A LABORATORY STUDY OF SOME EFFECTS OF IRRIGATION WITH MUNICIPAL SEWAGE EFFLUENT

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INTRODUCTION

The technical ramifications of spreading waste water on land have been receiving a great deal of attention since the beginning of the anti-pollution crusade. Although this practice has been used for centuries, the effects on soils, crops, and groundwater have only begun to be fully understood.

Considerable work has been done to determine the effectiveness of soils in removing some of the constituents from sewage effluent.

A fine sandy loam in California (5) completely removed ammonia and phosphates from an effluent containing 434 mg/liter of total dissolved solids, but the nitrate concentration increased as the effluent percolated through the soil. In a later paper on the same plots (6), it was reported that the amount of potassium decreased by 50% during percolation through 3.9m of soil and that the number of sulfate and bicarbonate ions increased with depth. Henry *et al* (7), working with a silt loam and an effluent having sodium percentage of 79.5 and a total cation content of 37.2 meq/liter, found that nitrogen, potassium and phosphorus were largely removed by a growing crop and the soil; they also found increases in calcium and magnesium in the percolate. Yields of Reed canary grass were about 50% higher when effluent was applied than when city water only was used.

The following percentage reductions occurred after passing municipal sewage effluent through 90 cm of silt loam (3): Chemical Oxygen Demand, 65; Biochemical Oxygen Demand, 88; Detergents, 26; Total N, 70; and PO$_4$, 93. In Pennsylvania (9) passing sewage effluent containing 220 mg of dissolved solids per liter through 120 cm of soil resulted in the following percent reductions in constituent content of the effluent: detergents, 98; NO$_3$-N, 60; organic N, 88; P, 99.4; K, 70; Ca, 83; Mg, 91; Na, 79; and Cl, 76. Lehman and Wilson (8) reported that even under continuous irrigation 98% of the lead in effluent was eliminated from the percolating water after passage through 7 cm of soil. They found some translocation of copper and zinc at deeper sampling points when the application rate was high.

The capacity of soils to perform as a waste disposal medium is of particular value in determining the potential life of a disposal system. This investigation was initiated to determine the effect of municipal sewage effluent irrigation on groundwater and soils as a function of the amount of effluent applied and depth of soil. The effect of the effluent on crop yield was investigated in the greenhouse. Particular emphasis was placed on soluble inorganic salts because the salinity of most of the sewage effluents in southern Alberta is higher than that reported in the literature.

MATERIALS AND METHODS

Effluent was obtained in the autumn from an aerobic lagoon serving a small residential town. The effluent characteristics are shown in Table I. The two soils used in the experiment, Cavendish sandy loam and Chin loam, are common in southern Alberta.

The soils were air-dried and passed through a 2 mm sieve, then packed in plastic tubes 3 m high and 10 cm in diameter. The tubes were filled to within 45 cm of the top, thus allowing for an effluent reservoir. Filter candles inserted in the columns at 60 cm intervals provided for the extraction of percolation fluid either by gravity flow or by gentle suction if required. An amount of sewage effluent equivalent to the consumptive use of a grass crop (42 cm) was applied weekly for seven weeks. About 400 ml of column effluent were removed after each application from each of the five filter candles as the effluent moved through the soil column. The extracted solution represented about two-thirds of the effluent applied. The remainder was allowed to drain from the bottom of the columns between applications. The solutions were analyzed for most constituents present within 24 hours of extraction. However, for the analysis of detergents and organic carbon the solutions were frozen and sent to another laboratory.

Sodium and potassium were determined by flame photometry, calcium and magnesium by the versenate method, and

TABLE I CHEMICAL CHARACTERISTICS OF EFFLUENT

BOD	15 mg/liter	SAR	3.3
TDS	1,160 mg/liter	F	0.22 mg/liter
Na	6.5 me/liter	NH$_3$-N	53 mg/liter
K	0.29 me/liter	Detergents	1.0 mg/liter
Ca + Mg	7.6 me/liter	Total PO$_4$	26 mg/liter
Cl	1.6 me/liter	Cu	0.005 mg/liter
HCO$_3$	11.2 me/liter	Pb	0.10 mg/liter
pH	7.2	Zn	0.019 mg/liter

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detergents, total phosphorus, fluoride and ammonia of the effluent and percolating solution by Standard Methods (1). Organic carbon was determined by a method approved for the analysis of water and wastes (4).

One week after the seventh sewage effluent application, samples of the soils in the columns were dried, passed through a 2 mm sieve, and analyzed. The saturation extract was analyzed by methods described in USDA Handbook 60 (11). Available nutrients were determined by Alberta Soil and Feed Testing Laboratory methods. Total N was determined by Kjeldahl apparatus (2) and total P colorimetrically after perchloric acid digestion (10). Copper, lead, and zinc were determined by atomic adsorption methods.

The effect of the effluent on barley yield was measured in the greenhouse in half-gallon pots. Half the pots were irrigated with effluent, the other half with the same amount of city tap water. The experiment was replicated three times. The yield was measured by weighing the aerial portion of the plants at maturity and the data were then subjected to analysis of variance.

RESULTS AND DISCUSSION

Sodium

The sodium concentration (Figure 1) in the effluent was much higher than that of the saturation extract of the original soils. Both soils reacted similarly in that the sodium concentration of the column percolate approached or equalled that of the original sewage effluent, the only difference being that the reaction was somewhat slower with the Chin soil.

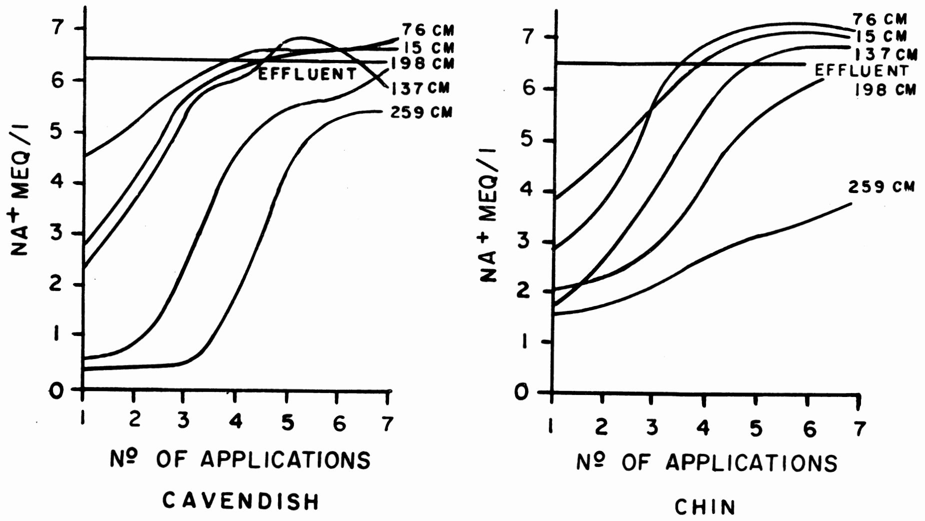

Figure 1. Sodium distribution in soil columns.

Equilibrium between the column percolate throughout the column and the original effluent was generally reached after six applications of sewage effluent to the Cavendish soil, but was never reached at the 259-cm depth in Chin soil. This difference was, no doubt, due to the higher cation exchange capacity of the Chin soil. As the solution moved through the soil other exchangeable cations were displaced by the sodium.

Potassium

The sewage effluent contained 0.29 meq/liter of potassium (Figure 2). This concentration was low compared to that in the saturated extract of the original soil. The concentration of potassium was therefore higher in the column percolate than in the original effluent but at the 15 cm depth it approached equilibrium with the sewage effluent during the seventh application.

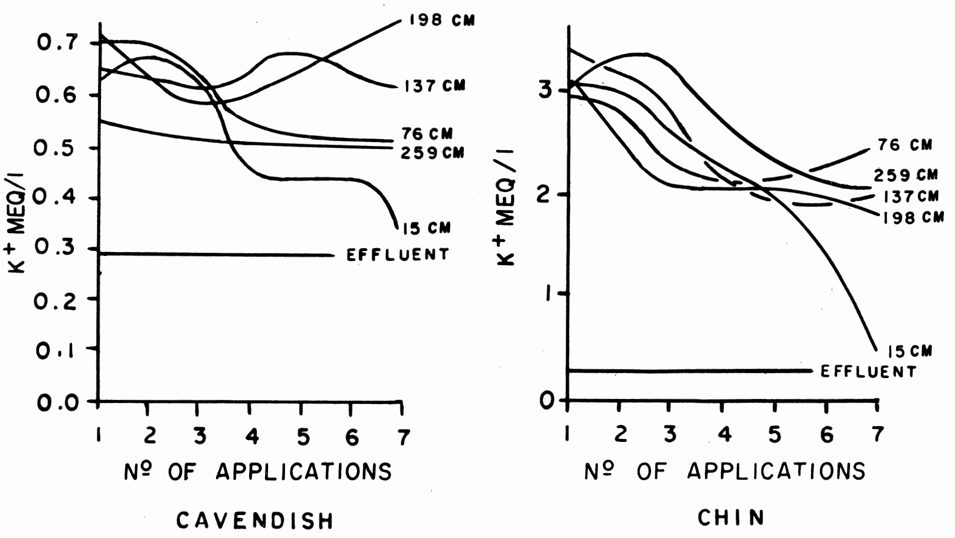

Figure 2. Potassium distribution in soil columns.

Calcium Plus Magnesium

The concentration of calcium plus magnesium (Figure 3) in the solution removed from the lower portion of the columns was much higher than that in the original sewage effluent applied plus that of the saturation extract of the untreated soil. This would indicate that the excess was made up of exchangeable calcium and magnesium displaced from the soil by sodium from the sewage effluent.

Total Cations

The maximum concentration of total cations (Figure 4) removed from the 259 cm depth of the Cavendish core was 21.5 meq/liter which was equal to the sum of the concentration of the cations in the sewage effluent (14.4 meq/liter) and the saturated soil extract (7.1 meq/liter). The same relationship holds for the Chin soil. There was no overall removal of major cations but rather a shift in the ion species ratio. It appears that with continuous irrigation, the composition of the percolating solution will be similar to the applied effluent in respect to major cations.

Detergents

The concentration of detergents (Figure 5) in the sewage effluent was reduced by over 30% when passed through 15 cm of soil, 70% through 76 cm of soil and 80% through 135 cm of soil. At greater depths no further decreases resulted.

Total Phosphorus

Percolation through 135 cm of Cavendish soil removed all but a trace of

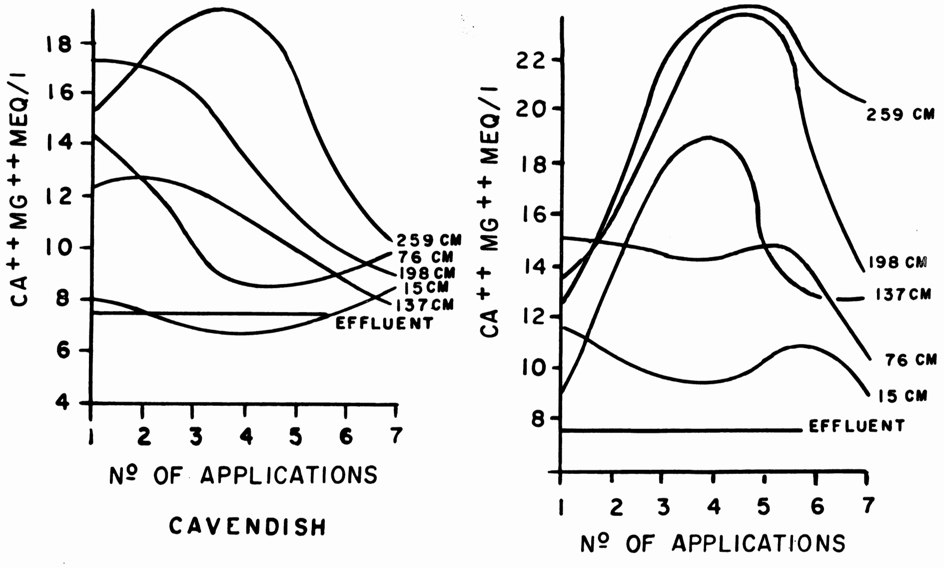

Figure 3. Calcium +magnesium distribution in soil columns.

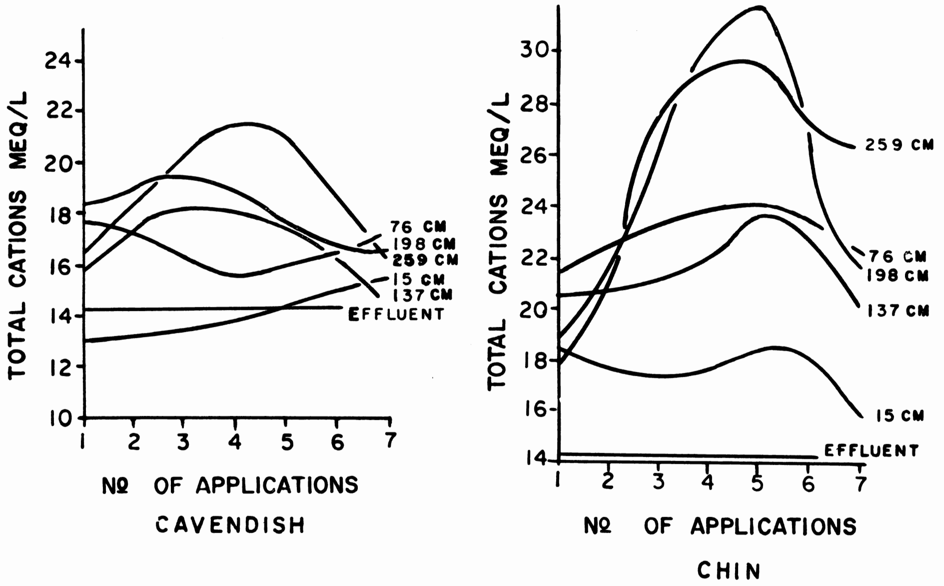

Figure 4. Total cation distribution in soil columns.

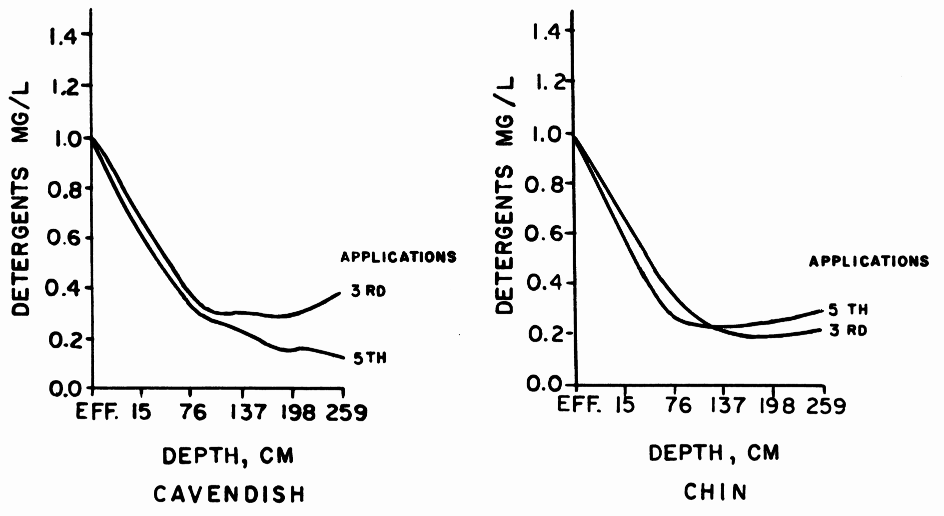

Figure 5. Detergent distribution in soil columns.

phosphate from the sewage effluent after the fourth application (Figure 6). The concentration was reduced by about 80% in the lower depths of the Chin soil.

Total Organic Carbon

Total organic carbon (Figure 7) increased greatly as the sewage effluent moved down through the soil cores. In the Cavendish soil this concentration in the column percolate generally decreased with the addition of successive applications. In the Chin soil, with its higher control of organic matter, this trend was reversed. The increase in sodium adsorptive ratio (SAR) that occurred in the soil during the addition of the sewage effluent likely contributed to the increase in organic carbon.

Fluoride

A 75-cm depth of Cavendish soil removed 75% of the fluoride (Figure 8) from the sewage effluent. This removal was not apparent in the Chin soil because the fluoride content of the soil was higher than that of the effluent.

Ammonia

The concentration of ammonia (Figure 9) in the sewage effluent was reduced by 30% at the 15-cm depth and 70% at the 75-cm depth in both soils and over 80% at the 135-cm depth in the Cavendish soil. This decrease in ammonia in the effluent as it passed through the soil probably involved adsorption or nitrification, or both.

The concentration of lead in the column percolate and in the original sewage effluent remained below 0.10 mg/liter throughout the experiment. The concentration of copper and zinc, however, was always higher in the column percolate than in the original effluent. This was attributed to the high concentration in the soil itself.

Table II shows that the application of sewage effluent to barley on Cavendish and Chin soils produced significant yield increases of 19% and 18% higher than those produced by tap water.

Changes in the soil columns due to the treatments are shown in Table III. The effect of sewage effluent was more pronounced on the Cavendish soil than on the Chin soil. Both electrical conductivity (EC) and SAR were increased more drastically in the coarser textured Caven-

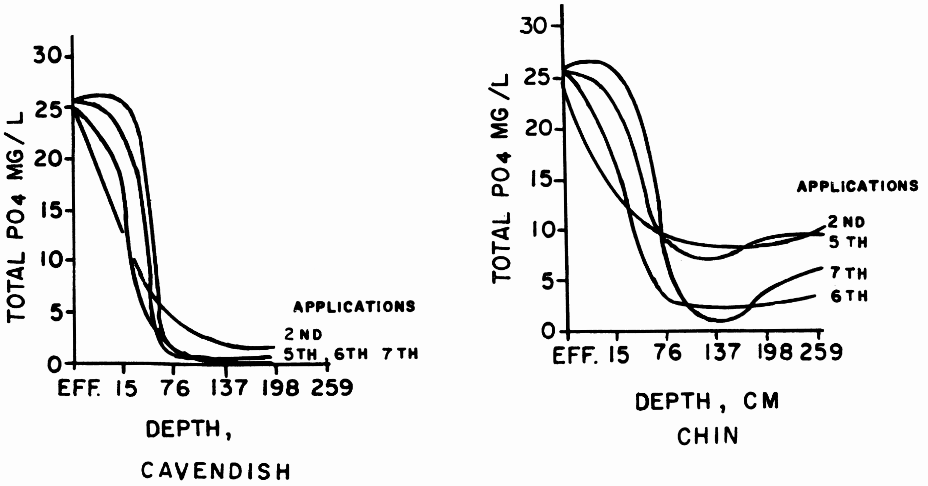

Figure 6. Total phosphorus distribution in soil columns.

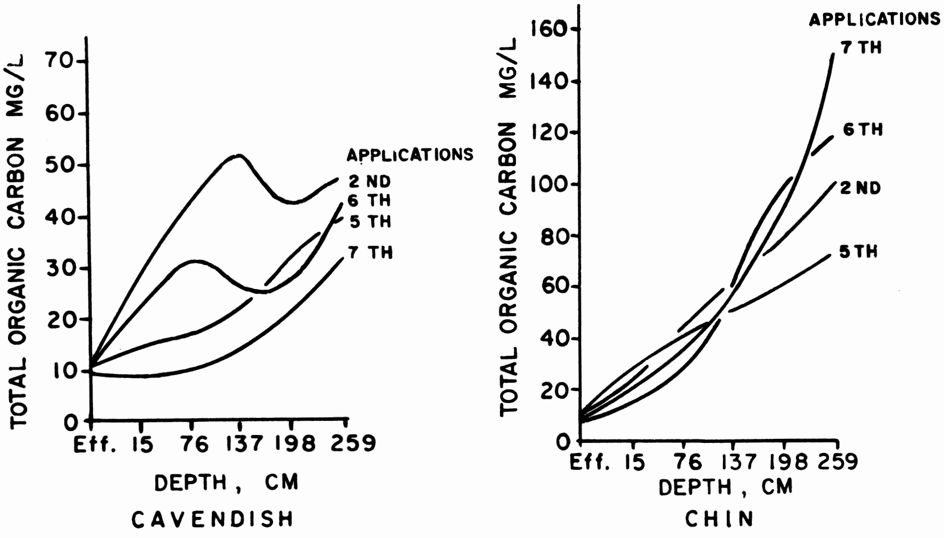

Figure 7. Total carbon distribution in soil columns.

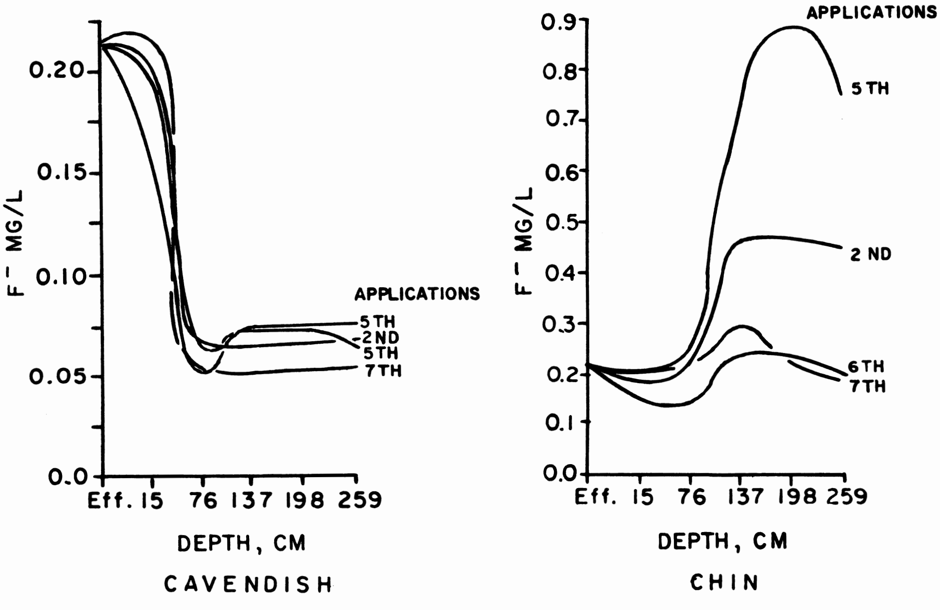

Figure 8. Fluoride distribution in soil columns.

dish soil because of its lower initial salt and sodium content and lower cation exchange capacity (CEC). The resultant EC of both soils was similar; however the SAR was slightly higher in the Cavendish soil than in the Chin soil. The soluble potassium remained essentially unchanged during the treatment. There appeared to be some increase of total nitrogen and phosphorus due to the addition of sewage effluent, and a greater increase in available nitrate and phosphorus, particularly in the top 30 cm of the soil column.

CONCLUSION

The data obtained clearly show the effectiveness of the two soils in reducing or removing detergents, phosphorus, ammonia, and possibly fluoride from municipal sewage effluent.

The sewage effluent had an important effect in that it added considerable quantities of nutrients to the surface 30 cm of soil and increased the yield of barley. A vigorous crop must be grown and harvested so that these nutrients can be reused. Salinity and sodium adsorption also were increased by the application of sewage effluent but not to the extent that they seriously affected plant growth or soil texture.

The data show that both soils removed sodium from the sewage effluent for some time. This removal of sodium is accompanied by a considerable movement of calcium plus magnesium ions into the lower depths of the column, thus increasing the hardness of the solution. There was also an overall increase in total dissolved solids at the lower depths due to the leaching of soluble salts from the soil plus the exchangeable calcium and magnesium replaced by the sodium. The results indicate that the above changes in major cations will gradually taper off to where the concentration in the percolating solution at lower depths is similar to the concentration in the sewage effluent.

The results suggest that irrigation of the two soils with municipal effluent in an area that has a high water table could result in the addition of considerable quantities of calcium and magnesium to the groundwater system within a few years, thus increasing the hardness of the groundwater. The concentration entering the groundwater would decrease with time, but the decrease would be accompanied by an increase in sodium and thus

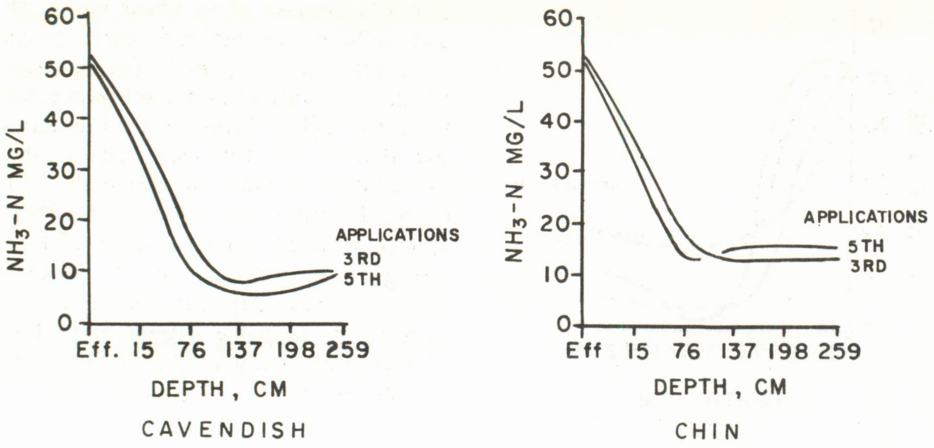

Figure 9. Ammonia distribution in soil columns.

TABLE II MEAN DRY WEIGHT OF PLANT MATERIAL IN GRAMS/POT

	Cavendish Sandy Loam	Chin Loam
Tap Water	3.78	8.87
Effluent	4.49	10.47

result in a decrease in hardness of the groundwater. The concentration of the total dissolved solids in the water entering the groundwater would be increased soon after the initiation of irrigation and gradually taper off until it approached that of the effluent.

The time intervals between these changes in the composition of the water entering the groundwater depends upon the CEC of the soil, the depth to the water table and, of course, to the volume of solution passing through the soil.

The possibility that a great increase in salinity and SAR could result from the use of sewage effluent on land makes it imperative that this aspect be investigated.

SUMMARY

Sewage effluent from an aerobic lagoon serving a small town was passed through 260 cm of two different soils. A number of chemical analyses were performed on the percolating solution at different depths of soil over a period of time as 42 cm of effluent was applied. A depth of 135 cm of soil removed 80% of the detergents, and 80% or more of the phosphorus and ammonia present in the

TABLE III CHEMICAL ANALYSIS OF THE SOILS BEFORE AND AFTER EFFLUENT APPLICATION

Depth	pH	EC	Ca + Mg	Na	K	HCO_3	Cl	SAR	N	P	P	NO_3-N
cm		mmhos/cm	meq/liter						Total %		Available (mg/l)	
Cavendish Soil												
Original	7.2	.69	6.2	.4	.5	3.8	1.2	.2	.100	.032	4.3	1.0
After												
0 - 15	7.1	1.53	4.8	10.8	.3	5.2	1.8	7.0	.104	.038	27.9	24.6
15 - 30	7.2	1.49	6.2	10.4	.5	5.8	1.6	5.9	.108	.036	16.6	16.0
60 - 90	7.3	1.20	7.0	7.1	.5	3.6	1.5	3.8	.100	.032	7.0	6.0
120 - 150	7.3	1.17	10.3	5.0	.6	3.1	1.8	2.2	.103	.031	6.3	6.2
180 - 210	7.3	1.23	10.5	5.4	.7	3.4	1.7	2.4	.100	.031	7.6	0
240 - 258	7.3	0.86	6.2	4.4	.6	3.9	1.5	2.5	.102	.031	5.4	0
Chin Soil												
Original	7.5	1.28	11.0	2.1	2.8	5.7	1.9	0.9	.192	.057	7.4	2.4
After												
0 - 15	7.6	1.55	6.6	10.7	2.4	4.6	1.7	5.9	.195	.062	16.4	24.3
15 - 30	7.2	1.56	11.8	8.2	2.2	4.6	1.8	3.4	.196	.057	20.0	19.5
60 - 90	7.4	1.41	9.4	7.7	1.7	4.2	1.7	3.6	.187	.061	27.2	.5
120 - 150	7.3	1.49	11.3	5.4	2.5	6.0	1.7	2.3	.202	.066	17.4	0
180 - 210	7.4	1.18	8.5	4.2	2.4	6.0	1.5	2.1	.200	.061	19.1	0
240 - 258	7.5	0.95	7.6	3.8	1.9	7.8	1.3	1.9	.200	.059	9.3	0

sewage effluent. The sodium ion was adsorbed by the soil in the early stages of experiment but equilibrium was eventually reached between the effluent and the percolating solution. However, while the sodium concentration of the effluent was being reduced, the concentration of calcium plus magnesium in the percolating solution was increased. The results of the experiment show that there was no overall removal of major cations but rather a shift in the ion species ratio.

The application of sewage effluent to barley on the two soils produced significant yield increases of 19% and 18% higher than those produced by tap water.

The sewage effluent treatments increased both the electrical conductivity and the SAR of the soil but not to a serious level. The water soluble potassium remained essentially unchanged during the treatment. There appeared to be some increase of total nitrogen and phosphorus due to the sewage effluent application, and a greater increase in available nitrate and phosphorus particularly in the top 30 cm of the soil columns.

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