MANAGING SALINE WATER FOR IRRIGATION

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INTRODUCTION

With the growing demand for increased production and thereby improved economic return, farmers are looking towards irrigation as an alternative. In Saskatchewan, however, a water source is the main constraint for producers considering irrigation. Recently the Swift Current Research Station has received numerous requests for information regarding alternate sources of irrigation water.

The two principal alternate sources of water for irrigation are municipal sewage effluent and groundwater. Generally, these two sources of water in Saskatchewan contain considerably more salt than the surface water normally used for irrigation (Table 1). Without proper management, severe salinity problems could result from the use of such waters for irrigation.

Table 1. Salt content in Saskatchewan water

Source	Salt content (mg/ℓ
Surface water	
Swift Current Creek	480
Sewage Effluent	
Swift Current	2000
Moose Jaw	1600
Groundwater	
Bearpaw Aquifer	1680 - 2360
Hatfield Valley Aquifer	2020 - 2950
Wynyard Aquifer	1220 - 2830

When irrigation is practiced, particularly if the applied water contains an appreciable concentration of soluble salts, the evapotranspiration process tends to concentrate salts in the root zone. Unless leached, salts will sooner or later begin to hinder crop growth.

To prevent salts from accumulating in the root zone during repeated irrigation-evapotranspiration cycles, the obvious remedy is to apply water in an amount greater than evapotranspiration, so as to deliberately cause a fraction of the applied water to flow through the root zone and leach away the excess salts.

The amount of water which must be leached through the root zone to maintain acceptable soil salinity for crop growth has been a subject of many studies. Clearly, if an insufficient amount of water is provided for leaching, salt will accumulate and concentrate in the soil to a level which may adversely affect the crop yield. However, the application of too much water can be as harmful as the application of too little. Excessive leaching not only wastes valuable water and increases pumping costs but also tends to remove essential nutrients from the root zone and adds to the drainage problems as well. Therefore, when irrigating with saline water, application rate should be controlled to maintain a favorable salt balance in the soil for production of maximum return, but without excessive wasting of water. The purpose of this paper is to discuss the optimal quantity of water which must be applied to effect leaching.

SOIL SALINITY UNDER IRRIGATION

In irrigated agriculture the concentration and composition of the soil solution are derived from the salinity of irrigation water. Salts move and accumulate in soil as a result of movement of water. To prevent salt accumulation, and consequent decrease in crop yields, irrigation must be managed to remove as much salt as is brought into the root zone by the irrigation water. This is the so-called salt balance concept. Disregarding short-term changes in soil salinity in the first few years after irrigation, and furthermore assuming no appreciable dissolution or precipitation of salts in the soil and no removal of salts by the crop, a simple salt balance equation at the steady-state condition in a well-drained soil is given as (Jame and Nicholaichuk, 1979):

$$V_{iw}C_{iw} = V_{dw}C_{dw} \quad \ldots\ldots\ldots\ldots (1)$$

where V_{iw}, V_{dw} and C_{iw}, C_{dw} are volume and salt concentration of irrigation water (iw) and drainage water (dw). The fraction of the applied water that drains below the root zone is generally referred to as the leaching fraction (LF). Thus

$$LF = \frac{V_{dw}}{V_{iw}} = \frac{C_{iw}}{C_{dw}} \quad \ldots\ldots\ldots\ldots (2)$$

Based on equation (2) the leaching requirement concept was developed in 1954 by the U.S. Salinity Laboratory (USDA Handbook No. 60), and since then it has been adopted almost universally. When the maximum permissible C_{dw} for a certain kind of crop is specified, the minimum permissible LF, which is the leaching requirement, is determined. According to the guidelines (USDA Handbook No. 60, 1954; Bernstein, 1964; Bower et al. 1969), the maximum concentration of the soil solution for moderately salt tolerance crops like alfalfa should be kept below 8 mmhos/cm to maintain a good yield. Hence, to irrigate alfalfa with water of 2 mmhos/cm, the recommended leaching requirement in the guidelines is $C_{iw}/C_{dw} = 2/8 = 0.25$.

Since the volume of water drained is the difference between the volume of irrigation and evapotranspiration, i.e., $V_{dw} = V_{iw} - V_{et}$, equation (2) can be transformed to

$$V_{iw} = V_{et}/(1 - LF) \quad \ldots\ldots\ldots\ldots (3)$$

If alfalfa requires 60 cm of water to grow, this means the total water supplied should be 80 cm to satisfy the leaching requirement of 0.25.

Obviously, the leaching requirement concept does not take the distribution of salts within the root zone into consideration. In a well-drained soil under proper management practices, a steady-state salinity profile will develop in the soil after several years of irrigation. Generally, at this steady-state condition, the concentration of soil solution increases from a low value close to that of the irrigation water at the soil surface to a higher value near the bottom of the root zone, determined largely by the size of the leaching fraction (Bernstein and Francois, 1973, Schilfgaarde et al., 1974). Because the crop extracts most of its water supply from the upper layers of the soil where the salt concentration is lowest, several researchers (Schilfgaarde, et al., 1974; Rhoades, 1974) have pointed out that a lower leaching fraction than the generally recommended leaching requirement in the guidelines can be used without fear of significant reduction of yield.

Assuming water uptake by the crop from each quarter of the root zone is 40-30-20-10% (Pair et al., 1975), the resultant LF at the lower boundary of each of the four soil segments (from top to bottom) would be 0.64, 0.37, 0.19 and 0.1 for 10% leaching, and 0.7, 0.475, 0.325 and 0.25 for 25% leaching. Based on equation (2), the concentration of the soil solution at the bottom of each of four intervals within the root zone when irrigation with water of 2 mmhos/cm were calculated (Table 2) at two levels of leaching fractions, e.g., LF = 0.1 and 0.25.

Table 2. Projected long-term salt concentration of the soil solution in well-drained soil irrigated with water of 2 mmhos/cm

Depth	Leaching fraction 0.1		Leaching fraction 0.25
		mmhos/cm	
1	3.13		2.86
2	5.41		4.21
3	10.53		6.15
4	20.00		8.00

*Note: Values calculated for the bottom of each of four intervals within the root zone.

Since 1973, at the Swift Current Research Station, the suitability of using the relatively high salt content of sewage effluent (EC $\simeq$ 2.6 mmhos/cm) has been studied. Effluent from the aerobic secondary lagoon of the city sewage system was sprayed onto a 4-ha field to irrigate alfalfa. A nearby 6 m x 6 m check ploct with the same type of soil was irrigated with an equal amount of water from the Swift Current Creek (EC $\simeq$ 0.7 mmhos/cm) each time the 4-ha plot was irrigated with effluent. The average EC of the applied water by considering the dilution effect of precipitation in this study was close to 2.0 and 0.6 mmhos/cm for the effluent and the creek water, respectively. The application rate was set to allow a certain amount of the water to pass through the root zone. Based on 60 cm consumptive use of water by alfalfa, the estimated leaching fraction during seven growing seasons under irrigation was in the range of 0.1 to 0.16 (Jame et al., 1980).

The changes in salinity profiles from 1973 before irrigation to the fall of 1980 after eight years of irrigation are given in Figure 1 (effluent irrigation) and Figure 2 (creek water irrigation). Soil salinity was actually determined by measuring the EC of the saturation extract (EC_e) as specified in the USDA Handbook No. 60 (1954). Converting the EC_e to the concentration of the soil solution (EC_{sw}) is based on the assumption that EC_{sw} (at field capacity) = 2 EC_e (USDA Handbook No. 60, 1954). Also shown in the figures are the projected long-term steady-state salinity profiles.

The results indicate that the measured salt content at the upper layer near the soil surface is higher than the predicted value, whereas in the bottom of the root zone they are slightly lower than the estimated value for a leaching fraction of 0.1 to 0.16. The projected salinity profile was derived from the mass balance equation which is based on the continued downward water flow condition. This condition probably can only be attained with a very high level of management. However, in most practices, irrigation was applied on an "as needed" basis with up to 50% of available soil water used by the crop before irrigation water was again applied. During the irrigation intefval, a certain amount of water would tend to move upwards into the surface layer by capillary action and thus increase the salt content. Thus, it can be expected that the actual salt content near the soil surface would be higher (about double as the result from this study) than predicted.

The salt contents at the bottom layer of the root zone which is lower than the estimated value is probably the result of a slightly higher degree of leaching than expected as due to overestimation of the consumptive use of water by alfalfa.

CROP YIELD AND AMOUNT OF DRAINAGE WATER BETWEEN HIGH AND LOW LEACHING FRACTION

A review of the literature indicates a 7.3% yield reduction of alfalfa for each 1.0 mmhos/cm increase in EC_e above a threshold value of 2 mmhos/cm (Maas and Hoffman, 1977). These data were obtained from experiments in artifically-salinized field plots where salinity was maintained essentially uniform with depth throughout the root zone to minimize the ambiguity of interpreting results from non-uniform salinity profiles. In real system, salt distribution in soil varies with depth.

Under irrigation, water uptake is highest at the upper part of the root zone, where proportionally more roots concentrate. Thus, applying crop salt tolerance data to irrigated fields, the best way of relating plant yield to salinity is to use the weighted mean soil salinity based on water uptake. Estimated alfalfa yield decrements (%) at two levels of leaching fractions, e.g., LF = 0.1 and 0.25, when irrigating with water of 2.0 mmhos/cm were prepared (Table 3) based on the weighted mean salinity concept and the soil salinity profiles discussed in the previous section.

Comparisons of crop yield and the amount of drainage water between leaching fractions of 0.1 and 0.25 for areas of southwestern Saskatchewan are presented in Table 4. This table was prepared based on available irrigation water of 6000 M^3. When a high leaching fraction (0.25) is used, this amount of water is only enough to irrigate one hectare of land.

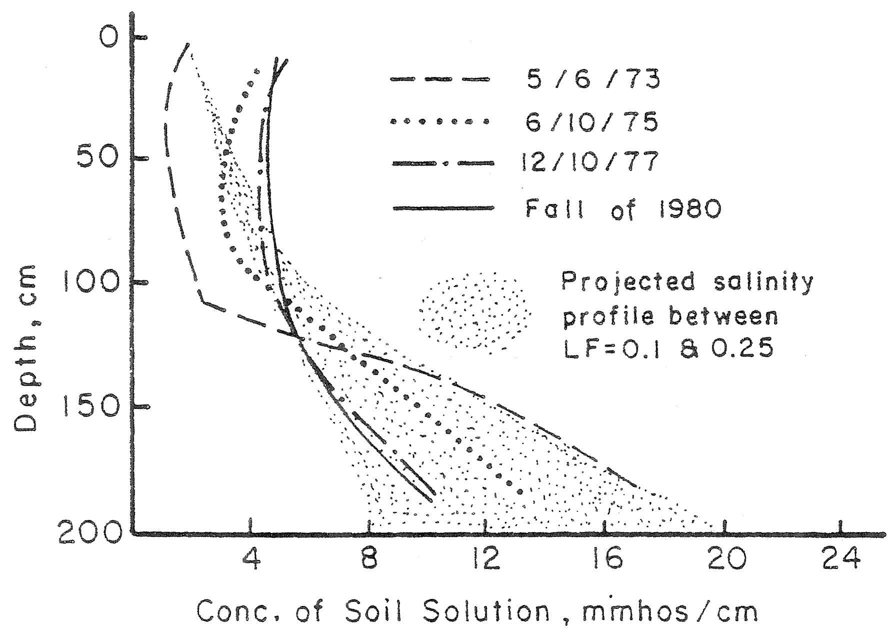

Figure 1. Soil Salinity under Effluent Irrigation

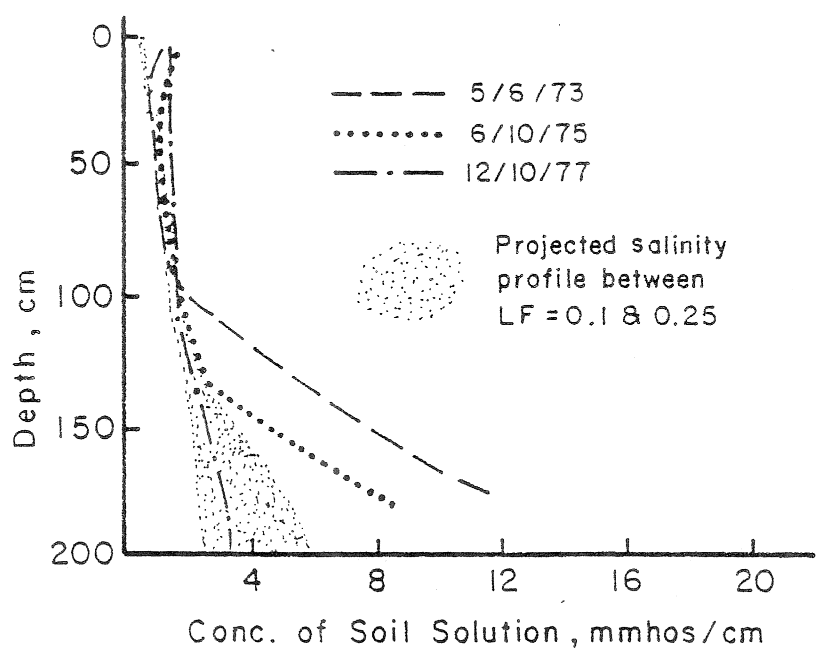

Figure 2. Soil Salinity under Creek Water Irrigation

Table 3. Estimated alfalfa yield decrement (%) due to irrigation water salinity

Salinity of irrigation water	Leaching fraction 0.1	0.25
	%	
2 mmhos/cm	8	2

Table 4. Comparison of yield and amount of drainage water between LF = 0.1 and 0.25

Crop	Alfalfa	
Consumptive water used	60 cm	
Potential yield under irrigation	12000 kg/ha	
Yield under dryland	4000 kg/ha	
Precipitation	20 cm	
Irrigation water	6000 M^3	
Salinity of irrigation water	2.6 mmhos/cm	
Leaching fraction	0.1	0.25
Irrigation acreage	1.3 ha	1.0 ha
Yield reduction as result of salinity	8%	2%
Total yield on basis of 1.3 ha	14352 kg	12960 kg (1 ha under irrigation and 0.3 ha under dryland)
Drainage water	750 M^3	1700 M^3

Whereas, when a low leaching fraction (0.1) is chosen, it will be able to increase the irrigated area to 1.3 ha. Although, with LF = 0.1, a 6% of yield reduction per hectare of land under irrigation might be expected as the result of slightly higher soil salinity as compared to LF = 0.25, yields on the basis of 1.3 ha are higher with the case of a low leaching fraction as the increase of irrigation acreage. Water is precious to agriculture in our area. Every measure should be taken to conserve water for increased crop production.

A startling fact is the difference in quantity of the drainage water as the result of high and low leaching fractions; in this case, it is 1700 M^3 for a leaching fraction of 0.25 versus 750 M^3 for a leaching fraction of 0.1. The flow rate at the lower boundary of the root zone may limit to pass through the large volume of drainage water because of the limited hydraulic conductivity of the subsoil. Excessive leaching often leads to waterlogging of the soil and thus aggravates rather than solves the problem.

Any attempt to leach without provision of adequate drainage is not merely doomed to fail but can indeed exacerbate the problem. Unless the water table is very deep or lateral groundwater drainage is sufficiently rapid, the excess irrigation will cause a progressive rise of the water table. Once the water table comes within a meter or two of the soil surface, groundwater will move upwards into the root zone by capillary action between irrigations. The soluble salt carried upward will deposit and concentrate in the upper soil layer. Therefore, the raised water table may cause more serious salinity. If artificial drainage by tiling, pumping or ditching should be provided to lower the water table, the costs will be higher with the larger volume of drainage water.

CONCLUSIONS

When irrigating crops with saline water, correct management is to restore any soil water deficit and maintain proper leaching. Under irrigation, the soil salinity generally increases from a low value at the soil surface, which is mainly associated with the salinity of irrigation water, to a higher value near the bottom of the root zone determined primarily by the degree of leaching. Because the crop extracts most of its water supply from the upper layers of the soil where the salt concentration is lowest, a relatively low leaching fraction can be used without fear of significant reduction of yield. The main advantages of using lower leaching fractions are (i) reduced water demands and hence increased irrigation acreage, (ii) reduced drainage costs. Water application should be controlled to maintain a favorable salt balance in the soil for production of maximum return, but without excessively wasting the water and without materially adding to the drainage problem.

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