Irrigation With Sewage Effluent: The Salt Balance

E. de Jong
Department of Soil Science
University of Saskatchewan
Saskatoon, Saskatchewan

Disposal of sewage effluent in the form of irrigation on crops has been practiced for centuries in Europe, examples are Edinburgh (since the mid-18th century), Berlin and Paris (since about 1850). The most common crop used is grass. In North America the Pennsylvania State Project has drawn considerable attention, in this project up to 4" of effluent is applied weekly to crops and forest with no detrimental effects. The effluent used in these projects is probably fairly low in salt content, for example a figure of 200 ppm is given for the effluent used in the Pennsylvania State Project. Investigations are also underway in Western Canada, for example in Taber since 1971 and in Swift Current since 1973. In Saskatchewan farmer-operated projects are underway in Balgonie (since 1970) and Davidson (since 1974). The effluent used at the various sites in Western Canada contains from 5 to 10 times as much salt as that used in the Pennsylvania State Project, and, hence considerable attention must be directed towards maintaining the salt balance of the soil.

The major advantages of sewage effluent irrigation over discharge of the effluent in waterways are:

1) fewer problems with pollution of the streams with disease carrying organisms, particulate matter and chemicals (organic and inorganic),
2) lower capital costs than expensive treatment plants, and
3) the nutrients and the water in the effluent may benefit crop growth.

In sewage effluent irrigation, the soil acts as a "living" filter that affects physical filtration, chemical filtration (ion exchange, absorption, precipitation) and biological filtration (uptake of nutrients by plant roots, biochemical transformations) of the effluent. The suitability of a soil depends on such factors as: infiltration and drainage rate; thickness; topography, stratigraphy, depth to groundwater, etc.; and texture and organic matter content.

The results of other studies show that most nutrients can be removed, as well as organic compounds, viruses, etc., and that generally effluent irrigation results in increased crop yields. Heavy metals present in the effluent are largely absorbed by the soil, while soluble salts (Cl, SO_4, Na, K, Ca and Mg) move through the soil although not necessarily in the same ratio as in the effluent. Generally, the soil absorbs Na (and K) and releases Ca and Mg. Sometimes this gives rise to problems with soil structure. The salt content of the soil usually increases and leaching requirements of up to 20% of the consumptive use by the crop may be needed. If the leaching requirement is not fulfilled, the build-up of salts will reduce the productivity of the soil (the build-up of heavy metals could do the same).

In this particular study, sewage effluent from the City of Moose Jaw was used. The raw sewage flows through three aerated lagoons, generally the effluent was collected from the third lagoon. The composition of the various batches of effluent used in this study are shown in Table 1.

Table 1. Composition of sewage effluent.

pH	8.47	8.51	8.32	8.12	8.21
EC, mmhos/cm	2.21	2.25	2.30	2.10	2.04
			ppm		
Na	225	240	254	248	247
K	16	20	22	22	23
Ca	118	125	124	91	94
Mg	103	93	89	54	53
Cl	161	183	195	268	254
SO_4	759	685	607	437	398
HCO_3	320	295	254	193	168
SAR	3.65	3.97	4.22	5.09	5.04

Most noticeable are the high levels of dissolved salts and the relatively high levels of Na in the effluent.

Soil samples were collected from an area south of Moose Jaw (Asquith soil), and from north of Saskatoon (Oxbow soil). Some soil properties are listed in Table 2.

Table 2. Selected properties of the soils used in the growth chamber experiment on irrigation with sewage effluent.

	Soil Properties					
	Asquith			Oxbow		
	0-6	6-12	12-24"	0-6	6-12	12-24"
Org. C, %	0.79	0.73	0.40	2.98	0.62	0.18
pH (1 soil : 1 water)	6.6	6.1	6.3	7.6	8.2	8.2
EC, mmhos (1 soil : 1 water)	0.1	0.1	0.1	0.3	0.3	1.0
CEC, meq/100 g	7.2	9.0	8.2	26.0	13.2	11.9
NH_4Ac Extr.						
Ca (meq/100 g)	3.7	11.8	4.5	12.1	19.3	18.4
Mg (meq/100 g)	1.4	5.1	1.6	6.0	8.8	9.3
Na (meq/100 g)	0.1	0.2	0.1	0.2	0.2	0.3
K (meq/100 g)	1.2	1.0	0.4	2.1	0.6	0.6
B.D., g/cm^3	1.41	1.51	1.54	1.10	1.39	1.40
o.d. soil, g	3740	4010	8260	2920	3690	7440
texture	LS	LS	LS	C	SCL-L	L-SL

The study was confined to what happens in the top few feet of the soil, Dr. Meneley of the Saskatchewan Research Council has investigated the expected effect of the effluent irrigation on the groundwater in the area south of Moose Jaw.

Fifty-four undisturbed soil cores of the Asquith and Oxbow sites were used in this study. The cores were subdivided into three groups of 18 cores each; each group of 18 cores was further subdivided into five treatments:

D dryland (no irrigation)	(2 columns)
9" effluent irrigation	(4 columns)
18" effluent irrigation	(4 columns)
27" effluent irrigation	(4 columns)
36" effluent irrigation	(4 columns)

The above listed irrigation rates were not always realized, the actual rates are given in Table 3. All columns had a tensiometer cup inserted in the bottom to provide for drainage, the tensiometer cup was kept under 1/3 atm suction. A limited number of columns were further instrumented to allow for the sampling of soil water and soil air (Figure 1). Fifteen pregerminated bromegrass seedlings were transplanted into each column. The drainage water was collected in vacuum flasks, periodically measured and assayed for a variety of properties. The remainder of this discussion is centered on the variations in quantity and quality of the drainage water.

Volume of Drainage Water

The volume of drainage water increased with increasing rates of effluent irrigation (Table 4). The data reported here are the average for the columns in each treatment and it should be noted that the variability is quite high, the standard errors vary from about 25 to over 50% of the average value reported. The variability in chemical properties was similar. The highest drainage rates were observed in the first season mainly since the cores were at field capacity when sampled and thus a large portion of the 4" (snowmelt) application applied at the start of this season drained through. With the exception of the last season, the Asquith soil generally showed more drainage than the Oxbow, this presumably reflects the difference in waterholding capacity. On the low irrigation rates, most of the drainage occurred early in the season, this was less noticeable under the 27 and 36" rates.

Soluble Salts in Drainage Water and Soil

The electrical conductivity of the drainage water on the Asquith soils gradually increased over the first growing seasons and then approached a steady level of 5 to 10 mmhos/cm. In contrast, the EC of the drainage water of the Oxbow columns started off rather high, decreased and then climbed to a steady value in the range of 5 - 10 mmhos/cm. These patterns are demonstrated in Figure 2 for the 27" effluent irrigation treatments. The difference between the two soils is probably due to native salts in the soil, the Oxbow columns lose large amounts of sulfates (largely as $MgSO_4$), see Figure 3. It may be of interest that the drainage water at times contains more $SO_4^=$, and Ca^{++} than appears possible based on the solubility product, thus undissociated molecules of $CaSO_4$ and $MgSO_4$ are likely present.

Table 3. Irrigation schedule for plant growth experiment.

Week	Snow or Rain	Sewage on Treatment 09	18	27	36	
	inches					
		Season 1				
1	4	0	0	0	0	
2	0.5	0	3	3	5	
3	0.5	3	0	1	0	
4	0.5	0	3	3	3	
5	0.5	0	0	0	0	Cut
6	0.5	0	3	3	5	
7	0.5	3	0	3	0	
8	0.5	0	3	3	5	
9	0.5	0	0	0	0	Cut
10	0.5	0	3	3	5	
11	0.5	3	0	3	0	
12	0.5	0	3	3	5	
13	0.0	0	0	0	0	Cut
Total	9.5	9	18	25	28	
	Season 2, 3, 4 and 5					
1	4	0	0	0	0	
2	0.5	0	3	0	5	
3	0.5	0	0	3	0	
4	0.5	3	3	3	5	
5	0.5	0	0	3	0	
6	0.5	0	3	3	5	
7	0.5	0	0	0	0	Cut
8	0.5	3	3	3	5	
9	0.5	0	0	3	0	
10	0.5	0	3	3	5	
11	0.5	3	0	3	0	
12	0.5	0	3	3	5	
13	0.0	0	0	0	0	Cut
Total	9.5	9	18	27	30	

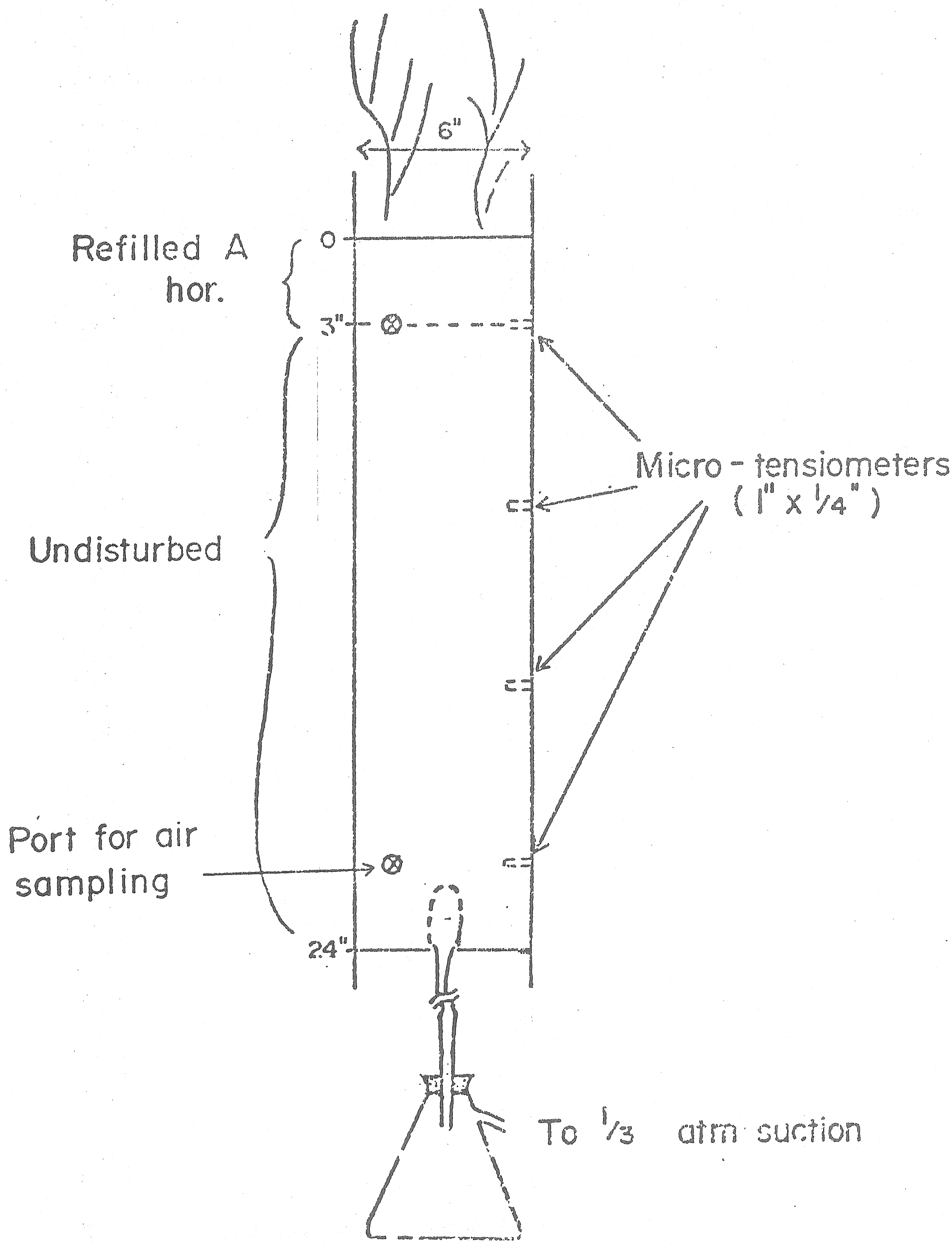

Figure 1. Drawing of soil columns used in Experiment #2.

Table 4. Approximate water balance (in/column).

Season and Treatment		Applied	Asquith Drainage	Asquith Used by Crop	Oxbow Drainage	Oxbow Used by Crop
1*	D	9.5	2.8	7.8	0.4	10.0
	09	18.5	5.5	13.5	2.9	15.6
	18	27.5	11.1	16.6	5.2	22.1
	27	34.5	13.1	21.6	7.1	27.7
	36	37.5	13.7	24.2	6.5	30.8
2	D	9.5	0.1	9.4	0.4	9.1
	09	18.5	4.1	14.4	2.4	16.1
	18	27.5	6.6	20.8	4.2	23.3
	27	36.5	9.2	27.3	6.4	30.1
	36	39.5	9.0	30.4	7.5	32.0
3	D	9.5	0.2	9.3	0.0	9.5
	09	18.5	1.5	17.0	0.8	17.7
	18	27.5	3.2	24.3	1.7	25.8
	27	36.5	5.1	31.4	3.6	32.9
	36	39.5	4.9	34.6	3.5	36.0
4	D	9.5	0.1	9.4	0.0	9.5
	09	18.5	1.4	17.1	1.5	17.0
	18	27.5	2.6	24.9	1.8	25.7
	27	36.5	3.3	33.3	3.9	32.7
	36	39.5	3.1	36.5	2.9	36.6
5	D	9.5	0.3	9.2	0.3	9.2
	09	18.5	2.4	16.1	3.0	15.5
	18	27.5	3.1	24.4	3.1	24.4
	27	36.5	3.6	32.9	4.6	31.9
	36	39.5	2.8	36.7	3.8	35.7

* During the first season water use is often greater than (applied - drainage) as in most instances there will have been a decrease in moisture content, i.e. prior to the 4" snowmelt in season 1 the cores were generally wetter than at the same stage in subsequent growing seasons.

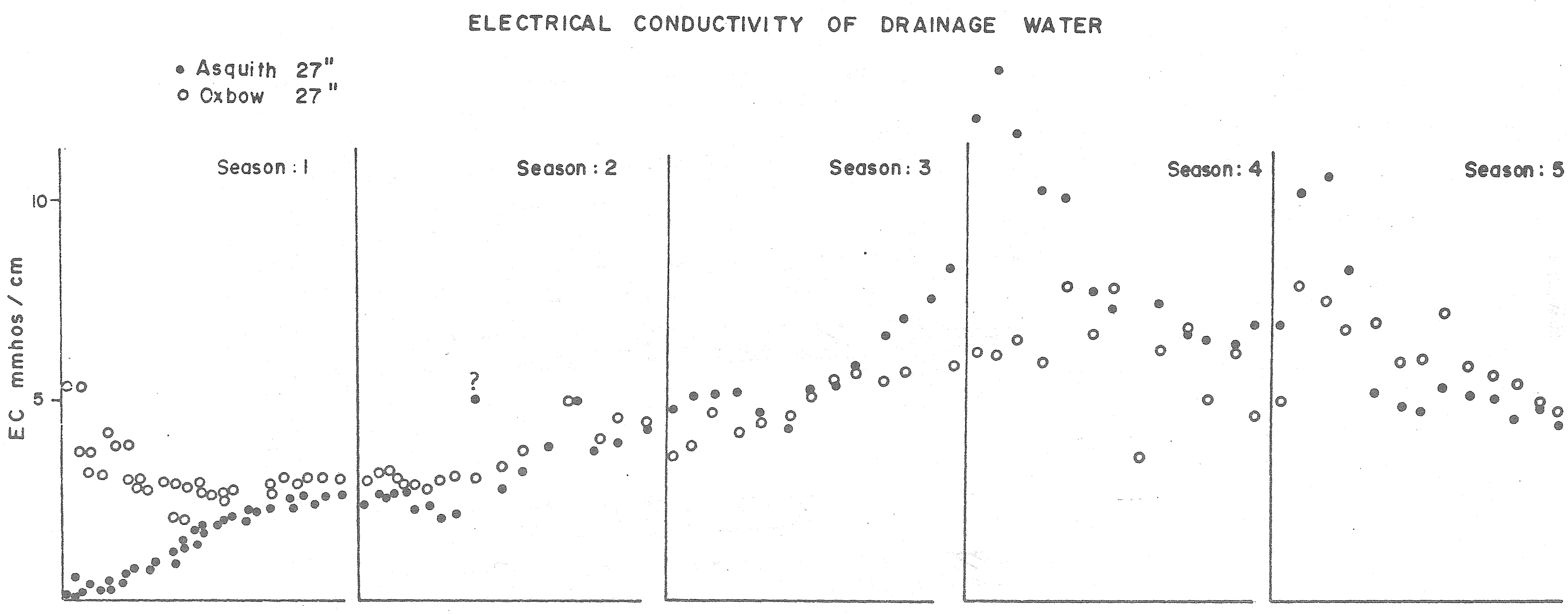

Figure 2. The electrical conductivity of the drainage water from the 27" irrigation treatment.

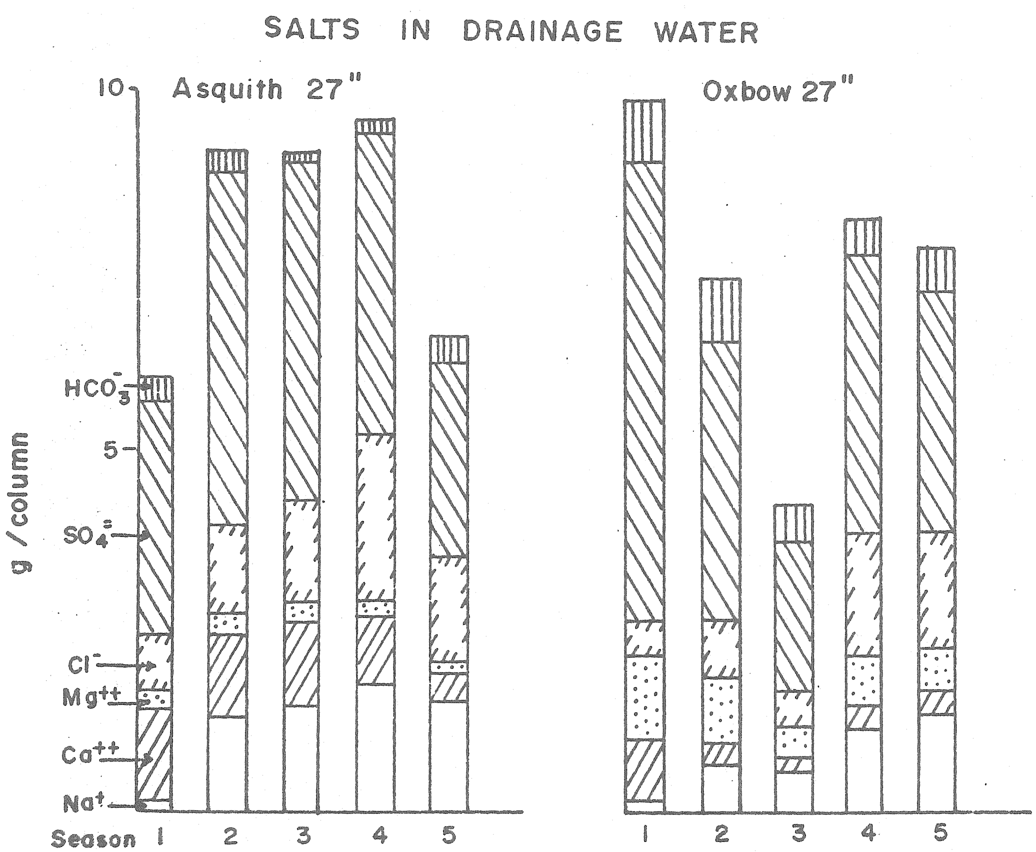

Figure 3. Total weight of the major ions in the drainage water of each season collected from the 27" irrigation treatment.

The total salt loss of the columns was estimated from the EC and is shown in Table 5. During the first season the effect of the native salt content in the Oxbow soil shows up at the lower rates of irrigation. Assuming an ash content of 10%, and neglecting volatilization of C and N compounds an approximate salt balance can be drawn up (Table 6).

Table 5. Total salt (g/column)* present in the drainage water based on EC.

Treatment	Season				
	1	2	3	4	5
			Asquith		
D	0.2	0.0	0.0	0.0	0.1
09	1.5	3.8	2.5	3.6	4.7
18	5.4	7.4	5.6	7.6	6.3
27	6.7	11.6	9.9	9.5	7.4
36	7.9	10.2	8.6	7.1	4.9
			Oxbow		
D	0.5	0.8	0.0	0.0	0.4
09	4.1	3.1	1.3	2.8	5.3
18	6.8	4.3	2.5	4.0	6.9
27	8.6	8.3	4.6	8.1	8.7
36	7.5	9.3	5.9	7.3	7.8

* 1 g/column is equivalent to approximately 510 lb/acre or 570 kg/ha.

Table 6. Salt balance of the various treatments (g/column).

Treatment	Season				
	1	2	3	4	5
			Asquith		
D	-0.1	-0.1	-0.1	-0.1	-0.1
09	5.4	2.8	3.7	1.7	0.3
18	8.1	5.8	6.7	3.0	3.8
27	12.1	8.1	8.5	6.4	7.8
36	13.2	11.7	11.9	10.5	12.2
			Oxbow		
D	-0.6	-0.8	-0.1	-0.1	-0.6
09	2.5	3.3	4.9	2.5	-0.2
18	6.6	8.6	9.8	6.6	3.2
27	9.9	11.3	13.9	8.0	6.7
36	13.4	12.4	14.6	10.4	9.3

In this balance the fertilizers applied during the first season are taken into account, but salts in the distilled water are neglected. Clearly, the salt content of the soils increases and no equilibrium is reached yet after 5 seasons for the higher irrigation rates. The increased salt content is hardly noticeable in the soil analysis carried out after 1, 2 and 5 growing seasons (Table 7) on the Asquith soil but does show more markedly on the Oxbow soil. Effluent irrigation has resulted in some changes in exchangeable cations (Table 8).

Table 7. Electrical conductivity (mmhos/cm) of a 2:1 soil extract.

Depth, in.	Treatment				
	D	9	18	27	36
	Asquith after one season				
0-6	0.03	0.20	0.26	0.26	0.26
6-12	0.03	0.35	0.27	0.27	0.33
12-18	0.02	0.47	0.31	0.28	0.24
18-24	0.02	0.44	0.26	0.26	0.27
	Asquith after two seasons				
0-6	0.06	0.23	0.25	0.28	0.24
6-12	0.02	0.24	0.29	0.39	0.28
12-18	0.02	0.25	0.38	0.40	0.35
18-24	0.04	0.29	0.42	0.35	0.46
	Asquith after five seasons				
0-6	0.10	0.30	0.31	0.33	0.32
6-12	0.08	0.30	0.37	0.43	0.33
12-18	0.07	0.35	0.42	0.57	0.38
18-24	0.15	0.47	0.59	0.48	0.56
	Oxbow after one season				
0-6	0.23	0.29	0.20	0.18	0.60
6-12	0.19	0.22	0.16	0.13	0.46
12-18	1.05	0.57	0.40	0.48	1.64
18-24	0.70	0.75	0.19	0.32	1.20
	Oxbow after two seasons				
0-6	0.31	0.79	0.85	0.88	0.78
6-12	0.36	0.57	0.65	1.14	0.66
12-18	1.38	1.30	0.83	1.12	1.71
18-24	0.45	0.99	0.66	0.64	1.11
	Oxbow after five seasons				
0-6	0.26	1.12	1.24	1.12	0.79
6-12	0.25	0.78	1.04	0.91	0.91
12-18	0.30	1.77	0.97	1.09	0.96
18-24	0.37	2.14	1.23	1.15	0.80

Table 8. Exchangeable Na (meq/100 g).

Depth, in.	Treatment				
	D	9	18	27	36
			Asquith after one season		
0-6	0.03	0.31	0.36	0.36	0.35
6-12	0.03	0.29	0.45	0.49	0.41
12-18	0.05	0.15	0.35	0.38	0.42
18-24	0.03	0.12	0.16	0.24	0.29
			Asquith after two seasons		
0-6	0.03	0.24	0.29	0.29	0.35
6-12	0.03	0.32	0.54	0.42	0.35
12-18	0.04	0.20	0.38	0.41	0.50
18-24	0.04	0.12	0.25	0.42	0.46
			Asquith after five seasons		
0-6	0.05	0.24	0.30	0.30	0.31
6-12	0.05	0.44	0.46	0.44	0.51
12-18	0.04	0.54	0.51	0.38	0.56
18-24	0.03	0.32	0.65	0.42	0.43
			Oxbow after one season		
0-6	0.02	0.39	0.60	0.53	0.42
6-12	0.03	0.16	0.34	0.38	0.40
12-18	0.04	0.13	0.15	0.16	0.18
18-24	0.05	0.08	0.11	0.11	0.09
			Oxbow after two seasons		
0-6	0.07	0.42	0.52	0.74	0.70
6-12	0.07	0.19	0.63	0.56	0.56
12-18	0.05	0.13	0.26	0.36	0.33
18-24	0.07	0.10	0.18	0.36	0.33
			Oxbow after five seasons		
0-6	0.07	0.71	1.15	1.23	1.15
6-12	0.07	0.51	0.86	0.99	0.80
12-18	0.09	0.19	0.61	0.57	0.59
18-24	0.10	0.17	0.53	0.48	0.69

Effect of Physical Soil Properties

At the beginning of each growing season, the infiltration rate of the columns that were carried through 5 growing seasons was measured. This was done by applying the "snowmelt" water in 4 increments of 1" each and observing the time required for each 1" to disappear. The results were quite variable, and no consistent effect of sewage effluent irrigation could be detected.

Bulk density was calculated from the 6" segments in which the columns were cut after 1, 2 and 5 seasons. Again no effect of effluent irrigation was noted.

Aggregate stability was determined on airdry aggregates (0.8 - 2 mm) by sieving for 5 min on a 0.25 mm sieve. A correction was made for primary particles. After 2 and 5 growing seasons no effect of effluent irrigation could be detected. This agrees well with values for exchangeable Na.

Conclusions

Due to the high salt content of the sewage effluent, maintenance of the salt balance of the soil is one of the primary prerequisites for successful irrigation with sewage effluent. To stabilize the salt level in the soil, 20% and more of the total applied water (rain, snowmelt and effluent) must be allowed to drain through the soil. This causes a heavy salt burden on the groundwater (up to 5 tons/acre), mainly in the form of Na, Ca, Mg, Cl, SO_4 and HCO_3. The actual composition of the drainage water depends on the composition of the effluent and, especially in the first few years, on the soil type. If this prerequisite is met, successful production of bromegrass can be achieved with no damage to the chemical and physical properties of the soil as long as the effluent irrigation continues. When the scheme is terminated, it is probably advisable that irrigation with good quality water be continued for a few years to decrease the soluble salt content of the soil. At this stage it may be necessary to add some Ca-containing amendments.