Optimal irrigation management under poor drainage and saline conditions

J. Letey □ Ariel Dinar □ Keith C. Knapp

Decision-making is more demanding than for land free from these problems

Agricultural production on the west side of California's San Joaquin Valley is jeopardized by rising water tables over a fairly wide area. The perched water tends to be brackish and may contain significant concentrations of trace metals, particularly selenium. Viable production under these conditions depends on installation of drainage systems and a means of disposing of the drainage water. Optimal agricultural management might be considerably different in this area than in locations not subject to high water tables or salinity. Decisions such as crop selection, water application quantity, type of irrigation system, means of drainage water disposal, and use of brackish waters for irrigation must be based on economic as well as physical-biological considerations. This report summarizes some recent research on optimum crop management under saline and high water table conditions.

Crop production functions

Economic analysis of water management requires information on the relationship between crop yield and the quantity and quality of irrigation water (crop production function). It is also necessary to know the relationships between the quantity and quality of irrigation water and the quantity and quality of the water moving beyond the root zone to the water table. Under poor drainage and saline conditions, there is a trade-off between benefits from higher yields and costs of increased drainage water resulting from increased water applications.

One approach to developing crop production functions is to conduct field experiments in which the quantity and quality of irrigation water are experimental variables. The combination of the two variables, however, leads to a large number of treatments, which are expensive to conduct on a field scale. Furthermore, the results are limited to the specific crop and physical conditions at the experimental site.

A less time-consuming and expensive approach is to use a model based on scientifically established physical-biological relationships to compute production functions. We developed such a model by combining three relationships previously established in the scientific literature: (1) yield and evapotranspiration (ET), (2) yield and average root zone salinity, and (3) average root zone salinity and the fraction of the applied water that moves below the root zone. The model allows plant growth adjustment and therefore evapotranspiration adjustment to root zone salinity.

The crop water production function can be expressed in relative terms, which is helpful in transferring the relationships among geographical areas of different climates and growing conditions. Yields are expressed on a relative basis with the value of 1.0 representing maximum yield. The seasonal values of applied water (AW) are scaled by seasonal pan evaporation (Ep) to adjust for climatic conditions affecting evaporation. The model allows not only computation of yield as related to applied water, but also computation of quantity and quality of water percolating below the root zone to the water table.

Results from the production function model are now available for alfalfa (fig. 1), cauliflower, celery, corn, cotton, cowpea, lettuce, oats, sugarbeets, tall fescue, tomato, and wheat. We checked the validity of the model by using limited available experimental data obtained at different locations in the United States and Israel with quite good agreement between observed and predicted yields.

For a given level of applied water to alfalfa, the yield decreases with increasing salinity of irrigation water (fig. 1). Increasing water application can contribute to higher yields when using brackish water, but it also results in higher volumes of drainage water (fig. 2). The amount of deep percolation from a given quantity of applied water increases as the salinity of that water increases, because the reduced plant growth under saline conditions results in less evapotranspiration. Some deep percolation occurs even with very low water applications if the irrigation water is saline.

The production functions are for cases of uniform irrigation. Irrigation is never completely uniform and is sometimes highly nonuniform. Optimum water application on all parts of the field is not possible under such circumstances; some parts of the field are over-irrigated and others under-irrigated. We expanded the model to compute yield as a function of average amount of applied water on a field basis for assumed irrigation uniformity distributions.

Drainage situations

These crop production functions served as the basis for economic evaluation of water management at the field level under various drainage situations typical of the west side of the San Joaquin Valley. The assumption under one situation was that no perched water table developed, so that no disposal of drainage water was required. In another situation, we assumed a perched water table requiring a drainage system and three drainage water disposal options: a free off-farm facility for disposal, an on-farm evaporation pond on nonproductive land, and an on-farm evaporation pond constructed on productive land. Optimum applied water and associated profits, yields, and drainage volumes were computed for corn and cotton, representing crops sensitive to and tolerant of salinity, respectively. We used

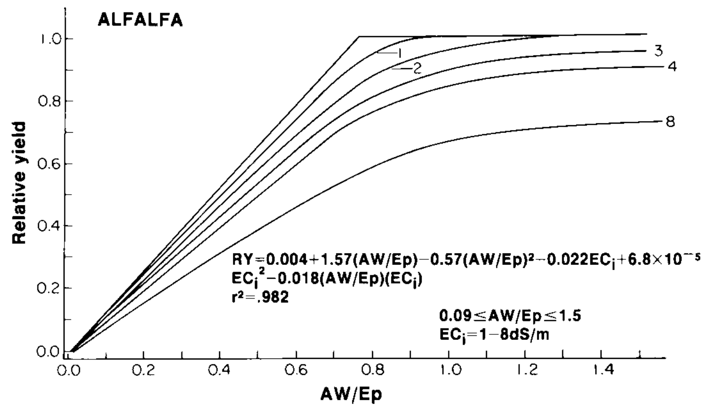

Fig. 1. Computed relationship between relative alfalfa yield and applied water (AW) scaled to pan evaporation (Ep). Each curve is for a given electrical conductivity of the irrigation water (dS/m). At a particular level of applied water, yield decreases with increasing salinity.

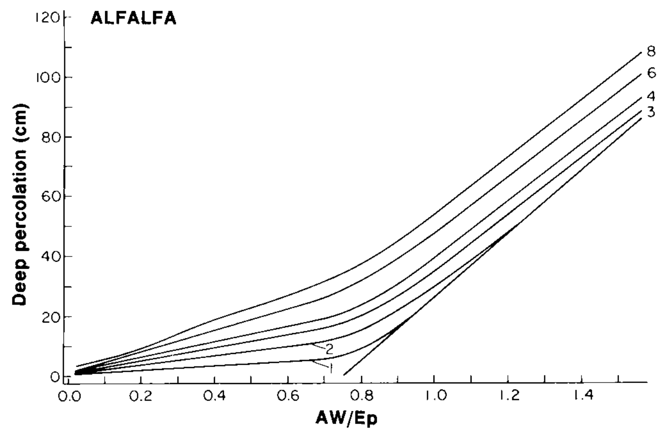

Fig. 2. Computed values of deep percolation when alfalfa is irrigated with various quantities of applied water at a given dSm. Increasing application of brackish water increases the volume of drainage water.

a range of hypothetical irrigation uniformities and irrigation water salinities in the analyses.

Results indicate that high yields can be achieved with very little deep percolation under perfectly uniform irrigation with nonsaline water, a condition which rarely, if ever, exists. Under those circumstances, optimal water management and profits were about the same for all drainage situations. With nonuniform irrigation, saline water, or both, high yields are achieved by larger water applications, resulting in greater drainage volumes. The benefits of increased yields are offset by costs of increased drainage volumes.

Optimal irrigation and profits are highly dependent on the costs associated with drainage. The situation without a perched water table has no drainage costs, so there is an incentive to apply large quantities of water under nonuniform and/or saline conditions; decreases in profit are comparatively low, except when irrigation water prices are very high. With a perched water table, drainage volumes have definite costs. These are relatively low if a free off-farm facility is available, so that the optimal management and profits do not differ greatly from the case with no perched water table. On the other hand, on-farm evaporation ponds are costly, particularly if productive land must be used, so that significantly lower irrigation amounts are optimal and profits decrease accordingly.

Because of the high costs associated with placing evaporation ponds on productive land, growers have an incentive for a cooperative arrangement to transport the drainage waters to nonproductive land.

Since the effect of irrigation uniformity on economically optimal yields and profits is strongly related to the costs associated with drainage volumes, investments to upgrade irrigation are more likely to be profitable when costs associated with drainage are high. In principle, uniformity can be improved by changing irrigation management or systems, or both. Unfortunately, we do not yet have reliable procedures for characterizing irrigation uniformity in the field in a manner that can be used in crop production analysis. Such procedures are the missing link for combining all the factors in a complete quantitative economic analysis for a given field or farm.

Breeding for salt tolerance

We investigated the profitability of breeding more salt-tolerant varieties of crops for the same drainage situations by adjusting parameters in the model as if the plant were more salt tolerant. Increasing tolerance had relatively little effect on yields and profits when irrigation waters were low in salinity, regardless of drainage conditions. When high-salinity waters were used, however, greater salt tolerance increased yields and profits.

The effects of increasing tolerance by breeding are more significant for crops that are initially sensitive than for tolerant crops. Since most surface supplies of irrigation water in the Valley are relatively low in salinity, crop breeding for salt tolerance becomes a factor only when use of saline drainage water for irrigation is considered.

Reuse of drainage water

Using the production function model, we determined the optimal combination of fresh surface and saline drainage waters in a crop production system. Equal yield curves (isoquants) were calculated from the production function model for different quantities of fresh and saline water (electrical conductivity of 4, 6, or 11 decisiemens per meter — dS/m). Information about crop prices, water prices, and other variable costs is required in determining the optimal rate of combining the two water sources.

Results showed that using a combination of fresh and saline water was not feasible for the more sensitive crops. Combining fresh and drainage waters became more feasible as the salinity of the drainage water decreased, crop tolerance to salinity increased, or the relative price of drainage to fresh water decreased. In other words, disposal of brackish drainage water by irrigating crops is feasible only under a limited set of circumstances and cannot be considered a general solution. Nevertheless, conditions can be specified for profitably using drainage waters for irrigation.

Conclusion

Optimal water management on farmland plagued by saline conditions and high water tables is considerably different from management on land free from such problems. With appropriate data, solutions can be computed for water management. One major limitation is the lack of reliable procedures for characterizing irrigation uniformity in a manner that can be used in the models.

Our analyses assumed no subsurface lateral flows from one farm to the next. To the extent that considerable subsurface lateral flow is occurring, the analysis would have to be expanded to a regional basis, whereas the present analysis has been restricted to individual farms and in some cases to individual fields. Also, the analysis does not address the potential hazard of trace elements in some drainage waters. The research, however, does provide some insights and guidelines to water management under saline and drainage problem conditions.

J. Letey is Professor of Soil Physics, Ariel Dinar was Postdoctoral Research Agricultural Economist, and Keith C. Knapp is Assistant Professor of Resource Economics, Department of Soil and Environmental Sciences, University of California, Riverside. Ariel Dinar is now associated with the Center of Agricultural Economic Research, Hebrew University of Jerusalem, Rehovot, Israel. *This research was supported by the UC Kearney Foundation of Soil Science.*