MANAGING POOR WATER PENETRATION USING:
- WATER QUALITY TESTING
- UC GUIDELINES FOR INTERPRETATION
- IRRIGATION WATER TREATMENT

Prepared by

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Acknowledgements:

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ABSTRACT

About 2.25 million acres of crops are affected by poor water penetration in California. Economic losses range from $20 to $500 per acre due to the inability to adequately irrigate crops limited by poor water penetration. Sandy to clay textured soils can develop poor water penetration. Mineral, physical, biological and chemical soil properties can all be factors causing poor water intake.

This report discusses the effect of irrigation water quality on water penetration. Two trials were conducted in Kings County during 1990, one in walnuts and the other in cotton. Both sites had an established history of poor water penetration. Water amendment appeared to improve water penetration at both sites. Short term indicators of tree stress were lower in walnuts irrigated with improved water quality. Lint yields in the cotton field increased nearly 200 lbs/ac when irrigated with amended water. Irrigation water amendment was profitable in the cotton field.

INTRODUCTION

The effect of irrigation water quality on water intake is the focus of this report. Individual salt constituents and the total salinity of an irrigation water affect the stability of soil structure. Irrigation water with low total salinity cause clays to swell; the swelling causes breakdown of soil aggregates, promotes soil crusting, plugging of soil pores and reduced water penetration. Irrigation water with a high proportion of sodium, even with high total salinity, also enhances swelling, soil aggregate breakdown and reduced water penetration.

Both the total salinity and the proportion of sodium in the irrigation water must be considered to assess the potential effects of irrigation water quality on water penetration. Total salinity is evaluated using the ECw (electroconductivity of an irrigation water) and the proportion of sodium is assessed using the SARw (Sodium Adsorption Ratio) of an irrigation water. Both of these indices are commonly provided in a water analysis. Figure 1 provides guidelines for interpreting the ECw and SARw from a water analysis for water penetration problems.

The guidelines suggest no reduction in water intake due to water quality when the SARw is less than 5 times the ECw, slight to moderate reductions in water penetration when the SARw exceeds 5 and approaches 10 times the ECw, and severe reductions in water intake when the SARw is more than 10 times greater than the ECw.
Many surface water supplies and well waters in the San Joaquin Valley are either low in total salinity or contain a large proportion of sodium. As a result, there has long been interest in developing a method of water treatment to improve the irrigation water quality before it is applied to the crop. In recent years, a method has been developed to continuously inject dissolved gypsum (calcium sulfate dihydrate) into the water supply at low, controlled rates, hence, increasing the total salinity and calcium levels compared to sodium.

In 1990, two on-farm trials were conducted in Kings County to experience a new method of water amendment. The goals were to improve the irrigation water quality, increase water intake rates of soils with poor water penetration, evaluate crop responses to improved water intake and assess the profitability of water treatment.

SITE SELECTION

Two sites were selected in 1990, an 80 acre walnut orchard (Vina variety on Paradox rootstock) and a 26 acre cotton field (GC-356 variety). Both sites had a long history of poor water penetration especially during the summer months. Poor nut quality due to sunburn and shrivel was the main production concern in the walnut orchard while unsatisfactory lint yields were of concern in the cotton field. Water quality analyses suggested that undesirable water quality was contributing to poor water penetration at both sites.
The orchard consisted of a fine sandy loam to clay loam surface soil which developed cracks upon drying, the subsoils were course sandy loams, surface soils were disked before some irrigations, traffic and tillage increased during harvest, and the irrigation water was low in total salinity. The cotton field consisted of a course sandy loam surface soil which developed a firm surface crust following irrigation. The subsoils showed a gradual change in texture from sandy loam to loamy sand. The soil was ripped to a depth of 18 inches before planting and three cultivations were completed before crop layby. Wheel traffic was confined to specific furrows based on a six row planting configuration. Total salinity in the irrigation water was sufficient, however, sodium was the main soluble salt in the water.

WATER TREATMENTS

The untreated well water was compared to two levels of amended water in the walnut orchard during all irrigations (refer to plot plan in Appendix A). Each treatment was applied to two acre plots with a border flood system. Limited resources prevented replication. The applied water in the low gypsum treatment was amended by dissolving 570 lbs of 100% gypsum/ac-ft of water (2.5 meq Ca/l) and the applied water in the high gypsum treatment was amended by dissolving 1140 lbs of 100% gypsum/ac-ft of water (5.0 meq Ca/l). Applied water was measured with broadcrested weir and Parshall flumes. Similar amounts of water were applied to each treatment during the season. About 6 to 12 percent more water was applied in the treated plots. Differences in applied water were attributed to improved water intake from the treatments (refer to Appendix B for irrigation schedule).

The untreated well water in the cotton field was compared to one level of amended water (see plot plan in Appendix A). The well water was amended by dissolving an average of 975 lbs of 100% gypsum/ac-ft of applied water (4.2 meq Ca/l). The irrigation water was treated only after the last cultivation to minimize treatment costs. Each treatment was replicated twice using 4 acre plots. Water was applied using poly-pipe and was measured in six furrows per treatment with broadcrested furrow flumes. About 15 percent more water was applied in the treated plots; this was attributed to slower water advance possibly resulting from treatment effects on water intake (see appendix B for schedule).

TREATMENT EVALUATIONS

Water samples were taken for each treatment in the walnut orchard to determine the effects on water quality. The rate of water
intake was evaluated by determining the time required to achieve 50 and 100 percent orchard floor exposure after each irrigation. Water content was measured to a depth of five feet before and after each irrigation with a hydraprobe at four sites in each treatment.

At the onset of the walnut trial, minimal yield response was expected during the first year. Other irrigation research has indicated that one year of improved water conditions is needed to grow new fruiting branches that may bear more walnuts with improved quality the next year. In the short term, predawn leaf water potential was measured on the morning before each irrigation and in three hour increments for nearly a 24 hour period just before the last irrigation in July to determine levels of tree stress in each treatment. Stomatal conductance was also measured in three hour increments during the daylight hours in July to determine the rate of CO₂ transport into the trees during photosynthesis.

Production from each treatment was monitored using commercial walnut harvesting and quality grading methods. Soils were sampled in 6 inch increments to 24 inches and in 12 inch increments from 24 to 48 inches at four sites in each treatment. Total salinity and the proportion of sodium was determined for each soil sample.

Time required to achieve complete water disappearance after each irrigation was evaluated in the cotton field. Water content was measured before and about five days after each irrigation with a hydraprobe. Measurements were taken in each plot to a depth of 4 feet at 4 locations down one bed parallel to a non-traffic furrow. Total soil salinity and the proportion of sodium was measured in each treatment. Soil samples were collected after defoliation in 6 inch increments to a depth of 18 inches at 4 sites in each plot. Cotton subsamples were hand harvested at four locations near the hydraprobe access tubes in each plot. Each four acre plot was commercially harvested and ginned separately.

RESULTS AND DISCUSSION

Water Quality

Table 1 gives the water analysis for the untreated and treated irrigation waters at the orchard and cotton field. Treatments in the orchard increased the total salinity (ECw) from 0.2 dS/m in the untreated water to 0.4, and 0.7 dS/m in waters treated with the low and high gypsum rates. Treatments increased calcium levels while sodium levels remained the same as the untreated water. Since total salinity was increased and the proportion of
calcium to sodium was improved, overall water quality was improved from water with severe intake restrictions to a quality with no limit on water penetration (refer to Appendix C, Figure 1). Water treatment in the cotton field increased total salinity (ECw) from 0.8 dS/m to 1.2 dS/m; more importantly the proportion of calcium to sodium in the water was improved. As a result, the water quality was changed from one likely to reduce water intake to a quality that should not reduce water penetration (see Appendix C, Figure 2).

Table 1. Water quality analysis of untreated and amended water qualities applied in walnuts and cotton infiltration trials, Kings County 1990.

<table>
<thead>
<tr>
<th></th>
<th>ECw (dS/m)</th>
<th>Ca (meq/l)</th>
<th>Na (meq/l)</th>
<th>SARw</th>
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<td><strong>WALNUT ORCHARD:</strong></td>
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<tr>
<td>Common Water</td>
<td>0.2</td>
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<tr>
<td>Low Treatment</td>
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<td>High Treatment</td>
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<td>1.1</td>
<td>0.6</td>
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<tr>
<td><strong>COTTON FIELD:</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Common Water</td>
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<td>0.6</td>
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<td>14.6</td>
</tr>
<tr>
<td>Treated Water</td>
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<td>4.6</td>
<td>7.6</td>
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</table>

**Water Intake**

The days required to achieve 50 and 100 percent orchard floor exposure after an irrigation are presented in Figures 2a and 2b. Fifty percent orchard floor exposure was observed in less than 2 days after each irrigation in both plots receiving treated water while nearly 3 days were required to achieve 50 percent orchard floor exposure in the untreated plot. Less than 3 days were required to achieve 100 percent orchard floor exposure in the treated plots while more than 5 days was required for complete disappearance of water in the untreated plot. These water intake patterns were consistent from early May to early August, however, the time required for 50 and 100 percent water disappearance increased for all of the water qualities in August, apparently corresponding with increased tillage and traffic during harvest.

The results indicate that water treatment nearly doubled the rate of water intake into the orchard soil during mid-summer. It appears that the water treatments had less affect on the initial rate of water intake which might be expected for a cracking surface soil but maintained a higher basic rate of water intake after the surface soil had been wetted and the cracks had swelled closed.
Figure 2. Days required for a) 50 percent exposure of orchard floor after irrigation and b) 100 percent exposure of orchard floor exposure, Kings County 1990.

Figure 3 shows the increase in water content for the season in each treatment. These values are the summation of all of the measurements for all of the irrigations. The results indicate that an average of 9 and 16 acre-inches/acre more applied water actually infiltrated in the low and high rates of water treatments, respectively, than in the untreated plot. The trends of increased water intake were consistent among repeated measurements in each treatment.

Figure 3. Apparent increase in total water content in orchard with applications of untreated and amended irrigation water, Kings County 1990.
Even though water penetration improved, the intake rates in the treated plots were still relatively low. However, the apparent reductions in standing water and increased total depth of infiltrated water may benefit the walnut orchard performance by reducing drainage and aeration concerns, more satisfactorily meeting the crop water requirements, and making the orchard more accessible for spraying and other cultural practices.

Figure 4 displays the average increase in water content achieved with untreated and amended water during each irrigation after layby in the cotton field. The average water content had increased about 1.5 to 2 inches in the treated plots when measured about five days after each irrigation. In comparison, the water content in the untreated plots showed only a small increase and had apparently dried to near the water content before irrigation. These water content patterns were consistent for all of the mid and late season irrigations. Time required to achieve complete water disappearance was reduced from over 4 days to about 24 hours in the cotton field.

Figure 4. Apparent increased water content in cotton after each post-layby irrigation with untreated and amended irrigation water, Kings County 1990.

Crop Response

Figure 5 gives the average predawn leaf water potential for 8 healthy appearing walnut trees in each plot. Leaf water potential readings averaged 1.5 to 2.0 bars less tension in the treated plots than in the untreated plot from mid June to mid September. This suggests that the walnuts in the untreated plot were subjected to higher levels of stress consistently through the summer growing season when water penetration was the poorest. The leaf water potential and stomatal conductance readings taken during a 24 hour period showed that the walnuts irrigated with untreated water underwent higher stress levels earlier in the
day, reached higher stress levels during peak day temperatures, and did not recover to as low of stress levels during the cooler nights (refer to Appendix D Figures 1 and 2). Transport of CO$_2$ through the leaf stomata appeared to be significantly higher in the plots irrigated with treated water, also indicating less tree stress. There was no consistent difference in tree stress between the low and high gypsum rates.

Figure 5. Average seasonal predawn leaf water potentials in walnuts before irrigation with untreated and amended water, Kings County 1990.

Results from the commercial harvest revealed in-shell yields of 2.2, 2.3, and 2.4 tons/ac for the untreated, low rate, and high rate, respectively. Percent large sound walnuts averaged 54, 58, and 61 percent in the untreated, low treatment, and high treatment plots, respectively. These results should be interpreted cautiously since there is no replication in this trial and it is uncertain whether these differences are really a response to the water treatments and improved water intake or a result of conditions in past seasons. Production responses will need to become grossly improved in the treated plots to develop confidence in the trial results. However, results of the short term indicators of internal tree stress are encouraging. If these short term measurements of tree stress are representative indicators, the treated plots should begin to develop obvious improvements in tree growth, nut quality, and perhaps production next season.
Figure 6 provides lint yield after machine harvesting and commercial ginning the seed cotton from each plot. Lint yield averaged almost 200 lbs/ac more in the treated plots than in the plots irrigated with untreated water. The yield response was consistent for both replicates (statistically significant at a probability level of 0.15). Gin turnout averaged about 31.5 percent in both treatments. There appeared a reasonably strong correlation ($R^2$) between lint yield and water infiltrated after layby, when the hand harvested small plot yields were correlated to measurements made nearby with the hydaprobe (see Figure in Appendix E).

Figure 6. Machine harvested lint yields after irrigation with untreated and amended water supplies, Kings County 1990.

**Soil Salinity**

Figures 7a illustrates the average soil salinity profile in the orchard. Increased total salinity (ECe) corresponded to treatment rates as would be expected in the orchard. Total salinity was highest at the 12 and 18 inches suggesting minimal deep water penetration midway to late in the season. Total salinity could accumulate to harmful levels if leaching is inadequate during periods of low water use. Total salinity increased in the top 6 inches of soil in the treated plots but not to the levels at 12 through 18 inches. Since the gypsum was applied continuously in the irrigation water, it might have been expected that the salinity profile would be more uniform from the surface through the subsoil. This indicates significant crop uptake of calcium sulfate. Last, total salinity increased down to a depth of 48 inches indicating that deep water penetration was achieved most likely during dormant and early season irrigations. The added calcium throughout the profile improved the proportion of soluble and exchangeable calcium to sodium throughout the root zone.
Figure 7. Soil salinity profiles for a) walnut trees and b) cotton after irrigation with untreated and amended water.

Figure 7b displays the average soil salinity profile in the cotton field to a depth of 18 inches. Total salinity uniformly increased about 25 percent at the 6, 12, and 18 inch depths indicating that the treated water penetrated at least 18 inches deep after irrigation. Total salinity accumulation remained well within tolerable levels for cotton. The proportion of soluble and exchangeable calcium to sodium was improved as well.

Profitability

Finely ground and pure gypsum is critical to the successful operation of the gypsum applicator. As a result, the gypsum cost was $95.00 per ton (98% pure). Sale price for one gypsum applicator is about $4000 dollars and should easily last for 10 years. Using the above costs and accounting for machine maintenance and labor to fill the machine, the treatment costs were about $90/ac/yr and $180/ac/yr for the low and high rates of gypsum treatment in the walnut orchard. Treatment costs in the cotton field were about $90/ac/yr.

Added income generated from the water treatment in the walnut orchard can not be evaluated yet. However, if existing walnut yields are maintained which seems likely, an improvement in walnut quality worth $0.02/lb and $0.04/lb would pay for the cost of water treatment at the two rates tested in this trial. A yield response would accelerate the rate of pay back for the water treatments. Additional years of data are needed to evaluate the profitability of water treatment in the orchard.
Profitability of water treatment in the cotton field can be evaluated since it is an annual crop. The lint yield averaged 198 lbs/ac more in the treated plots than the untreated plots. Even with the simple trial design, the crop response was large and consistent enough to give a reasonable level of confidence in the results. The lint was marketed at $0.79/lb, hence, the value of the added production was about $155/ac which exceeded the treatment costs by $65.00/ac.

Many growers may be reluctant to risk $90.00/ac in cotton production to improve water quality, even in light of this experience. Few individual cotton management practices, with the exception of water and harvest costs, approach $90/ac. More development of treatment strategies to identify the minimal effective treatment rates, long term treatment needs and improvements, and additional information on crop response would help develop an attractive, economical water treatment approach for agronomic crops such as cotton.

CONCLUSIONS

The established guidelines for evaluating irrigation water quality for potential water penetration hazards were effective in identifying problem water supplies. However, these guidelines will be more effective if other factors such as abrupt textural changes in soil layers, organic matter content, tillage practices, and traffic are considered along with water quality.

A new method of improving water quality by injecting gypsum into the water supply is available and provides complete dissolution at very low, controlled rates. Further development of the method is encouraged to facilitate use of bulk supplies of high quality gypsum; hence, minimizing labor, inconveniences, and making the system more adaptable to large scale surface irrigation systems.

Results from the 1990 trials suggest that poor water quality can contribute to poor water penetration and limit production. Rates of water intake were improved in both trials but more dramatically in the cotton field where a sandy soil texture was more uniform throughout the root zone, annual deep tillage was possible, traffic was more controlled, and where the water intake appeared more restricted by surface soil crusting. Short term indicators suggest that the walnut trees irrigated with improved water quality may be under less water related stress. However, increased walnut yield and nut quality can not be assessed yet. A profitable increase in lint yield was observed when cotton was irrigated with amended water quality.
APPENDICES
APPENDIX A

PLOT PLANS OF WATER INFILTRATION STUDIES

WALNUT

[Diagram showing plot plans for Walnut with different treatment levels and monitoring sites.]

COTTON

[Diagram showing plot plans for Cotton comparing untreated and treated plots with monitoring sites.]
## APPENDIX B

## IRRIGATION SCHEDULES, KINGS COUNTY 1990

### WALNUTS

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### COTTON

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APPENDIX C

AMENDMENT AFFECTS ON IRRIGATION WATER QUALITY

WALNUTS

COTTON
APPENDIX D

CROP RESPONSE TO TREATMENTS

LEAF WATER POTENTIAL IN 24 HOUR CYCLE

CO₂ STOMATAL CONDUCTANCE IN 12 HOUR CYCLE
APPENDIX E

CORRELATION BETWEEN HAND HARVEST COTTON YIELDS AND TOTAL WATER INTAKE MEASURED WITH THE HYDRAFROBE, 1990.

\[ Y = 88.5x + 728 \]
\[ R^2 = 82.3 \]

(Post layby irrigations only)