2. SALINITY PROBLEMS

2.1 INTRODUCTION

Irrigation water contains a mixture of naturally occurring salts. Soils irrigated with this water will contain a similar mix but usually at a higher concentration than in the applied water. The extent to which the salts accumulate in the soil will depend upon the irrigation water quality, irrigation management and the adequacy of drainage. If salts become excessive, losses in yield will result. To prevent yield loss, salts in the soil must be controlled at a concentration below that which might affect yield.

Most water used for irrigation is of good to excellent quality and is unlikely to present serious salinity constraints. Salinity control, however, becomes more difficult as water quality becomes poorer. As water salinity increases, greater care must be taken to leach salts out of the root zone before their accumulation reaches a concentration which might affect yields. Alternatively, steps must be taken to plant crops tolerant to the expected root zone salinity. The frequency of leaching depends on water quality and the crop sensitivity to salinity.

The intent of this chapter is to illustrate the effect of water quality on the build-up of soil salinity and show how the latter can reduce the soil-water available to the crop. This is followed by a discussion of how leaching, crop selection and other management techniques are used to make salinity control easier and allow greater use of more saline water in irrigated agriculture. Emphasis will be on how to manage intermediate quality water with slight to moderate restrictions on use, as shown in Table 1. Such water could result in more severe problems if it is not properly managed. The same management techniques will apply to a poorer quality water, but as quality worsens the options for management become fewer.

2.2 BUILD-UP OF SOIL SALINITY

Salts are added to the soil with each irrigation. These salts will reduce crop yield if they accumulate in the rooting depth to damaging concentrations. The crop removes much of the applied water from the soil to meet its evapotranspiration demand (ET) but leaves most of the salt behind to concentrate in the shrinking volume of soilwater. At each irrigation, more salt is added with the applied water. A portion of the added salt must be leached from the root zone before the concentration affects crop yield. Leaching is done by applying sufficient water so that a portion percolates through and below the entire root zone carrying with it a portion of the accumulated salts. The fraction of applied water that passes through the entire rooting depth and percolates below is called the leaching fraction (LF).

$$\text{Leaching Fraction (LF)} = \frac{\text{depth of water leached below the root zone}}{\text{depth of water applied at the surface}} \quad (2)$$

After many successive irrigations, the salt accumulation in the soil will approach some equilibrium concentration based on the salinity of the applied water and the leaching fraction. A high leaching fraction (LF = 0.5) results in less salt accumulation than a lower leaching fraction (LF = 0.1). If the water salinity (ECw) and the leaching fraction (LF) are known or can be estimated, both the salinity of the drainage water that percolates below the rooting depth and the average root zone salinity can be estimated. The salinity of the drainage water can be estimated from the equation:

$$EC_{dw} = \frac{EC_w}{LF} \qquad (3)$$

where: EC_{dw} = salinity of the drainage water percolating below the root zone (equal to salinity of soil-water, EC_{sw})

EC_w = salinity of the applied irrigation water

LF = leaching fraction

In Example 1, the leaching fraction and water quality are used to predict drainage water quality. The plant, however, is only exposed to this drainage water salinity at the lowest part of the root zone. The salinity in this lower portion of the root zone tends to be higher than in the upper portion due to its much lower leaching fraction. The crop responds, however, to the average root zone soil salinity and not to the extremes of either the upper or lower zones.

EXAMPLE 1 - CALCULATION OF CONCENTRATION OF DEEP PERCOLATION FROM THE BOTTOM OF THE ROOT ZONE

A crop is irrigated with water of an electrical conductivity (ECw) of 1 dS/m. The crop is irrigated to achieve a leaching fraction of 0.15 (assumes that 85 percent of the applied water is used by the crop or evaporates from the soil surface).

Given:	EC_w	=	1 dS/m
	LF	=	0.15

Explanation:

The concentration of the soil-water percolating below the root zone (ECsw) is equivalent to the concentration of the drainage water (ECdw) accumulating below the root zone. The salinity of the deep percolation from the bottom of the root zone (drainage water) can be estimated by using equation (3):

$$EC_{dw} = EC_{sw} = \frac{EC_w}{LF} \qquad (3)$$

$$EC_{dw} = \frac{1}{0.15} = 6.7 \text{ dS/m}$$

The salinity of the soil-water that is percolating from the bottom of the root zone (EC_{dw}) will be approximately 6.7 dS/m.

Equation (3) can also be used to predict average soil-water salinity (ECsw) in the rooting depth if certain assumptions are made regarding water use within the root zone. The guidelines of Table 1 assume that 40, 30, 20 and 10 percent of the water used by the crop comes, respectively, from the upper to lower quarter of the rooting depth. This water use pattern closely fits conditions found under normal irrigation practices. An illustration is given in Example 2 where the above water use pattern is used to estimate average soil-water salinity (ECsw).

Example 2 shows that with a 15 percent leaching fraction and a 40-30-20-10 water use pattern the average soil-water salinity (ECsw) is approximately 3.2 times more concentrated than the applied irrigation water. At a leaching fraction of 20 percent, the average ECsw is 2.7 times the salinity of the applied irrigation water (ECw). The guidelines of Table 1 were developed assuming a 15–20 percent leaching fraction range which results in an average soil-water salinity (ECsw) approximately 3 times that of the applied water. The soil-water salinity (ECsw) is the average root zone salinity to which the plant is exposed. It is difficult to measure. Salinity measurement is normally done on a saturation extract of the soil and referred to as the soil salinity (ECe). This soil salinity, (ECe), is approximately equal to one-half of the soil-water salinity (ECsw). As a general rule of thumb, at a 15–20 percent leaching fraction, salinity of the applied water (ECw) can be used to predict or estimate soil-water salinity (ECsw) or soil salinity (ECe) using the following equations:

$$EC_{sw} = 3\ EC_w \quad (4)$$
$$EC_e = 1.5\ EC_w \quad (5)$$
$$EC_{sw} = 2\ EC_e \quad (6)$$

If irrigation practices result in greater or less leaching than the 15–20 percent LF assumed in the guidelines of Table 1, a more correct concentration factor can be calculated using a new estimated average leaching fraction and the procedure illustrated in Example 2. Table 3 lists concentration factors for a wide range of leaching fractions (LF = 0.05 to 0.80). The predicted average soil salinity (ECe) is estimated by multiplying the irrigation water salinity (ECw) by the appropriate concentration factor for the estimated leaching fraction (see equation (8) in Table 3). These predicted average soil salinities reflect changes due to long-term water use and not shortterm changes that may occur within a season or between irrigations. Figure 2 illustrates typical soil salinity profiles that can be identified and are typical of salinity distribution in the crop root zone after several years of irrigation with one water source and closely similar leaching fractions.

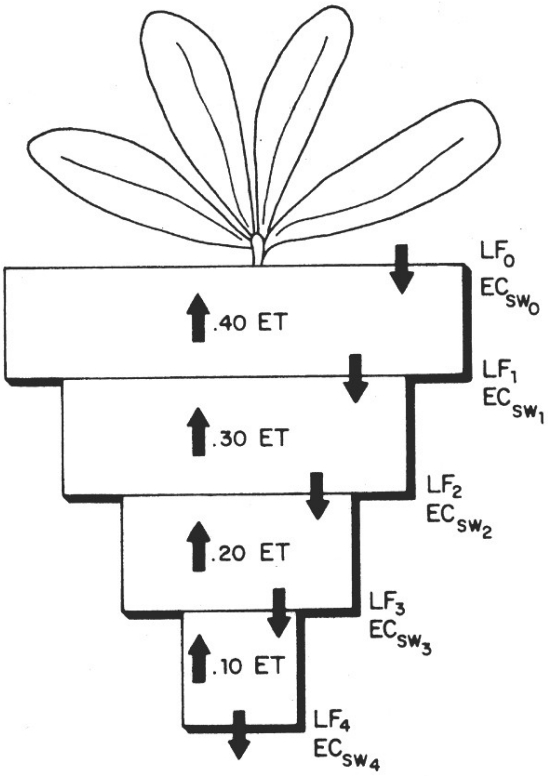
2.3 SALINITY EFFECTS ON CROPS

The primary objective of irrigation is to provide a crop with adequate and timely amounts of water, thus avoiding yield loss caused by extended periods of water stress during stages of crop growth that are sensitive to water shortages. However, during repeated irrigations, the salts in the irrigation water can accumulate in the soil, reducing water available to the crop and hastening the onset of a water shortage. Understanding how this occurs will help suggest ways to counter the effect and reduce the probability of a loss in yield.

The plant extracts water from the soil by exerting an absorptive force greater than that which holds the water to the soil. If the plant cannot make sufficient internal adjustment and exert enough force, it is not able to extract sufficient water and will suffer water stress. This happens when the soil becomes too dry. Salt in the soil-water increases the force the plant must exert to extract water and this additional force is referred to as the osmotic effect or osmotic potential. For example, if two otherwise identical soils are at the same water content but one is salt-free and the other is salty, the plant can extract and use more water from the salt-free soil than from the salty soil. The reasons are not easily explained. Salts have an affinity for water. If the water contains salt, more energy per unit of water must be expended by the plant to absorb relatively salt-free water from a relatively salty soil-water solution.

EXAMPLE 2 - DETERMINATION OF AVERAGE ROOT ZONE SALINITY

The average root zone salinity can be calculated using the average of five points in the rooting depth. The following procedure can be used to estimate the average root zone salinity to which the crop responds.



ASSUMPTIONS

1. Applied water salinity (EC_w) = 1 dS/m.

2. Crop water demand (ET) = 1000 mm/season.

3. The crop water use pattern is 40-30-20-10. This means the crop will get 40 percent of its ET demand from the upper quarter of the root zone, 30 percent from the next quarter, 20 percent from the next, and 10 percent from the lowest quarter. Crop water use will increase the concentration of the soil-water which drains into the next quarter (EC_{sw}) of the root zone.

4. Desired leaching fraction (LF) = 0.15. The leaching fraction of 0.15 means that 15 percent of the applied irrigation water entering the surface percolates below the root zone and 85 percent replaces water used by the crop to meet its ET demand and water lost by surface evaporation.

EXPLANATION

1. Five points in the root zone are used to determine the average root zone salinity. These five points are soil-water salinity at (1) the soil surface, (ECsw0); (2) bottom of the upper quarter of the root zone, (ECswl); (3) bottom of the second quarter depth, (ECsw2); (4) bottom of the third quarter, (ECsw3) and (5) bottom of the fourth quarter or the soil-water draining from the root zone (ECsw4) which is equivalent to the salinity of the drainage water (ECdw).

2. With a LF of 0.15, the applied water (AW) needed to meet both the crop ET and the LF is determined from the following equation:

$$AW = \frac{ET}{1 - LF} = 1176 \text{ mm of water} \qquad (7)$$

3. Since essentially all the applied water enters and leaches through the soil surface, effectively removing any accumulated salts, the salinity of the soil water at the surface (ECsw0) must be very close to the salinity of the applied water as shown using equation (3) and assuming LF0 = 1.0.

$$EC_{dw_0} = EC_{sw_0} = \frac{EC_w}{LF_0} = \frac{1}{1} = 1 \text{ dS/m} \quad (3)$$

4. The salinity of the soil-water draining from the bottom of each root zone quarter is found by determining the leaching fraction for that quarter using equation (2) and then determining the soil-water salinity using equation (3).

$$LF = \frac{\text{Water leached}}{\text{Water applied}} \qquad EC_{sw} = \frac{EC_w}{LF}$$

For the bottom of the first quarter:

$$LF_1 = \frac{1176-.40(1000)}{1176} = 0.66 \qquad EC_{sw_1} = \frac{EC_w}{LF_1} = 1.5 \text{ dS/m}$$

--- at the bottom of the second quarter:

$$LF_2 = \frac{1176-.40(1000)-.30(1000)}{1176} = 0.40 \qquad EC_{sw_2} = \frac{EC_w}{LF_2} = 2.5 \text{ dS/m}$$

--- at the bottom of the third quarter:

$$LF_3 = \frac{1176-.40(1000)-.30(1000)-.20(1000)}{1176} = 0.23 \qquad EC_{sw_3} = \frac{EC_w}{LF_3} = 4.3 \text{ dS/m}$$

--- at the bottom of the root zone (fourth quarter):

$$LF_4 = \frac{1176-.40(1000)-.30(1000)-.20(1000)-.10(1000)}{1176} = 0.15 \qquad EC_{sw_4} = \frac{EC_w}{LF_4} = 6.7 \text{ dS/m}$$

5. The average soil-water salinity of the root zone is found by taking the average of the five root zone salinities found above:

$$EC_{sw} = \frac{EC_{sw_0} + EC_{sw_1} + EC_{sw_2} + EC_{sw_3} + EC_{sw_4}}{5}$$

$$EC_{sw} = \frac{1.0 + 1.5 + 2.5 + 4.3 + 6.7}{5} = 3.2 \text{ dS/m}$$

6. This calculation shows that the average soil-water salinity of the root zone will be 3.2 times as concentrated as the applied water.

Table 3 CONCENTRATION FACTORS (X) FOR PREDICTING SOIL SALINITY (ECe)[1] FROM IRRIGATION WATER SALINITY (ECw) AND THE LEACHING FRACTION (LF)

Leaching Fraction (LF)	Applied Water Needed (Percent of ET)	Concentration Factor [2] (X)
0.05	105.3	3.2
0.10	111.1	2.1
0.15	117.6	1.6
0.20	125.0	1.3
0.25	133.3	1.2

0.30	142.9	1.0
0.40	166.7	0.9
0.50	200.0	0.8
0.60	250.0	0.7
0.70	333.3	0.6
0.80	500.0	0.6

[1] The equation for predicting the soil salinity expected after several years of irrigation with water of salinity ECw is:

$$EC_e \text{ (dS/m)} = EC_w \text{ (dS/m)}.X \qquad (8)$$

[2] The concentration factor is found by using a crop water use pattern of 40-30-20-10. The procedure is shown in example 2.

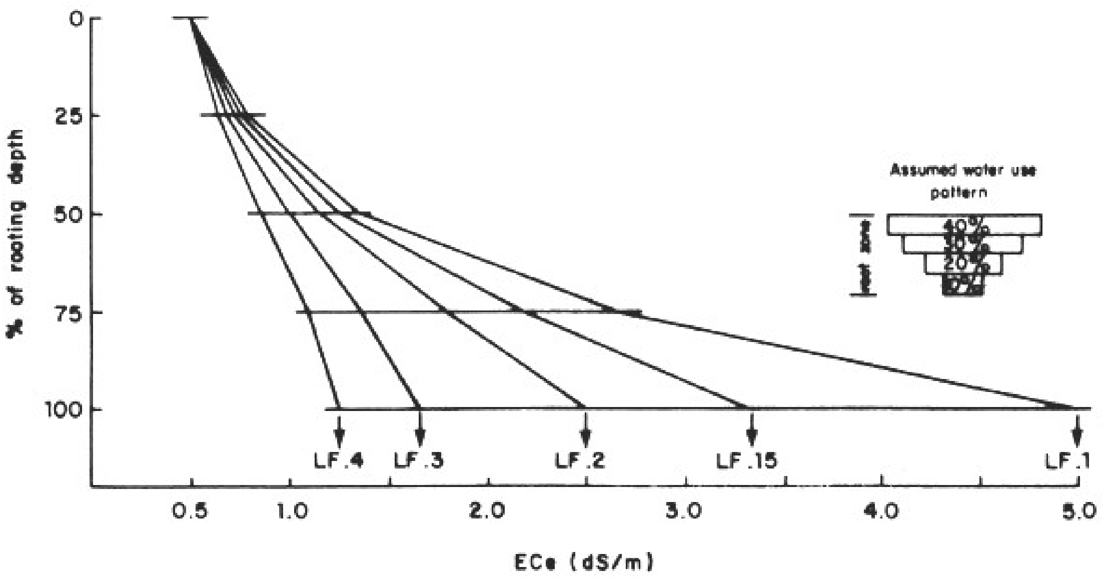


Fig. 2 Salinity profile expected to develop after long-term use of water of EC_w = 1.0 dS/m at various leaching fractions (LF)

For all practical purposes, the added energy required to absorb water from the salty soil (osmotic potential) is additive to the energy required to absorb water from a salt-free soil (soil-water potential). The cumulative effect is illustrated in Figure 3 and results in an important reduction in water available to the crop as salinity increases. Salinity effects are closely analogous to those of drought as both result in water stress and reduced growth. Stunting, leaf damage and necrosis or obvious injury to the plant are only noticeable after prolonged exposure to relatively high salinity.

The previous discussion showed how the concentration of salts in the soil varied with leaching fraction and depth in the root zone and resulted in an increase in concentration as the leaching fraction decreases or with increasing depth in the root zone. As the soil dries, the plant is also exposed to a continually changing water availability in each portion of the rooting depth since the soil-water content (soil-water potential) and soil-water salinity (osmotic potential) are both changing as the plant uses water between irrigations. The plant absorbs water but most of the salt is excluded and left behind in the root zone in a shrinking volume of soil-water. Figure 4 shows that following an irrigation, the soil salinity is not constant with depth. Following each irrigation, the soil-water content at each depth in the root zone is near the maximum, and the concentration of dissolved salts is near the minimum. Each changes, however, as water is used by the crop between irrigations.

The plant exerts its absorptive force throughout the rooting depth and takes water from wherever most readily available (the least resistance to absorption). Usually this is the upper root zone, the area most frequently replenished by irrigation and rainfall. Since more water passes through this upper root zone, it is more thoroughly leached and the osmotic or salinity effects are much less than at greater depths. Between irrigations, the upper root zone dries more rapidly than the lower because of the proliferation of roots in this zone which extract the readily available soil moisture. The plant must then meet more of its water demand from increasingly greater depths as the upper soil-water is depleted. Both the soil moisture at depth and the soil moisture remaining in the upper portions have a higher soilwater salinity and thus a greater osmotic potential. As the plant depletes the soil-water, a water extraction pattern develops. The extraction pattern of 40, 30, 20 and 10 percent for the upper to lower quarters of the root zone is assumed in the guidelines in Table 1. This closely fits water extraction patterns under normal irrigation practices and is assumed throughout this paper.

The pattern for water uptake is closely related to the frequency of irrigation. With infrequent irrigations, as assumed for the guidelines in Table 1, the typical extraction pattern is 40-30-20-10, but for more frequent irrigations the water uptake pattern is skewed towards greater uptake from the upper root zone and less from the lower and the crop rooting depth tends to be at shallower depths. A typical extraction pattern might be 60-30-7-3. Whatever the frequency, irrigations must be timed to supply adequate water and prevent crop moisture stress between irrigations, especially if soil salinity is also affecting water availability.

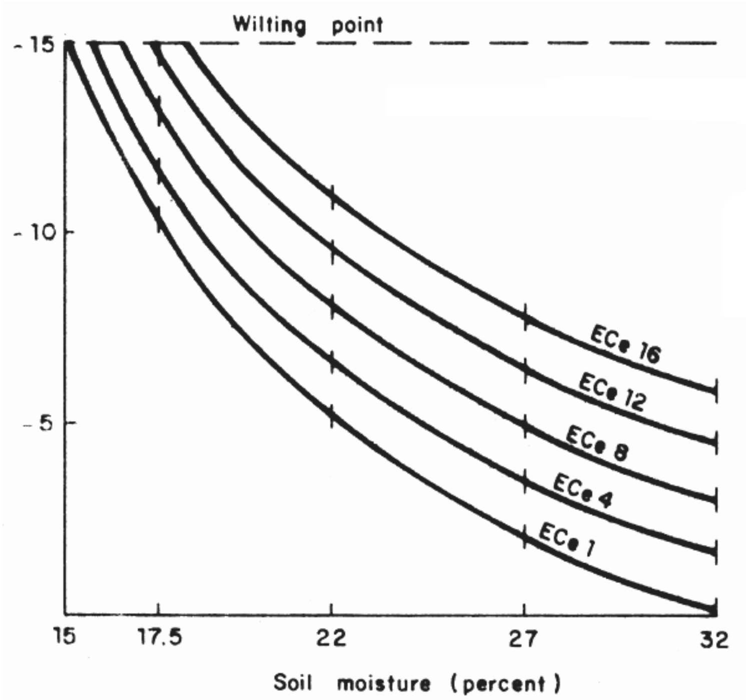
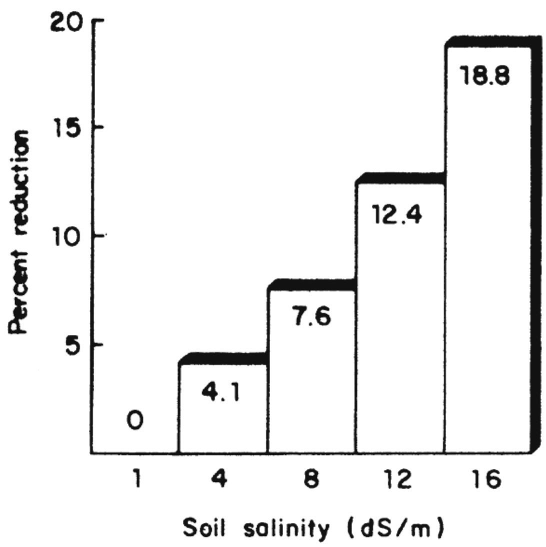


Fig 3 Soil moisture retention curves for a clay-loam Soil at varying degrees of soil salinity (EC_e)



Assumptions:

1. Salinity in irrigation water x 3 = salinity of soil-water.
2. No removals or additions of salts from the soil-water.
3. Soil-water depletion effects and salinity effects on water availability are additive (EC x .36 = osmotic pressure).
4. Available soil-water is difference between % soil-water at water holding capacity and at wilting point.
5. Evapotranspiration (ET) by the crop is removing water from the soil.

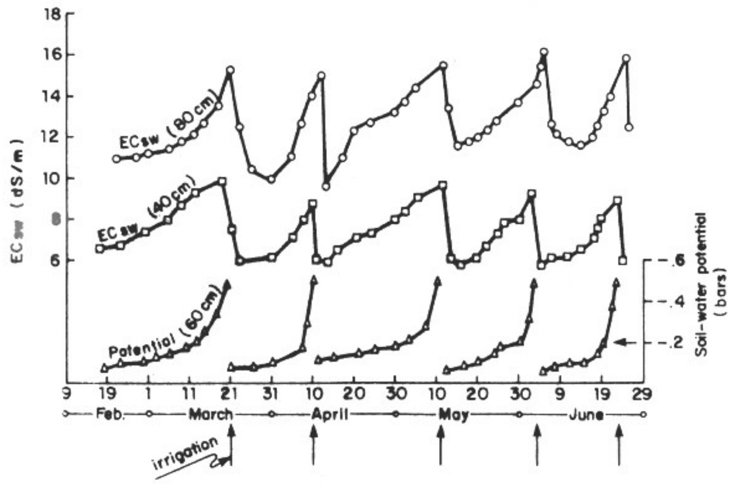


Fig.4 Change in salinity of soil-water (EC_{sw}) between irrigations of alfalfa due to ET use of stored water (Rhoades 1972)

When the upper rooting depth is well supplied with water, salinity in the lower root zone becomes less important. However, if periods between irrigations are extended and the crop must extract a significant portion of its water from the lower depths, the deeper root zone salinity becomes important particularly if, in the latter stages of a 'dry-down' (soil moisture depletion) period between irrigations, a high crop water demand should occur, such as on a hot, windy day. In this case, absorption and water movement toward the roots may not be fast enough to supply the crop and a severe water stress results. Reduced yields or crop damage can be expected for most crops when there is a shortage of water for a significant period of time.

The preceding discussion assumes that salinity reduces water availability in a similar manner for all types of plants, but not all crops are equally affected at the same soil salinity. Some are more able than others to extract or absorb water from a salty soil and are, therefore, more tolerant of salinity. The reasons for differences in tolerance are not well understood, but tolerance data show that there is an 8 to 10-fold range in salt tolerance of agricultural crops. In areas where irrigation management (leaching) cannot control salinity within the tolerance of a preferred crop, a yield loss will result unless an alternate crop more tolerant to the expected salinity is planted. A detailed discussion of crop tolerance to salinity is presented in Section 2.4.3.