IRRIGATION TO MINIMIZE SALT PROBLEMS

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The U. S. Salinity Laboratory is charged with discovering basic principles of chemistry, physics, and physiology that will help develop water management strategies to make irrigation a permanent part of our society. I'll first discuss the physical principles governing water and salt transport that we need to understand to irrigate efficiently, and in such a way that salt does not accumulate. Later we'll see how these principles apply to the specific problems of alfalfa.

Irrigation water contains both salt and water. Figure 1 illustrates the fact that the proceseses of transpiration by the plant and evaporation form the soil surface remove only water, leaving the salt behind in the soil. In addition to the salt added to the soil with the irrigation water, if a water table exists sufficiently close to the soil surface, salt can move into the rootzone with the upward movement of water. Salt within the rootzone has the effect of making water unavailable for plant use, as is illustrated in Figure 2. Although the mechanisms are different, plants growing in saline soil behave similar to those suffering from lack of water.

The solution of the problem of soil salinity is simple in principle. As is illustrated in Figure 3, by adding extra water to the soil surface the salt can be displaced downward and leached from the soil. Of course, this requires that subsurface drainage be adequate to carry this extra water away. Otherwise, the water table will rise, inundating the rootzone, which only complicates the problem. Where natural drainage is insufficient, it is necessary to install artificial drainage with tiles, open drain ditches, or wells to prevent the water table from rising.

One of the important questions addressed by U. S. Salinity Laboratory research is what is the minimum quantity of extra water for leaching necessary to keep salinity from causing crop damage. It is desirable to reduce this extra quantity of water to the bare minimum, not only to conserve water and nutrients, but also to avoid or reduce the cost for drainage. This minimum quantity of water is called the leaching requirement. Figure 4 illustrates the relationship between the leaching requirement and the soluble salt concentration within the rootzone. In all three situations shown, the electrical conductivity (EC), a measure of salt concentration, of the irrigation water is 2 mmho/cm, a moderately saline water. On the left, a very sensitive crop may only be able to withstand 4 mmho/cm at the bottom of the rootzone and, therefore, 50% of the water added would have to percolate below the rootzone to avoid salt damage. In the center, a moderately tolerant crop capable of withstanding water at an EC of 8 mmho/cm at the bottom of its rootzone would require only half as much, or 25% of the irrigation water to percolate below the rootzone to keep the salt concentration below this value. On the right, a tolerant crop capable of withstanding an EC of 16 mmho/cm within its rootzone would require less leaching still. In all three instances, if the salinity of the irrigation water were less, the leaching requirement would also be less. For example, if the EC of the irrigation water in Figure 2 were cut in half, the leaching requirement would also be half. The leaching requirement, therefore, depends on both the quality of the irrigation water and the sensitivity of the crop being grown.

With high-quality water and moderately tolerant crops, only a small fraction of the applied irrigation water is theoretically needed for leaching. Unfortunately in irrigated agriculture there is a wide gap between the leaching required and that actually occurring. On the average, more than half of the irrigation water percolates below the reach of crop roots. A major reason for this is that no one sees this water. Recently, farmers are becoming aware of excess percolation for other reasons. One is the cost of this wasted water itself. Another is the increased cost for fertilizer that is leached out by excess deep percolation. Excessive percolation below the root zone increasingly comes to the attention of farm operators in the form of waterlogging and salt accumulation at the soil surface. Not only is the crop-producing capability of the soil destroyed by salt, but the high water table causes a hazard to equipment traffic.

Being aware of the hazards and expenses of excessive deep percolation and knowing what to do about them are two different things. Figure 5 illustrates the reason for a good part of the excessive deep percolation that occurs in irrigated agriculture. Most irrigation in the U.S. is with surface distribution systems. Systems that pond water place control of infiltration in the soil. If the soil is nonuniform, infiltration will be nonuniform. Areas of the field with coarse-textured soils can permit considerable water to percolate

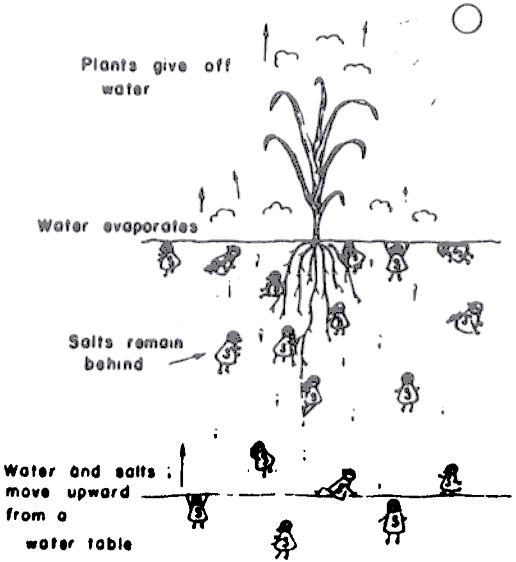

Fig.1

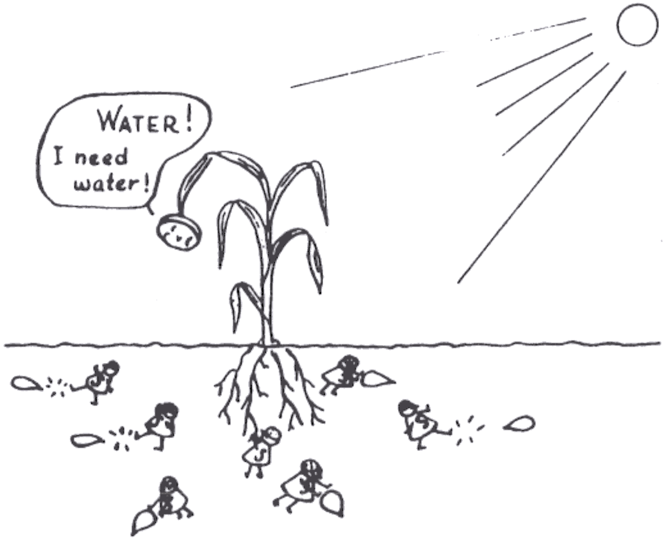

Fig.2

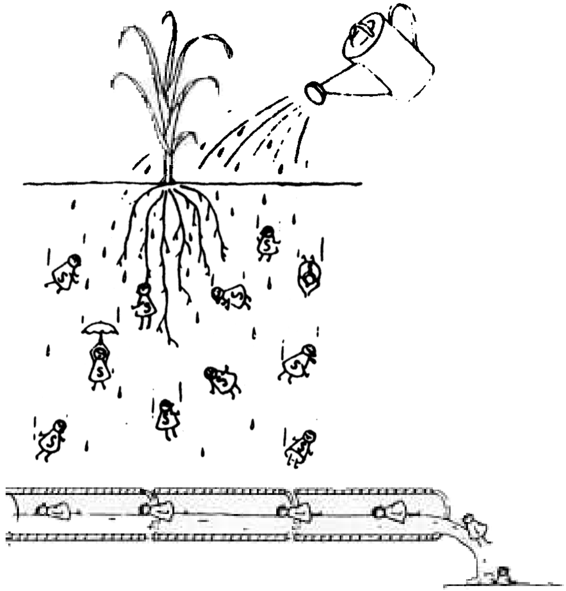

Fig. 3

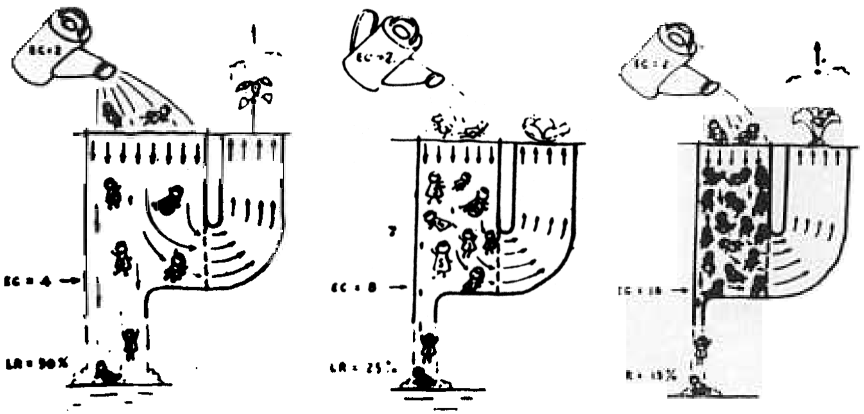

Fig.4

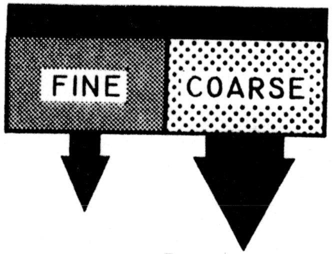

Fig.5

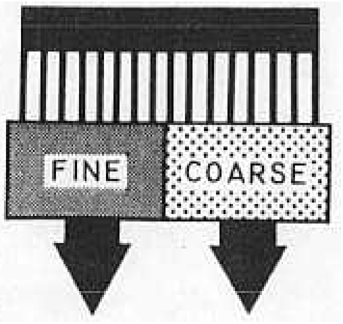

Fig.6

through them before areas with fine-textured soils receive sufficient water. Because it is seldom of economic advantage to give the crop less water than it needs, most farmers irrigate for a time sufficient to provide adequate water to those parts of the field with the lowest intake rate. Even the most sophisticated scheduling program will not eliminate the waste of water caused by this nonuniform intake. Because it is impractical to make intake rates of soils uniform, many surface irrigation systems are inherently wasteful. Commonly used surface irrigation systems are flood and furrow. Where water intake rates vary within a field, irrigation uniformity can be improved by decreasing the size of flooded basins or shortening furrows.

The problem of soil nonuniformity can be overcome with closed-conduit irrigation systems that distribute water uniformly to all parts of the field. If they supply water at a rate less than that which causes ponding, in effect, they place control of infiltration in the irrigation system rather than in the soil. Figure 6 illustrates a system that does not pond water on the soil surface. It can attain uniform leaching regardless of soil nonuniformity because the water infiltrates where it is applied. Irrigation systems that distribute water through closed conduits have the capability of using water efficiently if, first, the irrigation system applies water uniformly at a rate less than that which would cause water to pond, and, second, only the amount of water required for evapotranspiration and leaching is applied. Sprinkler irrigation systems have this capability if they are properly operated.

Closed-conduit irrigation offers another significant advantage over most surface irrigation methods. Surface irrigation imposes two fundamental constraints on irrigation management. First, it depends on flow over the soil surface to distribute water from a turnout to the furthest point in the field. This requires a minimum depth of water simply to achieve coverage. Second, a fixed cost is usually associated with each water application. Both constraints make it economically advantageous to decrease the number of irrigations by increasing the time between them. As a consequence, in the past the science of irrigation management has focused primarily on decreasing irrigation frequency by storing as much water as possible, and using as much of this as practical before the next irrigation. The introduction of solid-set, closed-conduit irrigation systems that distribute water to all parts of the field uniformly essentially reverses this economic pattern. Because it costs no more to use the sytsem once it is permanently installed, the best use is almost continuous irrigation during the peak use period to reduce pipe size. This changes the irrigation pattern from one dominated by extraction following a brief period of infiltration to one dominated by infiltration. Under these circumstances, the soil water content remains significantly higher than it does under low-frequency irrigation, even with extremely low deep percolation rates.

Several different kinds of irrigation delivery systems are, then, capable of efficient use of irrigation water while maintaining salinity below that range causing reduction in crop yields. If these systems are capable of supplying water to each plant at a rate low enough to prevent ponded water from flowing over the soil surface, soil variability does not enter as a factor affecting the uniformity of application. From the point of view of salinity management alone, small frequent water applications just meeting the crop water requirement would seem to be ideal. For alfalfa grown in the greenhouse or in protected plots they often are. But in the field other factors limit the irrigation schedule.

When the hay is down you can't irrigate. This eliminates a week to ten days of every month, depending on the harvest practice. In addition, it's not wise to harvest when the surface soil is wet. We found in an experiment conducted in Arizona that a moist surface soil at harvest time allowed weeds to germinate and seriously compete with the alfalfa before it had regrown enough to shade them. Moist surface soil was also more subject to compaction from harvest traffic. The alfalfa stand was reduced more by compaction than was the stand of weed species, giving the weeds an added competetive advantage. As a consequence of these constraints imposed by cultural practices, as much as half of the time between cuttings is not available for irrigating. To make up the deficit, the irrigation system must be capable of delivering twice the volume of water per unit time as would be required for a system operating continuously. This may eliminate high-frequency irrigation systems that avoid ponding, resulting, in some cases, in less uniform leaching for alfalfa than for some other crops. Where irrigation is not uniform, sufficient extra water needs to be applied to adequately leach those areas of the field receiving the least. The information that follows regarding the leaching requirement for alfalfa, therefore, applies to these areas with the lowest leaching fraction.

Maas and Hoffman (1977) give a summary of the salt tolerance of various crops

Typically crops can tolerate a certain level of salinity in the rootzone before any reduction in yield results. For alfalfa this threshold salinity level is approximately 2 mmhos/cm in the saturated extract of a uniformly saline soil. Above this salinity, yield decreases about 7% for each mmho/cm increase in saturation extract salinity. Alfalfa is, therefore, moderately sensitive to salinity.

In practice, salinity is not uniform. It tends to increase with soil depth. The maximum salinity at the bottom of the rootzone depends on both the leaching fraction and the salinity of the irrigation water. To arrive at a value for the leaching requirement we need to know how plant roots average this varying salinity profile to compare it with the saturation extract salinity of a uniformly saline soil. Specifically, for alfalfa, we need to know for any given irrigation water salinity what leaching fraction yields a salinity profile equivalent to a uniform profile with a saturation extract of 2 mmhos/cm. Several different ways have been suggested for making this determination, but because good data under field conditions are scarce, it's difficult to choose one over another. A conservative estimate based on the available data suggests that the leaching requirement for alfalfa expressed as a percentage, is about ten times the irrigation water salinity expressed in mmhos/cm. That is, if the irrigation water salinity is 0.5 mmhos/cm, the required leaching is 5% of the infiltrating water. If the salinity of the irrigation water is 1 mmho/cm, the required leaching is 10%, and so forth.

An important conclusion from this is that, except for a few saline wells, irrigation waters used in California for alfalfa require less than 15% leaching. With most surface waters used in the Central Valley less than 5% leaching is sufficient. The required leaching is, therefore, usually less than the accuracy with which it can be measured. Because it is small, the most important consideration for salinity control is not the precise value of the leaching requirement, but the assurance that over a period of time there is at least some downward flux of water. If the net flow each year is downward, in all probability it will be sufficient. Salinity problems occur most often where yearly evapotranspiration exceeds infiltration, resulting in a net upward water flow.

This raises the question of how can we manage irrigation to assure a net downward flux of water over the season without wasting water. Experience has shown that it is virtually impossible to maintain a downward continuous flux of this small magnitude with any degree of precision. Instruments to measure soil water flux with this accuracy do not exist. It is, on the other hand, quite practical in the absence of a high water table, to maintain essentially zero downward flux throughout a growing season, and then apply the required leching water in one or more excess irrigations during the off season. To assure that downward flux does not exceed some minimum, it is only necessary to maintain a sufficiently dry zone of soil below the root zone. Because the hydraulic conductivity of soil decreases drastically as the soil dries out, even a small amount, it is easily possible to maintain downward flux low. For example, the hydraulic conductivity of many soils ranging from clays to sands is typically less than 0.1 mm/day at a soil water tension of only 0.3 bar. Thus, if the water content in a zone below the rootzone in such a soil is continuously maintained lower than that corresponding to a tension of 0.3 bar, downward water movement will be less than 0.1 mm/day. For a 200-day growing season the total deep percolation will not exceed 20 mm - less than one inch.

The quantity of leaching water required after a growing season in which no leaching has occurred can easily be calculated. It is important to realize, however, that although the procedure outlined above assures that deep percolation is minimum, it reveals nothing about the adequacy of the quantity of water applied. It is possible to use water from storage within the profile during the growing season. Measuring the profile water content throughout the season, for example with a neutron water content measuring device, can not only assure that the lower rootzone water content is low enough not to allow water to deep percolate, but gives a quantitative measure of the water used from the profile. The extra water applied at the end of the season or as a preirrigation needs to include this deficit as well as the water required for leaching. Because the leaching requirement needs to be met in thos areas of the field with the least leaching, it is important to select sampling sites for profile water content measurements in these areas.

The question has often been asked if it is necessary to leach continuously or if periodic leaching as described above is adequate. Recent research indicates that for waters used to grow alfalfa in California, leaching yearly or even less often is sufficient. This is fortunate because it gives the irrigator the flexibility of leaching when he has the extra water.

In summary, irrigating to avoid salt problems requires that an extra quantity of water equal to the leaching requirement must pass through the soil profile to carry away salts. This leaching quantity is small, but it is important that the parts of the field infiltrating the least water receive it. Where the application of irrigation water is not uniform, considerable excess water may leach through some parts of the field before the minimum is reached in others. The actual extra water required to assure adequate leaching, therefore, depends on how uniformly irrigation water can be applied. Leaching can be controlled more effectively if it is carried out infrequently rather than continuously.

REFERENCE

Hoffman, G. J., and Maas, E. V. 1977. Crop salt tolerance - current assessment Jour. of Irrig. & Drainage Div., ASCE, 203: 115-134.