flea beetle incidence and enhanced	Gliessman and Altieri 1982

		weed suppression	
	tomato-squash intercropping	enhanced tomato yields and reduced aphid densities on squash	(Trujillo, unpub. data)
	oats undersown with alfalfa	effective weed control	Flint and Roberts 1988
Crop field border diversification	<u>Rubus</u> blackberries surrounding vineyards	enhanced abundance, survival and efficiency of grape leafhopper parasitoid	Doutt and Nakata 1973
	Prune trees bordering vineyards	abundance, survival and efficiency of grapeleafhopper parasitoid	Flint and Roberts 1988
	Coyote brush surrounding vineyards	source of natural enemies of the orange tortrix	Kido et al 1981
	Weeds along edge of alfalfa	increased dispersal of predaceous Coccinellidoe	Altieri and Letourneau 1982
	borders of wild-mustards around cole crops	trap cropping of fleabeetles and cabbage aphids	Altieri and Schmidt 1986b

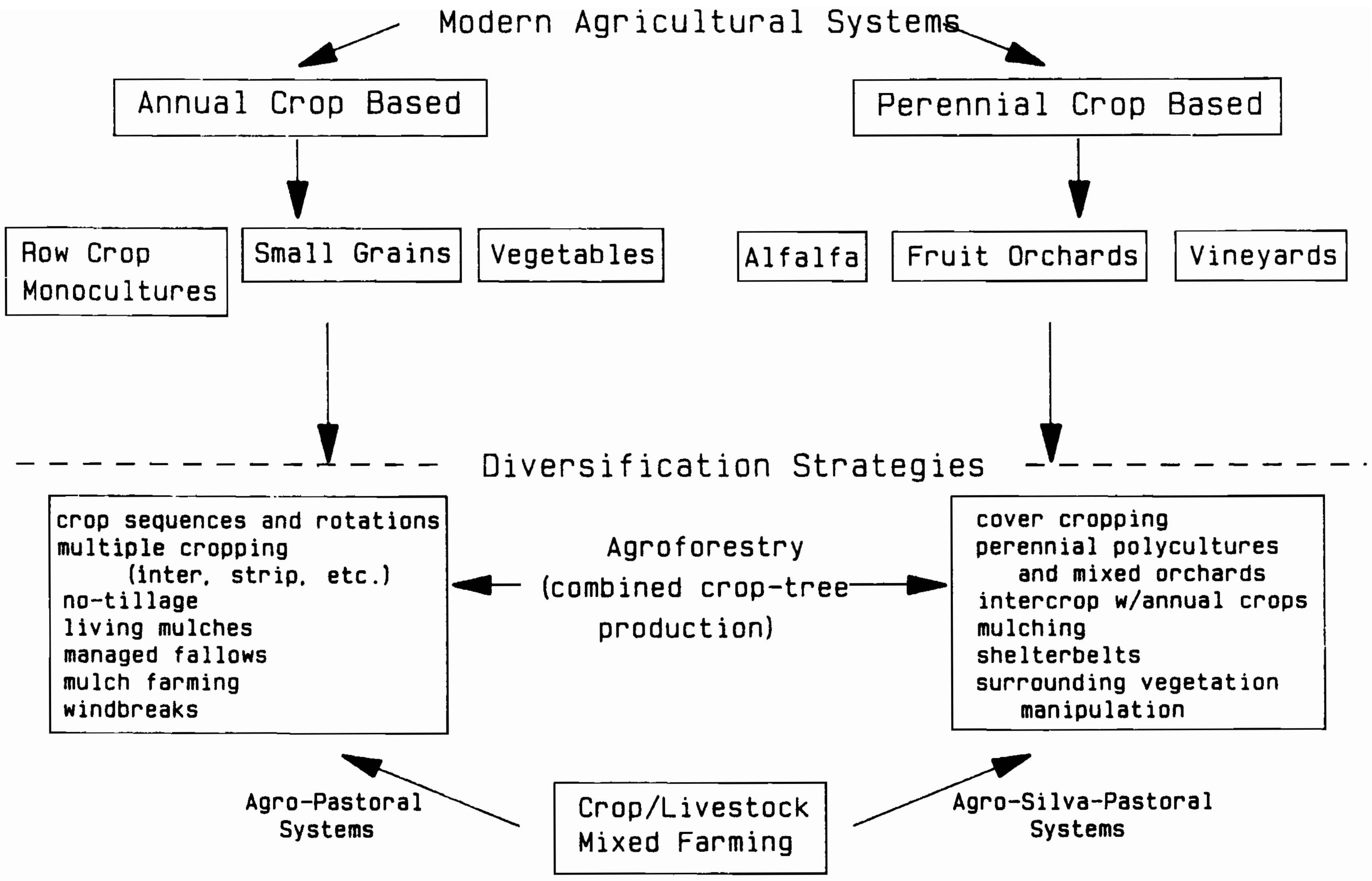

Figure 1. Diversification options for annual or perennial crop based conventional cropping systems in California.

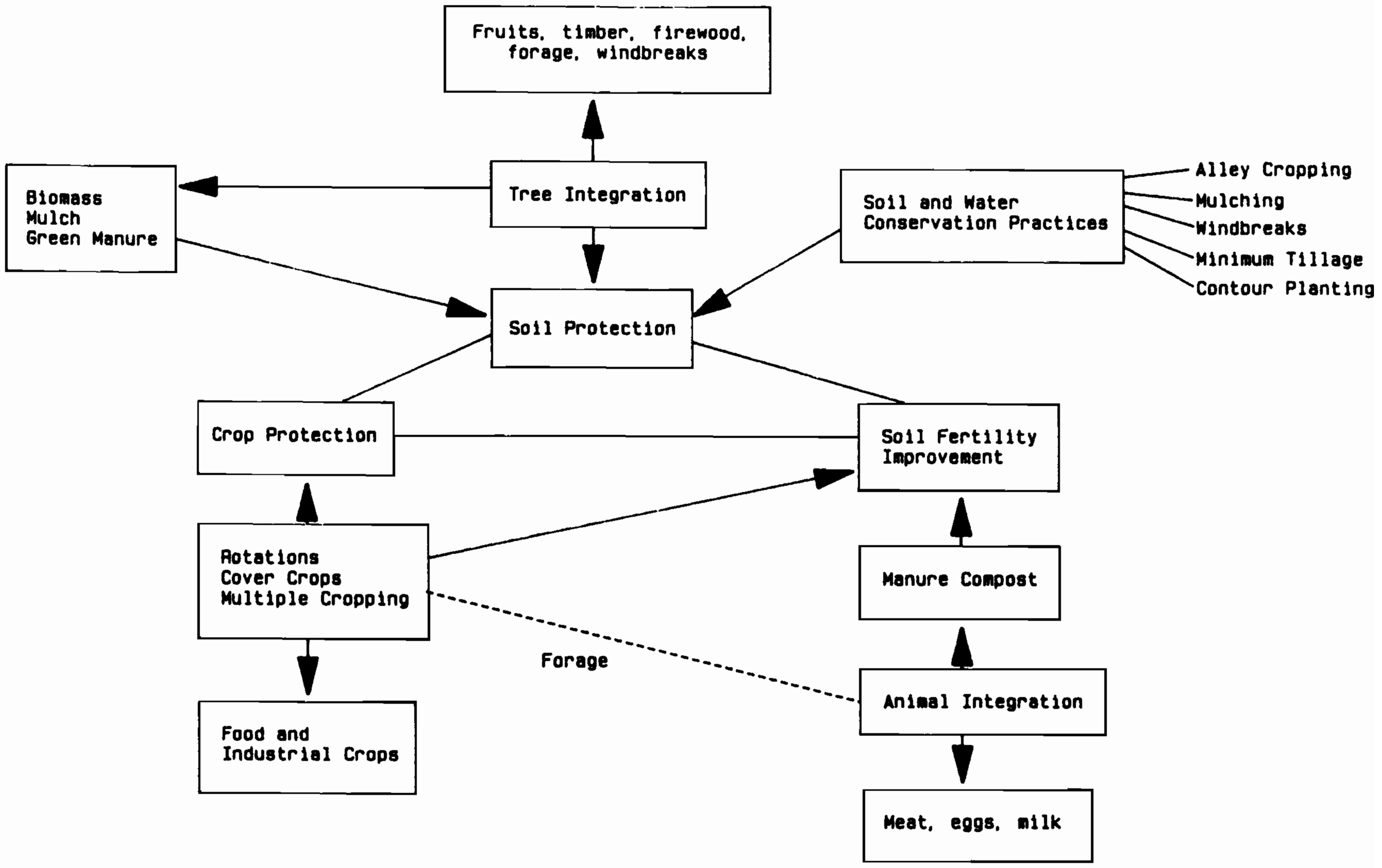

Figure 2. Complementary interactions in diversified cropping systems resulting in enhanced soil protection, soil fertility and biological crop protection.

BIOTECHNOLOGY AND SUSTAINABLE AGRICULTURE:
A PRELIMINARY STATUS REPORT

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It is generally held that the agricultural practises of primitive mankind, or even of the early decades of "industrialized" agriculture in the late 19th century, were less damaging to the environment than today's agriculture is proving to be. Whether or not this is so, today's agricultural practices are among the many factors that threaten the long-term stability of the earth's environment. Thus, changes are called for in adjusting agricultural practices to serve the long-term need for a more sustainable agriculture.

Sustainability requires that farming practises be based on the principle that agriculture is, first and foremost, a biological process. In practice, this means attempts to mimic the key characteristics of a natural ecosystem, while still maximizing the yield of one or more components. The management focus in sustainable agriculture is on strategies that balance the striving for high yields each year with the biological requirements of longer-term ecological stability. This requires a sophisticated approach that maximizes the use of genetic resources and emphasizes stewardship.

How can genetic manipulations be successfully applied to advance the agenda of sustainable agriculture and in particular, what contribution might modern biotechnology make?

Weed control. The first genes of agricultural interest to be tested using the recombinant DNA technology were genes conferring tolerance to herbicides. Early attention was focussed on the herbicide N-phosphonomethyl glycine (glyphosate) because the mode of action of the herbicide was known.

Glyphosate is a potent inhibitor of the shikimate pathway leading to the synthesis of aromatic amino acids in bacteria and plants. Two independent research groups set out to engineer resistance to this herbicide in the early 1980s. One group concentrated on engineering a mutant bacterial gene for expression in plants. The other group has pursued cloning and expression of a plant gene. Both have been successful and have had glyphosate-tolerant tobacco and tomato in field trials beginning in 1987. Other field trials in 1989 have included phosphinothricin resistance in alfalfa and bromoxynil resistance in cotton.

Contrary to the claims of some critics of biotechnology, some herbicide tolerances may result in lowered overall usage of herbicidal chemicals. Glyphosate tolerance in field-grown tomatoes for processing is a case in point. Herbicides currently play a major role in processing tomato production because weed control is crucial to achieving high yields at all stages of tomato culture. Early in the season, competition with weeds can cause yield reductions and delay harvest. At harvest, weeds can hinder mechanical harvesting. Current practices with processing tomatoes in the major US production area of California's Central Valley (>220,000 acres; >80% US processing tomato yield) include at least one preplant and preemergent application as well as a "lay by" herbicide application next to the plant row. As many as nine different chemicals have been recommended for spray and soil incorporation and typical practice involves the use of at least three of these chemicals on each acre. With the use of a glyphosate-tolerant tomato, post-emergence applications of the herbicide would economically control weeds without harming the tomato crop. The herbicide has a very wide phytotoxicity spectrum but low mammalian toxicity, a relatively short environmental half-life, and is systemic. Its use could result in a significant decrease in overall herbicide usage, and a decrease in toxicity from all the chemicals that are applied, because glyphosate is much less toxic than many other chemicals recommended for use with tomatoes. Fewer applications mean directly lowered overhead costs in time and chemical applied. Less immediately obvious are possible benefits from reduced soil compaction from fewer passes over the field with heavy equipment, and less energy expended on soil incorporation of herbicides.

Insect tolerance. One of the most straightforward applications of genetic engineering technology to crop plants to decrease reliance on chemical protectants is new uses of genes encoding proteins that inhibit insect growth and development. One of these approaches uses *Bacillus thuringiensis*, bacteria that produce a group of related proteins that are lethal to most moth and butterfly, or lepidopteran, larvae. The larval stage of a pest's life cycle is usually the most damaging to the crop because that is when the insect is herbivorous. Neither other groups of insects nor other life forms are significantly affected by the proteins. *B. thuringiensis* toxin can currently be purchased as an emulsion that is sprayed on plants. The bacterial gene coding for the toxic protein has been isolated.

There are at least three ways in which genetic modification can be used to improve the use of the *B. thuringiensis* toxin. The first is to attempt to do better than Mother Nature at the design of the toxin itself - perhaps to make it more specific, more efficacious, or more active against insect species for which *B. thuringiensis* toxin strains do not now exist. The second is to endow different bacteria with the ability to produce *B. thuringiensis* toxin. A reason one might take this second approach is to deliver the toxin to a place that is not accessible to sprays with *B. thuringiensis* in present formulations, such as roots. A third approach, which is related in its objective to the second, is to engineer the crop plant itself to produce toxic levels of the *B. thuringiensis* toxin. This approach makes sense in cases where the insects inhabit and feed on parts of the plant that are inaccessible to sprays, such as roots or young cotton bolls. New bacterial and fungal sources for insect toxins that can be used as natural insecticides like the *B. thuringiensis* are actively being sought.

Several strategies have been proposed to address the possibility of evolution in pest populations after exposure to plants expressing Bt toxin. Several factors may deter such pest evolution. Firstly, there are a number of Bt toxin genes, and the range of susceptible insect species is somewhat different for each. The concurrent use of more than one engineered Bt toxin gene, each with a different toxicity profile, may further reduce the possibility of pest evolution. Using genetic engineering techniques, the expression of toxin genes could be limited in overall level or to particular tissues to yield a partial insect kill. Also, it has been proposed that mixtures of transgenic and non-transgenic seed be developed as multilines. Finally, the concurrent use of different strategies with different modes of action, including perhaps some chemicals in an IPM program, can be used.

Disease resistance. A third area where biotechnology can contribute to sustainable agriculture is disease resistance. For example, although no chemical can impede viral infection directly, the use of plant genotypes resistant or tolerant to a virus would obviate the use of pesticides for the control of viral vectors such as thrips, aphids, beetles, and white flies. Advances in research on resistance mechanisms in plants and virulence of plant pathogens such as fungi and bacteria will likely lead quickly to advances in novel disease control methods. One recent example of a disease tolerant phenotype resulted from engineering genes for virus coat protein. Expression of the genes conferred a high degree of tolerance to engineered plants by delaying the onset of disease by a margin that may be significant to the farmer economically. In some cases, transgenic plants are resistant to infection by the virus. The effect is virus-specific. This phenomenon has been demonstrated in laboratory experiments for at least six plant virus families to date and field trials with transgenic tomato plants tolerant to tobacco mosaic virus (TMV) and two potato viruses (PVX and PVY) were conducted in 1989.

Quantitative genetic traits. One further example of the contribution recombinant DNA technologies are making to plant improvement is the use of molecular markers in breeding programs. The DNA sequences of genes in different individuals, within a species or from closely related sexually compatible species, can differ in subtle ways. These differences can be revealed as variations in the pattern observed when total DNA isolated, for example, from individual progeny of a cross, is cut with restriction endonucleases and the resulting fragment separated on the basis of length on an agarose gel. This technology can be useful in managing breeding programs and in identification and manipulation of single genes and chromosome regions contributing to quantitative traits such as water efficiency. Undoubtedly, this technology will be applied to other complex characters such as horizontal disease resistance to facilitate the breeding of these complex traits.

IMPACT OF POTASSIUM DEFICIENCY ON COTTON QUALITY

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Abstract

The effect of potassium (K) on cotton lint quality was evaluated during a three year field trial. A single cultivar (Acala SJ-2, 1985) and two cultivars (Acala SJ-2, Acala GC-510, 1986 and 1987) were grown with 0, 120, 240, or 480 kg K /ha in 10 blocked replications of each K level on an irrigated vermiculitic soil. The yield response to applied K was significant each year. Lint yield increased relatively more than seed yield. Higher lint percentages were observed as plant K supply increased. Greater lint percentage reflected increased fiber length and micronaire (secondary wall thickness) and was directly related to applied fertilizer K. Differences in fiber properties were more pronounced after the third year of this study due to the cumulative effect of annual K addition treatments. For both cultivars, fiber length, micronaire index, fiber strength and percent elongation, and fiber length uniformity ratio were each positively related to fiber K concentration at maturity, to leaf K concentration at early bloom, and to an index of soil K availability. Fiber quality of Acala GC-510 was higher than Acala SJ-2 at low fiber, leaf, or soil K levels. The results from this 3-year study demonstrate that plant K supply during the fruiting period is an important determinant of fiber quality under field conditions, and that the K requirements for optimum lint production and acceptable fiber quality differ among cultivars.

Table 1. Lint and seed yield, and lint percentage of two Acala cotton cultivars as influenced by K fertilization on a vermiculitic soil in 1986 and 1987. (Cassman et al. 1990)

Annual K rate	Cultivar	1986			1987		
		lint yield	seed + yield	lint percentage	lint yield	seed + yield	lint percentage
kg/ha		——kg/ha——		%	——kg/ha——		%
0	SJ2	759	1330	36.3	722	1149	38.6
	GC510	1046	1660	38.7	1028	1484	40.9
120	SJ2	908	1547	37.0			
	GC510	1148	1802	38.9			
240	SJ2	952	1626	36.9			
	GC510	1202	1863	39.3			
480	SJ2	1087	1813	37.5	1238	1899	39.4
	GC510	1319	2040	39.3	1411	1953	41.9
	Cultivar Means						
	SJ2	927	1579	36.9	980	1522	39.0
	GC510	1179	1842	39.0	1220	1719	41.9
AOV:							
	K rate	***	***	***	***	***	***
	Cultivar	***	***	***	***	***	***
	K x Cultivar	NS	NS	NS	*	*	NS

*, *** Indicate significance at $P < 0.05$ and 0.001, respectively.

\+ Ginned seed yield before delinting.

Table 2. Effect of fertilizer-K addition on nutrient concentrations in fiber at maturity (dry weight basis) in two cotton cultivars, 1987. (Cassman et al. 1990).

Cumulative Fertilizer-K addition	Cultivar	Nutrient Concentration of Fiber *					
		N	P	K	Na	Ca	Mg
kg/ha		%					
0	SJ2	0.18	0.06	0.57	0.12	0.0421	0.062
	GC510	0.19	0.07	0.52	0.13	0.0381	0.0608
1440 +	SJ2	0.18	0.07	0.63	0.09	0.0401	0.0644
	GC510	0.18	0.06	0.61	0.08	0.0361	0.0644
AOV							
K rate		NS	NS	***	***	NS	NS
Cultivar		NS	NS	***	NS	NS	NS
K x Cult.		NS	NS	**	NS	NS	NS

* Cations converted to % from mmol (+)/kg, N and P from g/kg.

\+ Cumulative total from annual application of 480 kg K ha made before planting cotton in 1985, 1986, 1987.

, * Indicate a significant treatment effect at P < 0.01 and P < 0.001, respectively.

Table 3. Effect of fertilizer-K addition on the K concentration of lint and delinted seed, and on fiber quality parameters of two Acala cotton cultivars in 1987. (Cassman et al. 1990).

Cumulative fertilizer-K addition	Cultivar	K Concentration		Fiber Quality Characteristics				
		lint	delinted seed	length	micronaire index	strength	elongation	uniformity ratio
kg/ha		——gK kg——		mm		kN m kg	%	
0	SJ2	5.64	11.76	27.9	3.23	218	5.1	0.80
	GC510	5.17	11.88	28.1	3.85	220	5.7	0.82
1440 +	SJ2	6.26	11.72	28.7	3.76	234	5.6	0.81
	GC510	6.06	11.85	28.5	4.21	231	6.2	0.83
	Cultivar means							
	SJ2	5.95	11.74	28.3	3.49	226	5.3	0.81
	GC510	5.62	11.85	28.3	4.03	226	5.9	0.82
AOV								
	K rate	***	NS	***	***	***	***	***
	Cultivar	***	**	NS	***	NS	***	***
	K x Cultivar	**	NS	***	NS	NS	NS	NS

+ Cumulative total from annual application of 480 kg k/ha made before planting cotton in 1985, 1986, and 1987.

, * Indicate a significant treatment effect at $P < 0.01$ and $P < 0.001$, respectively.

DESIGNING A TOP QUALITY PLANT

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Acala cottons at 2.5 to 3.0 plants per foot of row on 40-inch rows produce about 58, 21, 6, and 12 percent of the total yield on first, second, or third positions on fruiting branches, and on vegetative branches, respectively (see accompanying table). Dr. Jenkins in Mississippi has reported similar values for Delta variety cottons grown in the Delta.

We conducted replicated studies during 1986 and 1987 to compare quality of bolls set at different times during the year as well as potential effects of branch position. Bolls were harvested from the plant by branch and node position and analyzed separately. Results were summarized by averages for branch position as well as time of year when fruiting positions set blooms (see accompanying table.

Differences in fiber length were significant but rather small. The longest fibers were produced early in the year at first fruiting positions, while the shortest was produced on vegetative branches or late in the year. Differences in uniformity of fiber length (2.5 % span/50 % span) were about the same as fiber length. Overall percent short fibers averaged 7.7. There was a very strong effect of both time of year and position on the plant for short fiber percentage. First positions and early bolls had few while outer positions on fruiting branches and vegetative branches produced bolls with a high short fiber content.

The strongest fibers with the highest micronaire were produced early in the year or on the first positions of fruiting branches. Weaker fiber with lower micronaire was found on outer branch positions and also for bolls produced late in the year.

Bolls averaged 6.6 grams. Bolls in the first position were much larger than any other position. Time of bloom did not greatly reduce boll size until near the end of the season. Although both time and position had significant effects, branch position was the biggest factor. Cool germination percentage averaged 66.5 and followed time and branch position differences very similar to that of boll size.

Although we have the comparisons for branch position differences at exactly the same time of bloom and for time differences at the same branch position we have not included them because they are complex. However, I would like to make a summary statement that micronaire, boll size, and, to a lesser extent, cool germination percentage, all show lower values for early set bolls at all positions. These bolls should have the best chance at energy since they grow at a time when there is less of a boll load. The fact that later set bolls which are higher on the plant are more developed indicates there is enough shading by upper leaves that these lower early set bolls do not develop to their potential.

Quality Limiting Factors

- Vegetative branches and fruiting positions at the third or greater position on a fruiting branch produce poor quality fiber. The first position on a fruiting branch produces the very best fiber.

- Bolls set during the first 400 DD_{60}'s of flowering even at favorable branch positions show loss of size, germination of seed, and decreased micronaire, presumably due to shading of leaves important to their sustained development.

The Ideal Plant

To overcome the yield and quality limiting factors discussed, an ideal cotton plant should have vigorous development of early leaf area, produce squares early in the year, balance partitioning of energy to bolls and new growth so that production of new leaf area can be maintained, it would produce only short fruiting branches to avoid shading of lower bolls, and it would set bolls only at the first and second positions of fruiting branches. Such a plant type would likely do best in narrow-row spacings.

Plants exhibiting these characteristics have been noted for years, but have not fit our historical production scheme. We have made selections within the materials developed by the late Dr. Angus Hyer and are currently evaluating them for yield and response to management. Initial results are very encouraging. We are beginning our studies of fiber quality distribution with these types and intend to continue studies to bring to light best management strategies for them.

Effect of position of a boll on the plant and time of bloom on quality of bolls compared to the whole plant average as a percentage. Acala SJ-2 grown at Shafter, CA, 1986 and 1987. Fiber analysis by Dr. Ruppenicker, ARS, New Orleans.

	% of of Crop	Length (2.5% span)	Uni- formity Ratio	% Short Fibers	Strength (g/tex)	Micro- naire	Boll Size (g/boll)	Cool Germi- nation (%)
Whole Plant								
Average		1.130	44.03	7.67	26.92	4.38	6.60	66.50
<u>Fruiting Branch</u>								
First	58	101	101	91	101	106	107	112
Second	21	100	99	106	100	93	94	87
Third	6	98	98	118	98	86	84	81
Vegetative Branch	12	97	99	124	95	92	85	75
<u>Time of Bloom</u> (DD$_{60}$'s)								
900-1100	23	105	102	74	103	101	101	109
1100-1300	37	101	100	97	102	99	100	97
1300-1600	24	97	100	117	96	105	103	108
1600-1900	11	95	99	121	94	96	98	96
>1900	4	96	97	124	98	86	83	80
<u>Statistics</u>								
Position Effect		yes	yes	yes	yes	yes	yes	yes
Time effect		yes	no	yes	yes	yes	yes	yes