Table 3. Summary of soil sample collection and the quantity of net infiltration.

Date of Irrigation and Subsequent Soil Sampling (2003)	Irrigation Water Applied (cm)	Precipitation Since Last Leaching (cm)	Evaporation Since Last Leaching (cm)	Net Infiltration (cm)	Cumulative Net Infiltration (cm)
9 January	9.6	−−	−−	9.6	9.6
14 January	Soil samples collected after 1st leaching				
17 January	9.3	0.6	0.5	9.4	19.0
23 January	Soil samples collected after 2nd leaching				
24 January	13.4	0.0	0.4	13.0	32.0
29 January	12.7	0.0	0.5	12.2	44.2
6 February	Soil samples collected after 3rd leaching				
7 February	13.0	0.0	1.4	11.6	55.8
19 February	11.2	1.7	2.1	10.8	66.6
27 February	Soil samples collected after 4th leaching				

of lower salinity concentrations developed down through the soil profile.

Reclamation Leaching Water and Salinity Reduction

The gross depth of leaching water applied to the area of consideration was calculated by dividing the measured volume of water applied by the total area of the leaching study (width of 1.8 m and length of 83.8 m). The "area of consideration" was the area in which primarily vertical water movement occurred, which was assumed to be below the five inner soil cores, an area 1.2 m wide (fig. 5). It is assumed that any lateral movement of leaching water outside of the boundary originated from the outermost drip tapes.

The net infiltration for the area of consideration was then determined as follows:

Net infiltration of the water applied =

Depth of leaching water applied

+ Precipitation since the last leaching

− ETo since the last leaching.

in which the evaporation was assumed to be equal to the grass reference evapotranspiration because the soil surface was continually wet, the trees were dormant, and there was no weed growth.

The average daily reference evapotranspiration (ETo) was calculated with the FAO-56 Modified Penman-Monteith equation using CIMIS data. The net infiltration during each leaching event and the cumulative net infiltration are given in table 3. The third and fourth leaching applications were divided into two sets to minimize surface runoff.

To evaluate the reduction of the average salinity for a certain soil zone, the net leaching water that percolated through that soil layer was considered. Specifically, the change in soil moisture storage of a soil zone was subtracted from the net amount of water infiltrated to find the net amount of leaching water that percolated through that soil zone:

Table 4. Cumulative depth of net leaching water for each soil zone.

Soil Zone (m)	Cumulative Depth of Net Leaching Water through Each Soil Zone after Each Leaching Event (cm)			
	1st	2nd	3rd	4th
0 to 0.3	8.5	18.0	43.2	65.5
0 to 0.6	6.6	16.1	41.3	63.6
0 to 0.9	4.4	13.9	39.1	61.4
0 to 1.2	1.8	11.3	36.5	58.8
0 to 1.5	0.0	8.0	33.2	55.5
0 to 1.8	0.0	4.3	29.5	51.8
0 to 2.1	0.0	0.2	25.4	47.7
0 to 2.4	0.0	0.0	21.2	43.5

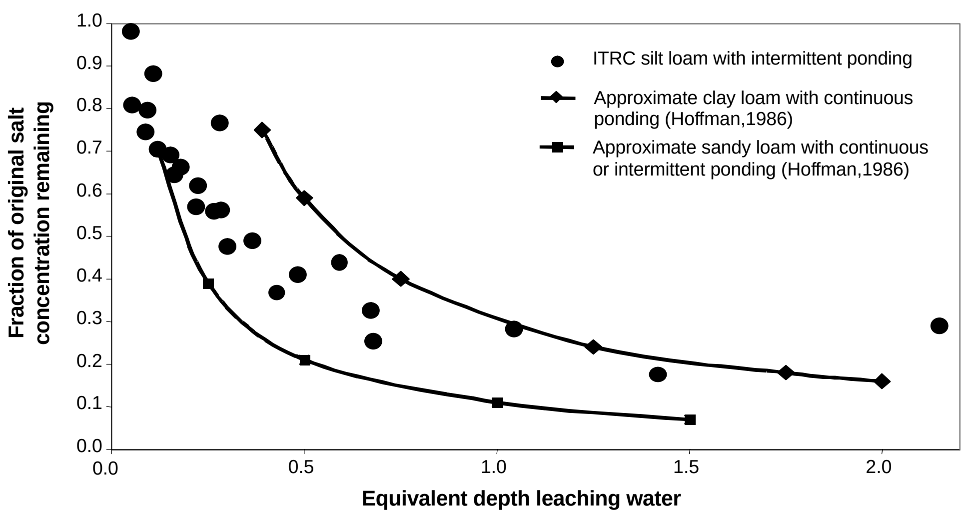

Figure 6. Relationship between the equivalent depth of leaching water and the fraction of initial salt content, considering five inner soil cores (modified).

Net leaching water of a soil layer=

Net infiltrated into that soil zone

− Depth of water required to bring

that soil zone to field capacity.

Since the root zone was not at field capacity when leaching water was initially applied, different depths of net leaching water percolated through each soil zone (table 4).

After each leaching, the new weighted average salt content in each area of consideration was also calculated. Four of the six sample locations were chosen as the most representative of salinity concentration patterns. ECe values from the five inner vertical cores at each sample location were used. The ECe values were then averaged and weighted according to their position in the salinity profile grid. The change in soil salinity content was then plotted against the equivalent depth of leaching water (fig. 6).

The fraction of the initial salt content remaining was defined as the new average soil zone ECe divided by the initial average ECe for that soil zone. Our data showed that our initial sampled average ECe benchmarks (shown in fig. 3) were too low because the average soil zone ECe in some sample locations, after the first leaching, were higher than before leaching. Such a discrepancy can occur because the soil sampling is destructive, and this variability clearly illustrates the difficulty of obtaining highly accurate statistical relationships in this type of study. Based on the theory that no average soil zone ECe should increase above the original average soil zone ECe, the initial ECe values were increased by 20% to develop a more realistic relationship curve seen in figure 6.

Equivalent depth of leaching water was defined as the depth of net leaching water divided by the depth of a soil zone (each having the same units). For example, one equivalent depth of leaching water for a 1 m soil zone was 1 m of net leaching water that percolated through that soil zone (because the change in soil moisture storage for that soil layer must be considered, the net water infiltrated would be greater than 1 m). Water that was stored in the soil zone was not net leaching water for that zone.

The relationship between equivalent depth of leaching water and the fraction of original salt content for a soil zone is shown in figure 6. Included in figure 6 are the approximate curves for the same relationship developed by Hoffman (1986). Based on figure 6, the approximate reductions in average soil zone ECe values for a range of leaching equivalent depths are shown in table 5. It should be noted that the depth of irrigation water applied for leaching must be greater than the leaching water because some of the applied water goes to soil moisture storage and evapotranspiration during reclamation.

Table 5. Approximate salinity reductions for various leaching equivalent depths (silt loam).

Equivalent Leaching Depth	Approximate Fraction of Original Salt Concentration Remaining
0.2	0.80 to 0.60
0.4	0.57 to 0.38
0.6	0.43 to 0.28
0.8	0.36 to 0.23
1.0	0.30 to 0.20

Maximum Efficiency of Leaching Techniques

In a field experiment conducted on a silty clay soil by Oster et al. (1973), the observed order of leaching efficiency was as follows: intermittent ponding > sprinkler > continuous ponding. Even though our experiment used low-flow drip tape and intermittent applications, the relatively high application rate (5.8 mm h^{-1}) caused some surface water ponding. Accordingly, the time-averaged water content within the depth wetted by drip irrigation was higher than under intermittent ponding. This counteracts the effects of reduced bypass flow and increased water content. Since there was some ponding in this experiment, it seems reasonable to find the curve for silt loam between clay loam with continuous ponding and the intermittent ponding curves developed by Hoffman (1986).

Relative Leaching Efficiency

The salt reduction/equivalent leaching depth curve (fig. 6) illustrates that as more leaching water is applied, the amount of salt removed per unit depth of leaching water decreases. In this case, the slope of a line tangent to the salt reduction/leaching curve represents the fraction of salt removed per unit depth of leaching water. Table 6 contains the relative leaching efficiencies for various equivalent depths of leaching water applied, derived from the slopes of tangent lines for a range of equivalent depths. The values in table 6 suggest that leaching quantities greater than 0.8 equivalent depths result in insignificant salt reduction.

Summary and Conclusion

Leaching can reclaim salt buildup that would cause poor crop health and reduced plant vigor, especially when a new crop is planted. The leaching study revealed that, for tree crops:

- Irrigation with a typical orchard drip system in an arid or semi-arid area can develop highly saline areas on the edges of the wetted area.
- The practice of reclamation leaching using multiple, closely spaced drip tapes allows water to be applied directly to the areas of salt accumulation, as opposed to applying water to the entire field. In this case, water was applied to 1/3 of the field area, requiring perhaps half the amount of leaching water (accounting for edge effects) when compared to conventional leaching techniques. This is significant since reclamation leaching requires a large depth of water.

Table 6. Relative leaching efficiencies for various equivalent depths of leaching water.

Equivalent Depth	Relative Leaching Efficiency (%)
0.1	100
0.2	38
0.3	21
0.4	14
0.5	10
0.6	8
0.7	6
0.8	5
0.9	4
1.0	4

- There is a relationship between the equivalent depth of leaching water and the fraction of initial salt concentration that remains. The results from this experiment on a silt loam soil are summarized in table 6. It is important to note that the depth of irrigation water applied for leaching must be greater than the leaching water because some of the applied water goes to soil moisture storage and evapotranspiration during reclamation.
- The salt reduction/leaching depth relationship was similar to that found by Hoffman (1986).

There was no attempt in this experiment to establish whether the trees in this field were negatively impacted by the soil salinity accumulation. But salinity buildup becomes particularly important when trees are removed and the field is replanted with salt-sensitive crops. The most effective and efficient reclamation leaching practices for tree crops irrigated with drip appear to include:

1. Apply leaching water only to the areas with salt accumulation, typically along the tree row with drip lines.
2. Use low application rates for maximum effectiveness of salt removal.
3. Multiple lines of low-flow drip tape can be used to achieve 1 and 2.
4. Consider the point of diminishing effectiveness for reclamation leaching: quantities of leaching water greater than 0.8 equivalent depth may result in insignificant salt reduction (for a typical silt loam soil using intermittent leaching).
5. Use intermittent applications of leaching water, which minimize the effects of bypass flow.

ACKNOWLEDGEMENTS

Funding for this study was provided by Cal Poly State University, using funds of the California State University Agricultural Research Initiative and the California Department of Water Resources. The authors express sincere appreciation to Gary Robinson for providing the use of his pistachio orchard and for his support of the project.

REFERENCES

Boman, B. J., and E. W. Stover. 2002. Managing salinity in Florida citrus. Gainesville, Fla.: University of Florida, Institute of Food and Agricultural Sciences, Cooperative Extension Service. Available at: http://edis.ifas.ufl.edu/AE171. Accessed 30 June 2003.

Burt, C. M., and B. Isbell. 2003. Soil salinity accumulation in orchards with drip and micro-spray irrigation in arid areas of California. ITRC Report No. R 03-005. San Luis Obispo, Cal.: California Polytechnic State University, Irrigation Training and Research Center. Available at: www.itrc.org/reports/salinity/treecropsalinitypdf.

CIMIS. 2003. California Irrigation Management Information System. Sacramento, Cal.: Department of Water Resources. Available at: www.cimis.water.ca.gov/. Accessed June 2003.

Hoffman, G. J. 1986. Guidelines for reclamation of salt-affected soils. *Appl. Agric. Res.* 1(2): 65-72.

Oron, G., Y. DeMalach, L. Gillerman, I. David, and V. P. Rao. 1999. Improved saline-water use under subsurface drip irrigation. *Agric. Water Manage.* 39(1): 19-33.

Oster, J. D., L. S. Willardson, and G. J. Hoffman. 1973. Sprinkling and ponding techniques for reclaiming saline soils. *Trans. ASAE* 16(1): 115-117.

Oster, J. D., I. Shainberg, and I. P. Abrol. 1999. Reclamation of salt-affected soils. In *Agricultural Drainage*, 669-672. ASA Monograph No. 38. R. W. Skaggs and J. Van Schilfgaarde, eds. Madison, Wisc.: ASA, CSSA, SSSA.

Pereira, L. S., T. Oweis, and A. Zairi. 2002. Irrigation management under water scarcity. *Agric. Water Manage.* 57(3): 175-206.

USDA-NRCS. 2003. Official soil series descriptions (OSD). Washington, D.C.: USDA Natural Resources Conservation Service. Available at: http://soils.usda.gov/technical/classification/osd/. Accessed March 2003.