SALT BALANCE IN A CATENA OF BIRSAY SOIL UNDER EFFLUENT IRRIGATION

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1. INTRODUCTION

The interest in using municipal wastewater to irrigate agricultural lands is growing rapidly on the Canadian Prairies. In Saskatchewan, eight communities are already using sewage effluent to irrigate crops and another seven communities are currently planning and preparing for effluent irrigation. In Alberta, an even greater number of communities have adopted the effluent irrigation as a better method of wastewater disposal.

In many cases, effluent irrigation is viewed by the urban community as the most practical alternative for tertiary treatment and disposal of wastewater. The soil, serving as a "living" filter, will effectively retain and thus remove harmful chemicals and microorganisms from the wastewater as it percolates through the soil profile.

To the farmers, the effluent is a valuable source of water for increased crop yields. Water is precious to agriculture here on the Canadian Prairies as it is the major limiting factor in crop production. Moreover, lagoon effluents contain substantial amounts of nutrients such as nitrogen, phosphorus, potassium and sulfur, essential for plant growth. Consequently, marked increases in the yield can be expected when the effluent is used for crop irrigation.

However, no matter how agronomically beneficial it may be, the use of effluent from nonindustrial communities for irrigation has encountered a number of problems; among them, the sanitary quality and high salt content of the wastewater are the two major concerns. It is quite clear that if this type of disposal of municipal waste and its utilization by agriculture is to gain public acceptance, the absence of health hazards for man and animals must be demonstrated.

Also, as one of the main objectives of wastewater irrigation is to utilize the water and nutrients for crop production, it is essential that the soil system be capable of sustaining a reasonable level of productivity. In Western Canada, municipal effluent usually contains considerably more salt than the surface water normally used for irrigation. The main requirement is, therefore, that wastewater used will not eventually render the soil unproductive.

In 1973, a pilot project was initiated at Swift Current Research Station to examine the suitability of using sewage effluent as a source of irrigation water. This study was designed to assess changes in the physical, chemical and microbiological characteristics of the soil, as well as yield and feeding quality of forage produced under frequent and prolonged irrigation with sewage effluent.

This paper will report on changes of salt content in the soil and the resultant effects on crop yield after five years of effluent irrigation. Results based on this study regarding bacteria and health aspects have been reported by Biederbeck and Bole (1979). Bole and Biederbeck (1979) also discussed nutrient uptake and plant productivity under wastewater irrigation.

2. EXPERIMENTAL SITES AND METHODS

A 4-ha site, located northeast of the city of Swift Current, was selected for this study. The area is situated on a height of land to the north of the sewage lagoon. Nonchlorinated effluent from the aerobic secondary lagoon of the city's sewage system was sprayed onto the field with a 335 m side-wheel-roll sprinkler system. A nearby 6 m x 6 m check plot was set up to irrigate with water from the Swift Current Creek each time the 4-ha plot was irrigated with effluent.

Roamer alfalfa was seeded on the test area in the spring of 1973. Thirteen light irrigations with a total of 19 cm of water were applied to assure good stand establishment. Irrigation scheduling was adopted starting in 1974 by using the balance sheet technique (Korven and Wilcox, 1964). Evapotranspiration was estimated by multiplying evaporation as measured by the class A pan by a factor of 0.7. Effluent was applied whenever the total available water in the top 135 cm of soil had been reduced to 50%.

In this effluent irrigation study, irrigation was managed so as to maximize crop production rather than to maximize effluent disposal. Thus, initially, the liquid application rate was matched closely with the water requirements of the alfalfa crop. The leaching required for removal of accumulated salts in the root zone was thought to be satisfied by snowmelt water and was not thought to necessitate excessive application of effluent. However, the results from the first two years indicated that there had been insufficient snowmelt entering the soil to meet the leaching requirement. As a result, a greater increase in salt content than expected was found in the root zone, especially in the upper layers of the soil. In order to control soil salinity, the liquid application rate was then increased slightly to allow a certain amount of the applied water to pass through the root zone.

Both sewage effluent and Swift Current Creek water were monitored in detail for water quality periodically throughout the season at the time of irrigation. The average electrical conductivities of the irrigation water (EC_{iw}) and total water applied from 1974 to 1977 are listed in Table 1.

The adjusted EC of applied water, last two columns in Table 1, were obtained from the weighted values for the conductivities of the rainwater and the irrigation water and by assuming that 15% of the total applied water would evaporate directly from the soil surface. The electrical conductivity of the rainwater was assumed to be 0.3 mmhos/cm. The average EC of the applied water in this study over the four years was thus close to 2.0 and 0.6 mmhos/cm for effluent and the creek water irrigation, respectively.

Table 1. EC_{iw} and Total Water Applied

Year	EC_{iw} mmhos/cm		Irrigation Application	Total Water Applied cm			Adj. EC of Applied Water (mmhos/cm)	
	SF*	CW**	(times)	Irrigation	Rainfall	Total	SF*	CW**
1974	2.72	0.76	5	36	31	67	1.86	0.61
1975	2.08	0.65	6	40	23	63	1.66	0.59
1976	1.00	0.60	6	44	24	68	1.63	0.56
1977	3.07	0.75	6	50	23	73	2.57	0.70

*SF - Sewage Effluent
**CW - Creek Water

The soils in the study area belong to the Birsay Association of the Chernozemic Brown great group, having a loam to fine sandy loam surface texture and are underlain by glacial till (Ayers, 1973). The catena consists of four soil series; namely, Orthic Regosol, Calcareous, Orthic and Cumulic Orthic soils. Figure 1 shows the soil map of the study site.

The Orthic Brown soil, occupying the well drained intermediate slopes, is the dominant series in the pilot study area. This type of soil with well-developed soil profile is regarded as one of the most desirable types of soil for general agricultural use.

The Calcareous Brown series occurs on the upper slopes of knolls, above the Orthic soils. Several small areas of eroded Orthic Regosol series are also indicated on the survey map (Figure 1). Both Calcareous Brown and Orthic Regosol series have very little profile development and free lime at the surface.

The Cumulic Orthic series occurs in the drainage channels. Those are basically Orthic profiles with an accumulation of dark-colored humus material that has been translocated downslope by water and wind. Also, a narrow bank of drift material was found along the western edge of the plot.

Soil samples used for salinity analysis were collected from four to five locations at each one of the four soil series. They were taken from a depth of 0-15, 15-30, 30-60, 60-90, 90-120, 120-150 and 150-180 cm twice every year; i.e., in early spring and late fall. Figure 2 shows the average salinity profiles, expressed as the electrical conductivity of the soil saturation extract (ECe), of the four soil types before the start of effluent irrigation.

The soil was previously in a 2-year wheat-fallow rotation. The divergence of the profiles shown in Figure 2 reflects differences in water penetration into different soils under dryland farming. The Cumulic Orthic soils, for instance, are representative of sites which, over the years, have received more water through runoff from higher land. This additional water is available for the process of leaching, and as a result, salt contents in this type of soil are low and rather uniformly distributed throughout the top 200 cm of the profile. In Orthic Regosol and Calcareous soils, however, salts were only leached down to 45 cm due to less water penetration. The salinity profiles in these two soil series are highly nonuniform with salinities at the bottom layer of the soil many times higher than those near the soil surface.

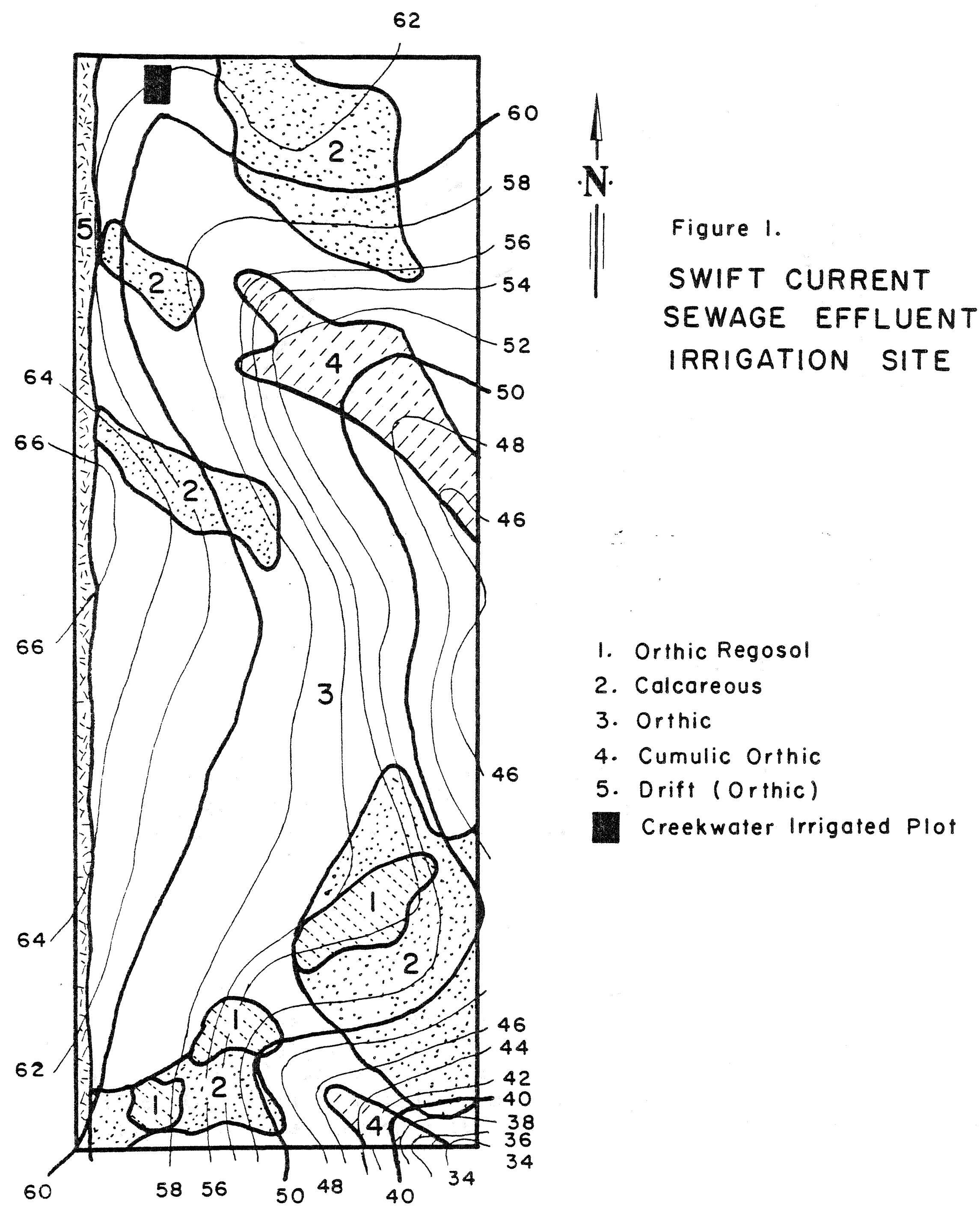
Figure I.
SWIFT CURRENT
SEWAGE EFFLUENT
IRRIGATION SITE
N
1. Orthic Regosol
2. Calcareous
3. Orthic
4. Cumulic Orthic
5. Drift (Orthic)
Creekwater Irrigated Plot
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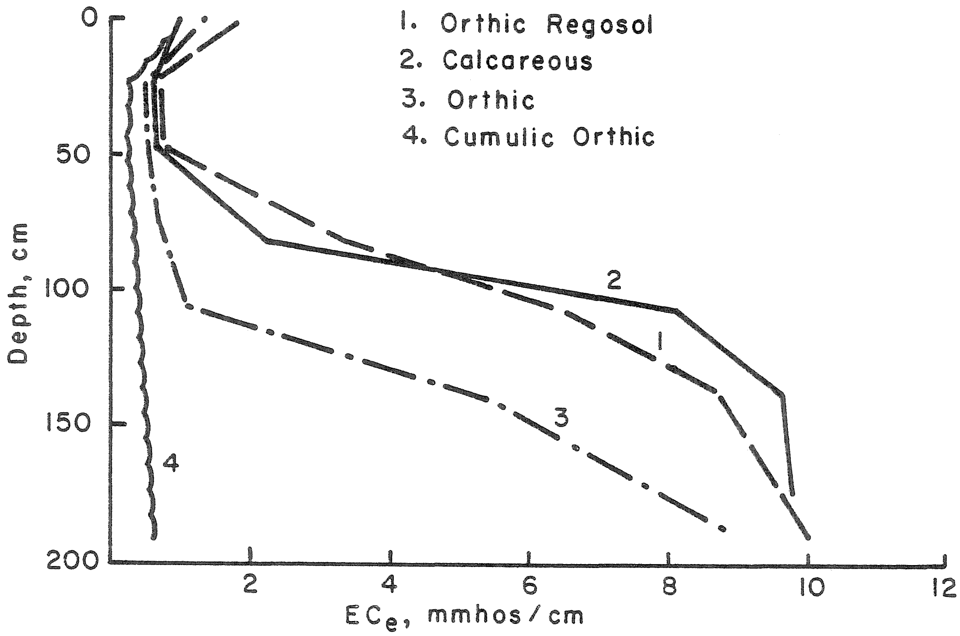

Figure 2. Salinity Profiles before Effluent Irrigation

3. RESULTS AND DISCUSSION

A. Theory and prediction of salt movement

The salt content in Swift Current sewage effluent is about four times higher than that in Swift Current Creek water. With an average EC of 2.5 mmhos/cm (1700 ppm TDS), the effluent is characterized as a salty water. When spraying it onto the field, plants absorb and transpire water from the soil, and most of the salts in the irrigation water would remain in the soil. Rainfall in this area is generally insufficient to leach these salts out of the soil. Hence, salts would accumulate and concentrate in the root zone to a level which would affect plant growth.

Disregarding specific ion effects, the effect of salinity on plant growth is primarily associated with the high ion concentration of the soil solution which makes it difficult for plants to absorb water from the soil. To prevent the buildup of salt in the root zone, irrigation must provide water for growth of the crop and at the same time supply enough water to leach excess salts out of the root zone. The fraction of the total applied water which would drain below the root zone for leaching is commonly referred to as the leaching fraction, LF.

Under irrigation, a steady state salinity profile generally develops in a well-drained soil through gradual changes in salinity near the surface to a level in equilibrium with the salinity of the irrigation water, and through gradual changes in salt contents of the deeper layers of the root zone to a level that is primarily a function of the size of the leaching fraction

(Schilfgaarde et al., 1974). Thus, salinity profiles in the soil may be rather uniform and change relatively little with depth when high leaching fractions are used. When low leaching fractions are chosen, the resultant salinity profile will vary drastically from salt concentrations near the soil surface approaching those of irrigation water to many-fold higher concentrations near the bottom of the root zone.

An equation relating the steady-state salinity profile to the salinity of the irrigation water (EC_{iw}) and the leaching fraction (LF) has been presented and discussed by Jame and Nicholaichuk (1979). The equation, derived on the basis of the steady downward water flow condition, was given as,

$$EC_{sw} = \frac{EC_{iw}}{1 - (1 - LF)\,\frac{x}{d}\,(2 - \frac{x}{d})} \qquad \cdots\cdots\cdots \quad (1)$$

where EC_{sw} is the electrical conductivity of the soil solution, d is the depth of the root zone, and x is the selected soil depth.

The annual water requirement of alfalfa in the Swift Current area varies from a minimum of 46 to a maximum of 68 cm, depending upon evaporative demand, but normally it falls between 56 and 61 cm (McElgunn and Heinrichs, 1975; Pohjakas et al., 1967; McElgunn, 1979; Irvine, 1979). The average total amount of water applied (rain and irrigation) during four years of this pilot study was about 68 cm (see Table 1). Hence, the leaching fraction was in the range of 0.1 to 0.17, which is well below the leaching requirement of 0.25 suggested in earlier U.S. guidelines (U.S. Salinity Lab. Staff, 1954; Bernstein, 1964; Bower et al., 1969).

B. Salinity changes in four soil types under irrigation

Figures 3, 4, 5 and 6 show the changes in salinity profiles from 1973 to 1977 for the Orthic Regosol, the Calcareous, the Orthic and the Cumulic Orthic soil series, respectively. A comparison of salinity profiles from the four soil series after five years of effluent irrigation is presented in Figure 7. Figures 3 to 7 also show the steady-state salinity profiles that are expected with the use of leaching fractions of 0.1 and 0.25, respectively. The expected steady-state salinity profiles, expressed in terms of ECe, are obtained from equation (1) and are based on an assumed 200-cm root zone. In these calculations, it is assumed that moisture contents in irrigated soils were at field capacity (FC) with the exception of the top 50 cm where moisture contents changed linearly from saturation to FC. Another assumption was that the electrical conductivity of soil water at FC is double that of ECe.

A comparison of Figures 3, 4 and 5 demonstrates similar trends in salinity profile changes for the Orthic Regosol, Calcareous and Orthic soil series. In all three soils, salt contents in the upper layers of the root zone increased gradually from 1973 to 1976, while salt contents in the bottom layers of these soils decreased substantially. By 1977, the salinity profiles appeared to have stabilized in all these three soils as there occurred only minor changes in salt content. After five years of effluent irrigation, the measured ECe values in the upper layers of these soils, except at the very

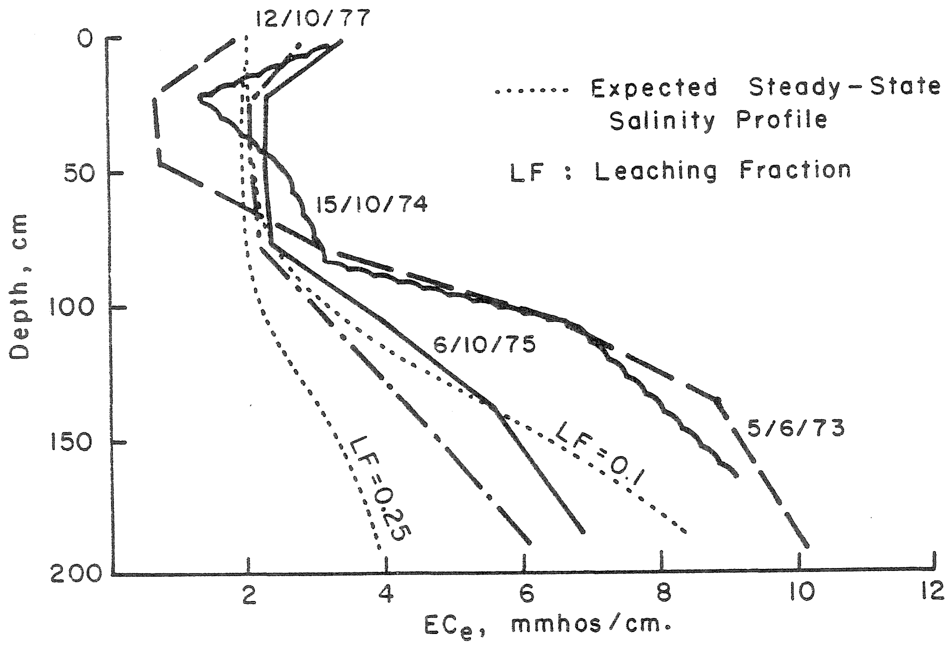

Figure 3. Salinity Profiles under Effluent Irrigation
Orthic Regosol

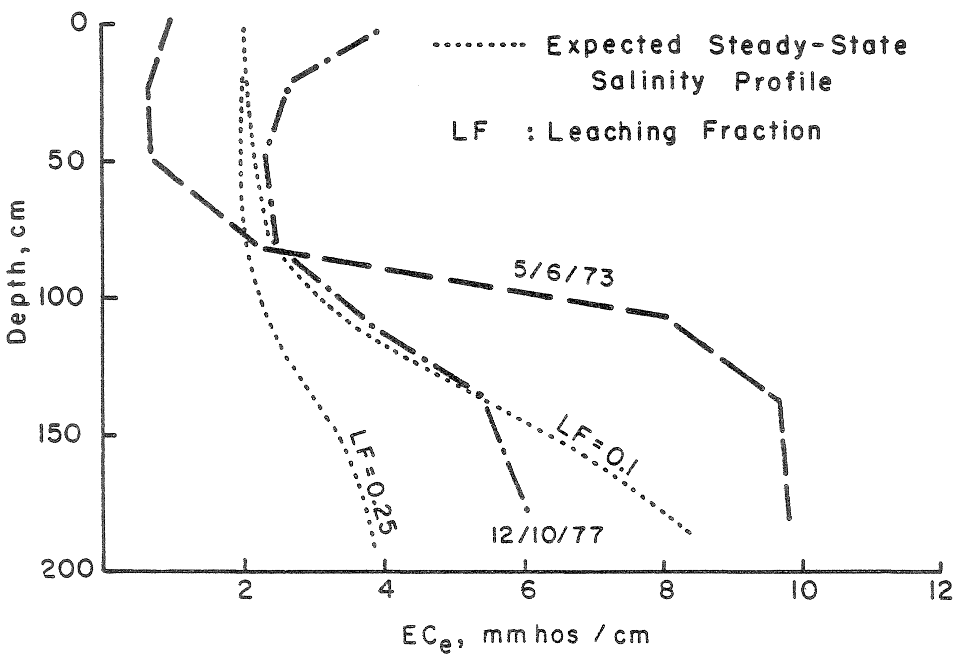

Figure 4. Salinity Profiles under Effluent Irrigation
Calcareous

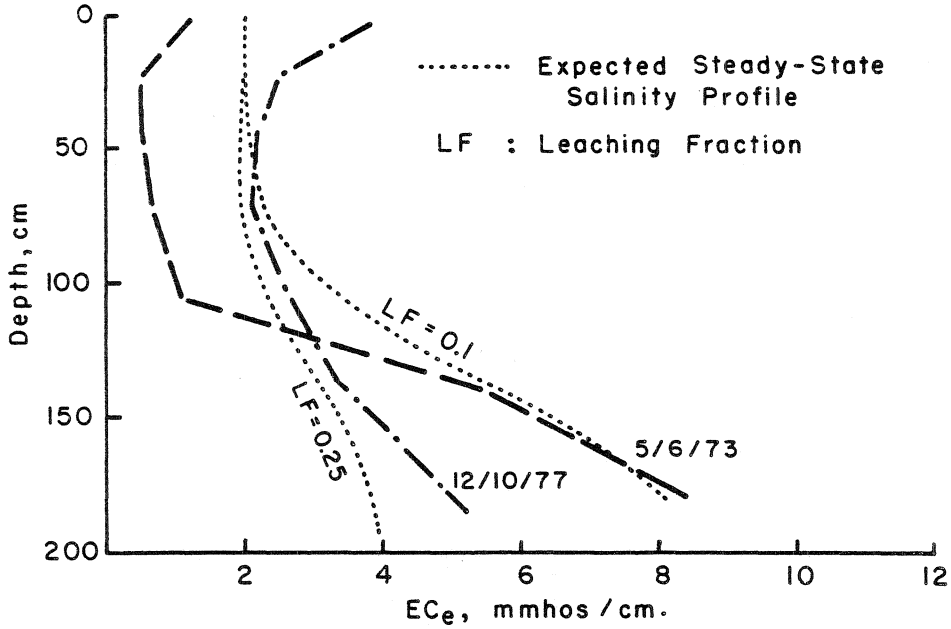

Figure 5. Salinity Profiles under Effluent Irrigation
Orthic

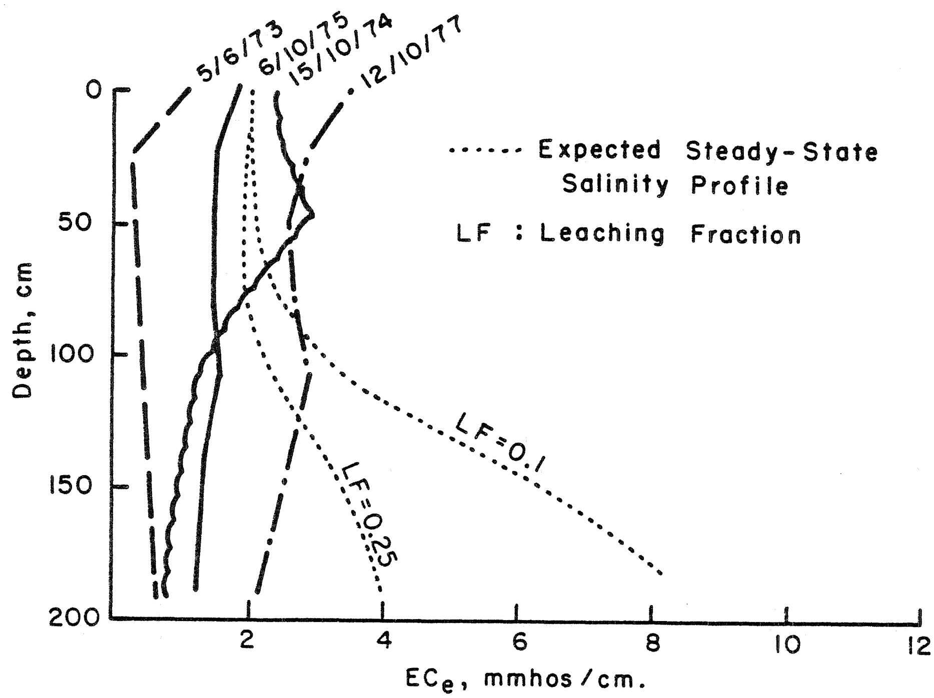

Figure 6. Salinity Profiles under Effluent Irrigation
Cumulic Orthic

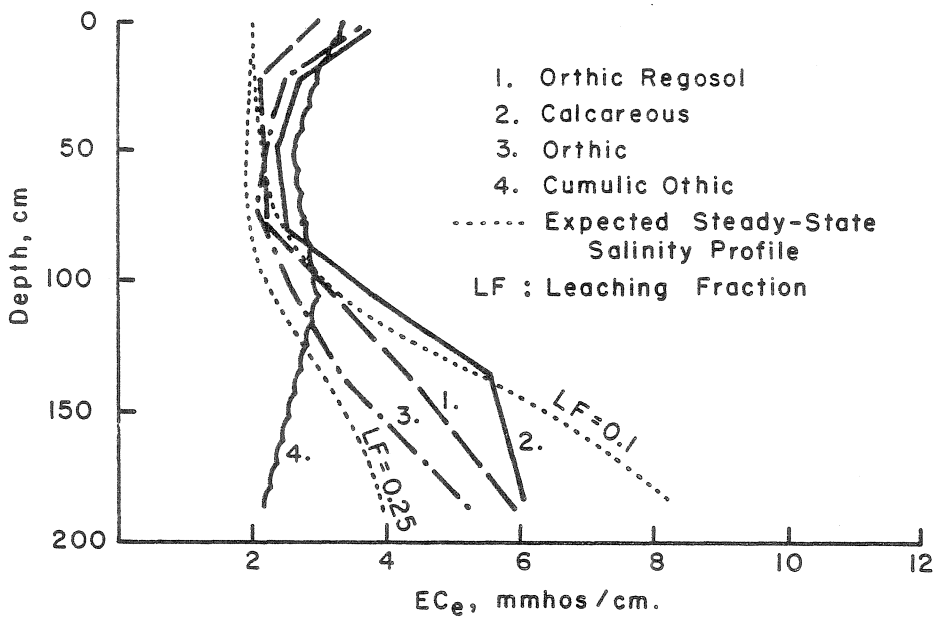

Figure 7. Salinity Profiles for Four Different Soil Series after 5 years Effluent Irrigation

soil surface, agree well with the expected (calculated) steady-state profiles. In the bottom layers of these soils, the average measured salt contents were slightly lower than the expected values for leaching fractions of 0.1 to 0.17. These small differences can be attributed to two reasons: (1) spring leaching from snowmelt water, and (2) overestimation of the consumption use of water by alfalfa.

Soil samples for salinity analysis were normally taken in late fall about three weeks after the last irrigation. During this period, a certain amount of water in the soil would move up to the surface and evaporate. Soluble salts carried upward with the water would be deposited on or near the soil surface. For this reason, a relatively high salt content was found near the soil surface. However, during the irrigation season the salt contents in the surface layer would be lower than those indicated in Figures 3 to 7.

A review of these results also indicates that a net reduction of total salt content in the top 200 cm was effected by effluent irrigation on the Orthic Regosol and the Calcareous soil series. In contrast, effluent application caused a small increase of salts in the Orthic soil because of the low initial salt content within this profile.

Among the four soil series, the greatest increase in total salt occurred with the Cumulic Orthic soil. This is primarily due to the very low salt content of this soil prior to irrigation. It is noteworthy that the salt content throughout this particular profile increased continually from 1973 to 1977 (Figure 6). By 1977, a steady-state condition was not yet reached. In this soil, salts were also distributed much more uniformly than in any of the other three soil types because it received considerably more water through runoff from irrigation and snowmelt.

Effluent irrigation produced a salt content in the upper layers of the Cumulic Orthic soil that was distinctly higher than those in the other three soil series. This higher salt content should be attributed to the relatively higher water table in low-lying areas.

Several piezometers were installed in the Cumulic Orthic soil in the drainage channels to monitor water table changes. In 1973, the water table was found to be more than 20 feet below the soil surface. Five years of irrigation had effected a rise in the water table. In 1977, the water table was found between 7 and 10 feet. Normally, the downward movement of water, immediately after irrigation, will reduce salt contents in the upper few feet of soil. But between irrigations, a high water table favors the upward capillary flow of water to the surface. The soluble salt carried upward will deposit and concentrate in the upper soil layers from where plants obtain most of their moisture and nutrients. Therefore, the raised water table may cause more serious salinity. The results from this study demonstrate the need for adequate drainage systems to ensure satisfactory leaching of salts from the root zone, especially in soils within the low-lying areas.

In Orthic soil irrigated with creek water, soil salinity in the upper layer of the soil remained virtually unchanged, while a substantial decrease in salt occurred in the bottom layers. Figure 8 indicates changes in salt content during five years of creek water irrigation.

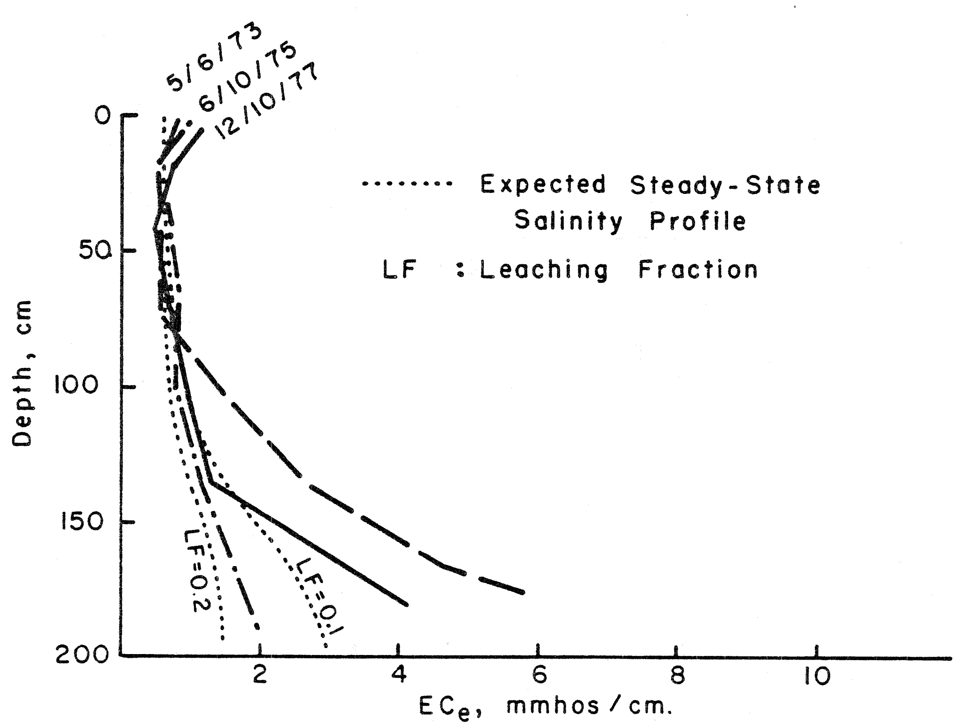

Figure 8. Salinity Profiles under Creek Water Irrigation

C. Effect of salinity on yield

A review of the literature indicates a 7.3% yield reduction of alfalfa for each 1.0 mmhos/cm increase in ECe above a threshold value of 2.0 mmhos/cm (Maas and Hoffman, 1977). These data were obtained from artificially salinized field plots where salinity was maintained essentially uniform throughout the root zone by irrigating waters of different salinity and by maintaining a high leaching fraction. In natural systems, salinity distribution is neither uniform nor constant. Applying these data to field conditions requires knowledge of the plant's response to changes in salinity.

Bernstein and Francois (1973) conducted a comprehensive leaching requirement study and found that the response by alfalfa was directly related to the weighted-mean salinity which was calculated based on the relative amount of water absorbed from each depth segment within the root zone. Based on the generally observed root distribution pattern for irrigated crops, we may assume that 40% of the crop water uptake originates from the upper quarter of the root zone, 30% from the second quarter, 20% from the third quarter and 10% from the lowest quarter. When this assumption is applied to irrigation of alfalfa with sewage effluent at Swift Current, the expected yield reduction due to salinity will be about 10% in case of the low leaching fraction, LF = 0.1, and only 3 to 4% in case of the higher LF (0.25) when compared to yields on nonsaline soil, i.e., soil with mean salinity of < 2 mmhos/cm.

Annual yields of alfalfa on the four different soil types irrigated with effluent and on the creek water irrigated plot are shown in Table 2.

Table 2. Yield (dry matter), kg/ha.

Year	Effluent Irrigation				Creek Water Irrigation
	1	2	3	4	
1974	6900	6600	6500	7900	5900
1975	7100	7700	8800	9300	9200
1976	7600	8300	9300	9800	8400
1977	10100	9300	11300	10600	9400

1 - Orthic Regosol 2 - Calcareous
3 - Orthic 4 - Cumulic Othic

Initially, alfalfa yields on the Cumulic Orthic soil were considerably higher than yields on the other three soil series as the former soil had a better developed profile as well as higher humus and nutrient content. However, by 1977, the yields on the Cumulic Orthic soil were slightly lower than those on the Orthic soil. This relative yield depression could be attributed to the considerably higher salinity in the upper layers of the Cumulic Orthic soil as the result of five years of effluent irrigation.

The salinity profiles shown in Figure 7 indicate an expected yield difference of 5 to 6% between the Orthic and the Calcareous soil. However, the actual yield difference by 1977 was 2000 kg/ha or 18% (Table 2), and much of this observed yield differential should be attributed to the inherently better soil structure and fertility level of the Orthic soil rather than to differences in effluent-effected soil salinity.

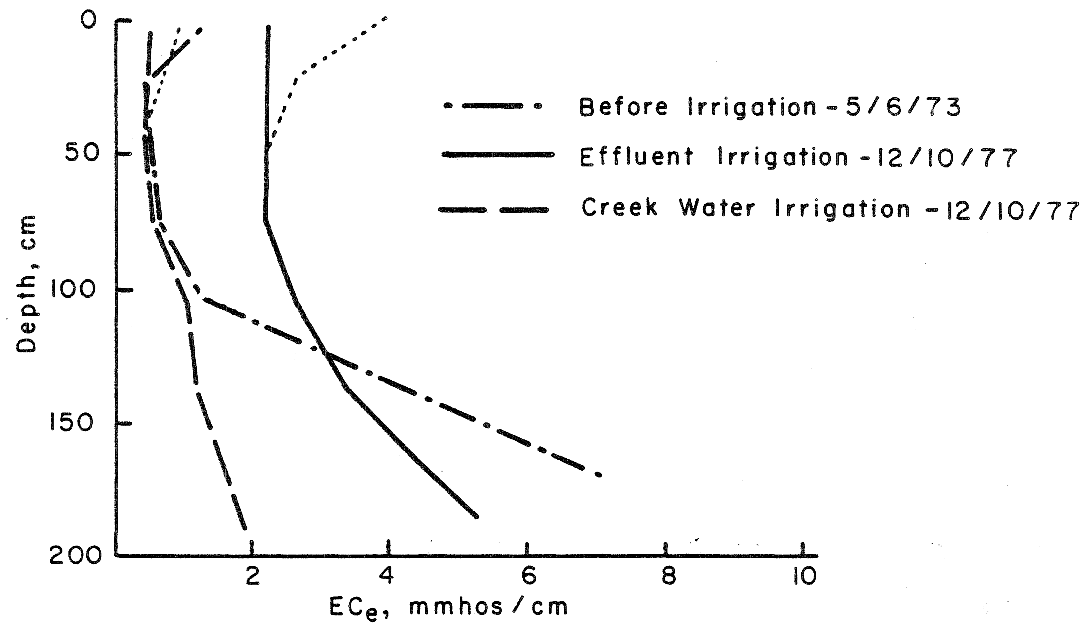

Figure 9. Comparison of Salinity Profiles between Effluent Irrigation and Creek Water Irrigation

Although the average salt content in the effluent-irrigated Orthic soil by 1977 was more than triple that in the creek water-irrigated Orthic profile (see Figure 9), the former soil actually outyielded the latter (Table 2) because the salinity-based yield reductions were masked by the much higher nutrient loading under effluent irrigation.

4. CONCLUSIONS

Results from the first five years of a pilot study at the Swift Current Research Station indicate that alfalfa will grow well under irrigation with sewage effluent if 10 to 15% of the applied water is allowed to leach through the root zone. On effluent-irrigated soil yields were markedly higher than on soil irrigated with creek water. Allthough the leaching fractions used in this study were substantially lower than those suggested in earlier guidelines (i.e., 25%), we believe that plant production level can be maintained at more than 90% of that on nonsaline soil with the same fertilizer treatment. The main advantages of using lower leaching fractions are (i) reduced water demands, (ii) an increase in irrigated areas, (iii) reduced drainage costs, and (iv) reduced total salt loads in return flows.

From this study, it is also evident that the requirement for adequate drainage systems to effect salt removal by leaching is of prime importance. Without adequate drainage, downward percolting water will fill the lower soil spaces and cause the water table to rise. A high water table favors upward capillary flow of water to the surface. The soluble salt carried upward will concentrate on the upper layers of the soil and may thus cause greater salinity.

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