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Disposal of saline effluent by controlled-spray irrigation

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Effluents arising from pulp and paper manufacture are highly mineralized, and special provisions have to be made to prevent pollution of water resources by these effluents. Investigations by the National Institute for Water Research (NIWR) have led to the development of a system of controlled-spray irrigation of the effluent from a large pulp and paper mill situated near Springs in the industrial heartland of South Africa.

A suitable irrigation area, consisting of about 470 ha of deep soil with a sandy-clay structure was found within a reasonable distance from the mill. To obtain information on the effect of the effluent on plants and soil, preliminary tests were conducted with a set of experimental plots on which different types of grass and pasture were established. Because of the high concentration of sodium present in the effluent and the consequent danger that it would cause the soil structure to deteriorate, the effects of regular application of soil amendments (gypsum and ferrous sulfate) were studied in a second set of plots. A series of lysimeters were also set up to determine long-term yields of alfalfa and the effects of gypsum and ferrous sulfate soil amendments. At the same time data on evapotranspiration rates and percolate quantity and quality were collected, and the effects of the saline irrigation water on the soil were studied. Finally 142 ha of land was suitably prepared for large-scale irrigation with the effluent.

PLOT EXPERIMENTS

To determine the effect of the effluent on the soil and on different types of grass and pasture, a block of 24 plots was laid out on an area of land close to the mill. Each plot measured 3.0 × 1.8 m with a 0.6 m pathway separating the plots. It was also deemed essential that a fertilizer program be incorporated in the experiments and hence the plots were divided into three groups of eight plots, each plot having been seeded or planted with a different species of grass or pasture. The three groups were treated as follows: (a) no fertilizer (control); (b) 75 kg N, 25 kg P, 50 kg K per ha/a; and (c) 37.5 kg N, 12.5 kg P, 25 kg K/ha/a.

The following species of grass and pasture were planted and sown:

- Mixed pasture (equal quantities of cocksfoot, perennial rye, and Italian rye grass, *Phalaris tuberosa* and *Landino clover*),
- Weeping lovegrass (*Eragrostis curvula*),
- Alfalfa (*Medicago sativa*),
- Buffalo grass (*Panicum maximum nanyuki*),
- Rhodes grass (*Chloris gayana*),
- Kikuyu grass (*Pennisetum clandestinum*),
- Antelope grass (*Echinochloa pyramidalis,*), and
- Nile grass (*Acroceras macrum*).

All plots were irrigated with effluent from the mill at a rate of 25 mm per week. This rate was continued throughout the year. Table I contains average figures for effluent quality during the period 1967 to 1969.

A second block of 24 plots, similar to the above and divided into two groups of 12, was laid out in order to compare gypsum and ferrous sulfate as soil amendments. All the plots in this block received 75 kg N, 25 kg P, and 50 kg K/ha·y. Gypsum and ferrous sulfate were applied at the following rates at the

TABLE I. Average chemical analysis of effluent applied to experimental plots (1967 to 1969).

	1967	1968	1969
pH	7.5	7.8	7.5
Na (mg/l)	1 010	700	690
K (mg/l)	19	14	14
Ca (mg/l)	180	70	90
Mg (mg/l)	32	21	22
Cl (mg/l)	1 430	820	870
SO_4 (mg/l)	250	115	210
HCO_3 (mg/l)	330	445	485
SAR	18	19	17

start of the experiment and every 2 years thereafter:

Gypsum rate (tons/ha)	Ferrous sulfate rate (tons/ha)
1.9 (4 plots)	3.05 (4 plots)
3.8 (4 plots)	6.1 (4 plots)
7.6 (4 plots)	12.2 (4 plots)

The following species of grass were planted on both the gypsum and ferrous sulfate treated plots: Kikuyu grass, Antelope grass, and Nile grass. Effluent was applied at the same rate as for the first block of plots.

Samples of top soil (0 to 30 cm) and subsoil (30 to 210 cm) were collected at regular intervals, air dried, and analyzed for soluble and exchangeable cations. Average results for sodium in the soil are compared in Table II for different soil amendments applied.

Crops from all the plots were regularly harvested and yields recorded. Figure 1 compares the average annual yields for the different species of grass and pasture on the first block of plots for the period October 1968 to September 1971. As some difficulties were experienced in establishing some of the grasses, the results for the first 2 years of the experiment were not included in Figure 1. In Figure 2 the yields of three species of grass are compared for the different soil amendments applied to the second block of plots.

LYSIMETER EXPERIMENTS

Twelve lysimeters, 750 mm in diameter and 1 200 mm deep, were filled with soil from the proposed irrigation area. Fertilizer was applied at a rate of 37.5 kg N, 12.5 kg P, and 25 kg $K/ha^{-1}/a^{-1}$, and the lysimeters were seeded with alfalfa. The alfalfa was irrigated with fresh water initially and in January 1969 irrigation with effluent from the mill com-

TABLE II. Effect of soil amendments on the Na content of soils in the experimental plots (1966 to 1971).

	Treatment	1966	1967	1968	1969	1970	1971
Soluble Na (me/100 g),[a] top soil	None[b]	0.07	3.0	3.8	1.3	1.7	0.6
	Ca[c]	0.03	2.6	3.0	1.8	2.1	0.2
	Fe[d]	0.03	3.2	2.4	2.5	3.9	0.4
Soluble Na (me/100 g), subsoil	None	0.16	0.8	1.0	1.0	1.1	0.8
	Ca	0.08	1.0	1.1	1.2	1.4	0.5
	Fe	0.05	0.8	1.4	1.9	1.1	0.7
Exchangeable Na (me/100 g) top soil	None	0.2	1.9	2.9	2.7	1.8	0.8
	Ca	0.2	2.1	3.2	0.9	0.9	0.3
	Fe	0.2	1.9	2.5	1.4	0.3	0.2
Exchangeable Na (me/100 g) subsoil	None	0.2	0.6	0.7	1.5	1.3	0.9
	Ca	0.2	0.7	1.1	0.7	1.0	0.4
	Fe	0.2	0.6	0.9	0.7	1.0	0.5

[a] me—metabolizable energy.
[b] None—No treatment.
[c] Ca—Gypsum (7.6 t/ha).
[d] Fe—Ferrous sulfate (12.2 t/ha).

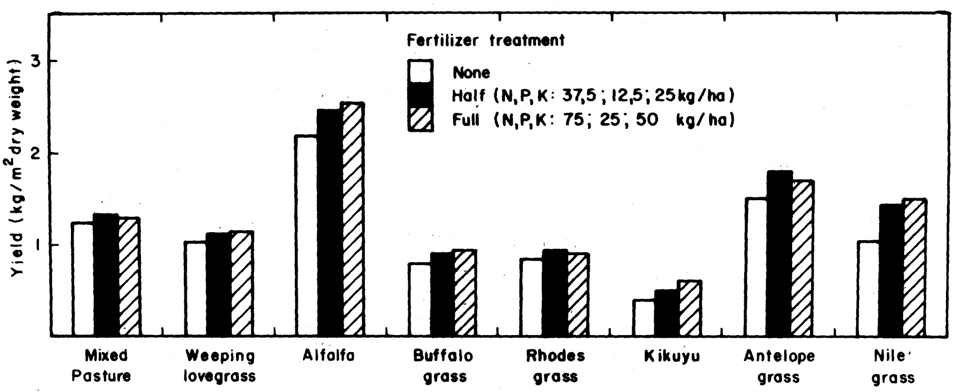

FIGURE 1. Average annual yield of grass and pasture on experimental plots. (October 1968 to September 1971)

menced. Data on irrigation and drainage water quantity and quality, rainfall, and crop yields were collected regularly.

To determine the effect of soil amendments on the condition of the soil and the yield of alfalfa the program of application in Table III was followed. The change in application rate in 1972 was decided on as no significant differences in results were obtained with the levels of application used prior to that year.

In October 1974, after 6 years, all the old plants were removed and the lysimeters reseeded with alfalfa in order to determine whether the soil was still capable of supporting a healthy crop. At this stage it was clear that ferrous sulfate as a soil conditioner was inferior to gypsum and accordingly it was decided to stop the ferrous sulfate treatment. Gypsum was applied to all the lysimeters, except the controls, at a rate of 3.85 t/ha.

Soil samples were taken from the lysimeters in 1968 at the beginning of the experiment and again in 1974 and 1976. All soil samples were analyzed according to the methods of the U. S. Salinity Laboratory staff.[1]

Results of analyses of the effluent used for irrigating the lysimeters are given in Table IV. Table V gives an indication of the quantity and quality of the irrigation water applied to the lysimeters and the drainage water for the duration of the experiment. As there was no significant difference in results between the different levels of application of soil amendments, the treatment was divided into three groups only, namely, no amendment, gypsum and ferrous sulfate. Results are given as

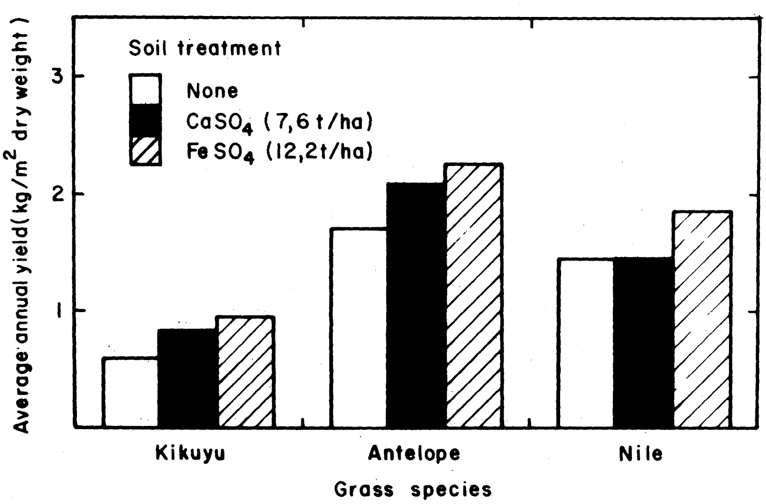

FIGURE 2. Effect of soil amendments on yield of grass on the experimental plots.

TABLE III. Quantities of soil amendments added to lysimeters.

Amendment	Date Applied 1968, 1970	1972, 1973
1. None (control)	—	—
2. Gypsum (t/ha)	1.96	3.85
3. Gypsum (t/ha)	3.92	
4. Ferrous sulfate (t/ha)	3.15	6.11
5. Ferrous sulfate (t/ha)	6.30	
6. Gypsum (t/ha)	1.96	
6. Ferrous sulfate (t/ha)	3.15	

weighted average and rainfall was taken into consideration with the calculation of ionic concentrations and sodium adsorption ratios (SAR). It was assumed that the salt content of rain water was insignificant. The difference in irrigation water applied and drainage water gives an indication of the quantity of water lost by evapotranspiration.

Yields of alfalfa are given in Figure 3. In Figure 4 the yields are compared with respect to the different soil amendments used, while in Figure 5 the comparison was made with respect to the period of time under irrigation. The yields of the first and seventh seasons were not recorded as the alfalfa had just been seeded and was not yet in full production. Results of chemical analyses of soil samples are presented in Table VI.

LARGE-SCALE IRRIGATION

Results obtained from the experimental plots and the lysimeters indicated that some forage crops could be grown successfully under irrigation with the mill effluent, and at the end of 1972, a total of 142 ha was prepared to receive about 5 500 m^3 of effluent daily by spray irrigation. The area was seeded with alfalfa, which had proved to be the most suitable cover crop. The ground available for irrigation comprised two separate areas.

The old black liquor farm (80 ha). This area had for many years been used as a disposal site for kraft black liquor from the mill. The soil was saturated with sodium salts; the soil structure had deteriorated and permeability was poor. Preparation consisted of leveling, ploughing, and heavily applying gypsum and fertilizer.

Plantation area (62 ha). This area was previously a bluegum (*Eucalyptus*) plantation. The trees were cleared and the site was leveled, ploughed, and fertilized before seeding with alfalfa.

The alfalfa was initially irrigated with process water from the factory (purified municipal effluent) until growth was well established. Thereafter factory effluent was spray-irrigated at an annual application rate of 1 000 mm on a 21-day cycle.

During the period when the experimental work was in progress, the effluent used for irrigation consisted of a mixture of the chlorination and first alkali-extraction-stage effluents from a conventional bleaching sequence. With the advent of the new oxygen bleach process, developed by SAPPI, it was introduced on the softwood line and the water used for irrigation became a blend of the effluent from this process and conventional extraction-stage effluent from the hardwood pulp line. This change resulted in a decrease in the volume of effluent for disposal that at present varies between 4 000 and 4 500 m^3/d. Average results of analyses for this effluent are presented in Table VII.

To counteract the detrimental effect of sodium in the soil, gypsum was applied at a

TABLE IV. Average chemical analysis of effluent received for irrigation in lysimeter experiments, 1968 to 1976.

		1968/69	1969/70	1970/71	1971/72	1972/73	1973/74	1975/76
pH						7.75		
EC (mS/m)						420	350	330
Na	(me/l)	29.7	29.8	35.1	33.4	36.8		
K	(me/l)	0.35	0.36	0.39	0.34	0.35		
Ca + Mg	(me/l)	5.59	5.19	5.68	4.14	4.97		
Cl	(me/l)					32.6		
SO_4	(me/l)					3.40		
HCO_3	(me/l)					5.44		
Total cations	(me/l)	35.6	35.4	41.2	37.9	42.1		
Total anions	(me/l)					41.4		
SAR		18	18	21	23	23		

TABLE V. Depth and quality of irrigation and drainage water and annual evapotranspiration rate (ET) in lysimeter experiments, 1968 to 1976.

Soil Treatment (see Table III)	Year	Depth (mm) IW[a]	Depth (mm) DW[b]	Cation Conc. (me/l) IW	Cation Conc. (me/l) DW	SAR IW	SAR DW	ET (mm)
None (control)	1968/69	2 300	50	16.5	17	11	3	2 250
	1969/70	3 600	140	15.1	240	10	14	3 460
	1970/71	4 400	790	20.5	110	13	25	3 610
	1971/72	3 510	370	26.2	104	19	45	3 140
	1972/73	3 400	530	33.6	175	21	66	2 870
	1973/74	3 560	500	25.6	184			3 050
	1974/75	1 900	90					1 810
	1975/76	2 860	480	21.0	126			2 380
Gypsum								
	1968/69	2 300	100	16.5	32	11	2	2 200
	1969/70	3 600	150	15.1	231	10	15	3 450
	1970/71	4 400	820	20.5	109	13	26	3 580
	1971/72	3 510	420	26.2	109	19	46	3 090
	1972/73	3 810	510	34.7	196	21	59	3 300
	1973/74	3 610	500	25.6	216			3 110
	1974/75	1 900	60					1 840
	1975/76	3 230	440	21.5	166			2 790
Ferrous sulfate	1968/69	2 300	70	16.5	26	11	2	2 230
	1969/70	3 600	170	15.1	212	10	15	3 430
	1970/71	4 400	1 120	20.5	80	13	23	3 280
	1971/72	3 510	330	26.2	103	19	43	3 180
	1972/73	3 410	480	34.5	237	21	60	2 930
	1973/74	3 000	560	24.1	143			2 440

[a] IW—Irrigation water.
[b] DW—Drainage water.

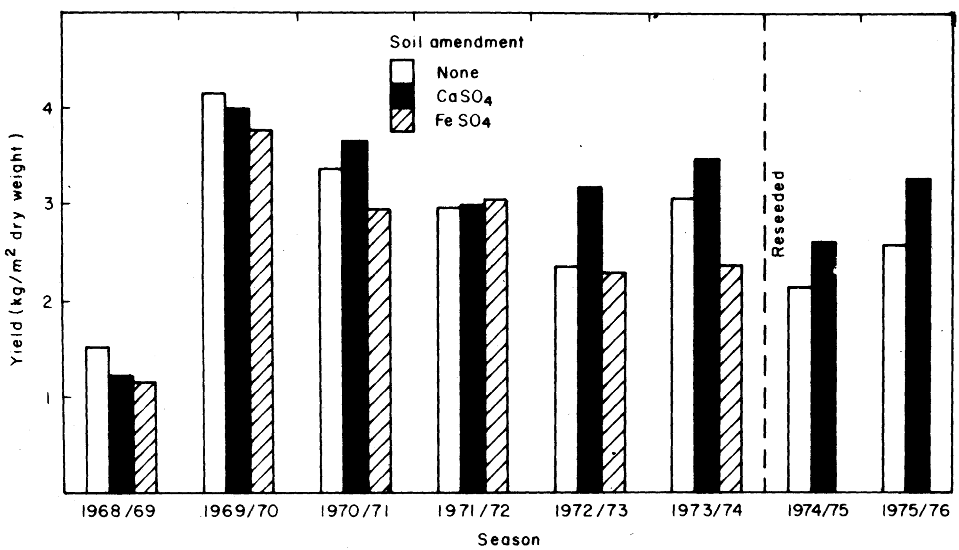

FIGURE 3. Annual yield of alfalfa in lysimeters.

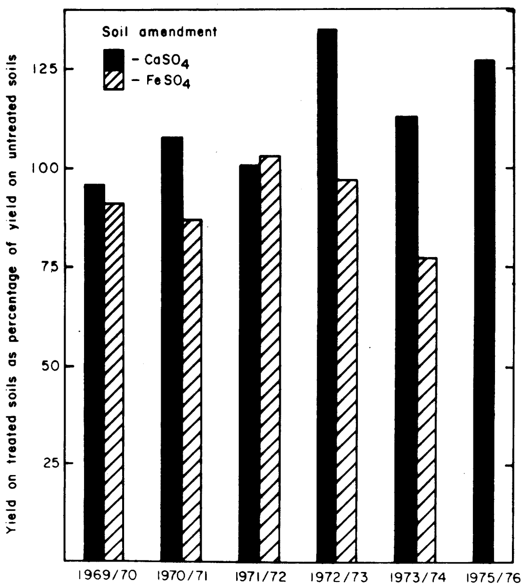

FIGURE 4. Effect of soil amendments on annual alfalfa yield in lysimeters.

molar ratio of 2 sodium:1 calcium, which amounts to approximately 5 t/d. Originally it was intended to add the gypsum directly to the effluent while it was pumped onto the lands. However, difficulties were experienced with the handling of such large quantities and at present the gypsum is added with a fertilizer spreader.

DISCUSSION

The plot and lysimeter experiments provided information on the most suitable type of plant, on the quantity and quality of the percolate, and gave an indication of evapotranspiration rates.

Of the eight different species of grass and pasture used in the plot experiments, alfalfa gave the highest yields (Figure 1). While most of the other plants died off or became dormant during winter, alfalfa achieved slow but continued growth and hence was chosen as the most suitable cover crop.

Average values for evapotranspiration in the lysimeters for the period 1969 to 1976, (1974/75 season excluded) were 3 700, 3 860, and 3 050 mm for the control, gypsum, and ferrous sulfate treatments respectively. However, it can be assumed that because of the "oasis effect," these values are considerably higher than might be expected in practice.

Analysis of drainage water (Table V) showed an almost linear increase in SAR during the first 5 years. Complete analyses for the year 6 were not available, but spot checks made during the year gave SAR values that varied between 65 and 88, which confirmed that the increase in SAR continued.

Alfalfa yield reached a maximum during the second season, namely 1969/1970 (Figure 3). During the period 1972 to 1976 the average yields were 64, 83, and 62% of the maximum for the control, gypsum, and ferrous sulfate treatments respectively (Figure 5). These results indicate that gypsum application gave the best results. This is confirmed by a comparison of yields for different soil amendment treatments (Figures 3 and 4).

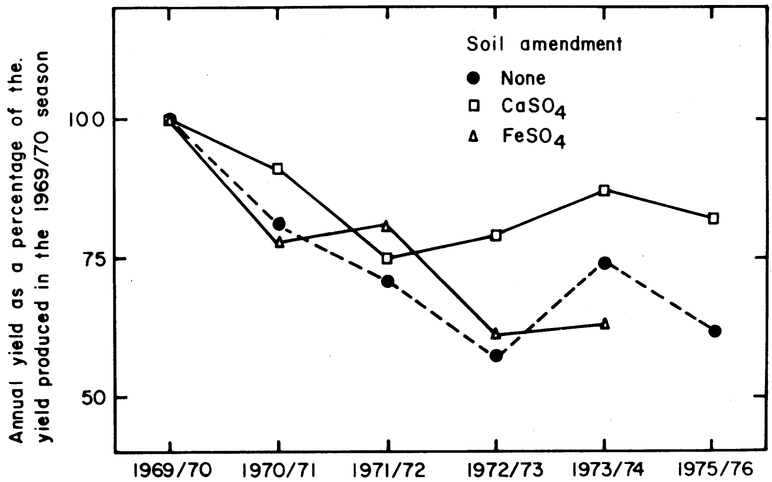

FIGURE 5. Effect of irrigation with saline effluent on annual alfalfa yield in lysimeters.

TABLE VI. Analyses of soil in lysimeters, at the beginning and after irrigating with effluent for 6 and 8 years, respectively.

		No Treatment				Gypsum				Ferrous Sulfate			
		Sample Depth (cm)				Sample Depth (cm)				Sample Depth (cm)			
		0–30	30–60	60–90	90–120	0–30	30–60	60–90	90–120	0–30	30–60	60–90	90–120
pH	1[a]	5.4	5.4	5.9	5.9	5.5	5.5	5.8	5.9	5.4	5.6	5.8	5.9
	2	8.0	7.8	7.6	7.3	7.9	7.9	7.7	7.3	7.5	7.3	7.1	6.9
	3	8.1	7.7	7.7	7.5	8.0	7.8	7.7	7.4				
Soluble Na (me/100 g)	1	0.03	0.03	0.08	0.12	0.02	0.03	0.07	0.13	0.03	0.04	0.08	0.12
	2	2.46	4.00	5.89	6.36	5.04	6.84	5.66	4.76	8.82	7.77	4.77	4.88
	3	2.44	4.12	5.90	6.98	5.24	6.80	5.68	5.48				
Soluble Ca + Mg (me/100 g)	1	0.21	0.14	0.16	0.19	0.19	0.15	0.18	0.22	0.20	0.14	0.16	0.21
	2	0.25	0.21	0.18	0.18	0.62	0.81	0.44	0.26	1.00	0.96	0.37	0.29
	3	0.24	0.22	0.20	0.20	0.65	0.58	0.58	0.37				
Sodium adsorption ratio	1	0.4	0.6	1.3	1.8	0.4	0.6	1.1	1.9	0.4	0.6	1.3	1.8
	2	34	80	108	109	45	58	64	70	62	65	59	66
	3	40	76	112	115	48	55	60	68				
Exchangeable Na (me/100 g)	1	0.09	0.09	0.17	0.27	0.09	0.11	0.15	0.25	0.09	0.10	0.16	0.27
	2	5.01	3.36	1.98	1.50	1.57		0.45	1.46			0.92	0.09
	3	6.30	3.45	2.10	1.75	1.14	0.82	1.01	1.46				
Exchangeable Ca +Mg (me/100 g)	1	4.76	4.18	4.21	4.49	4.28	4.18	4.28	4.49	4.54	4.31	3.95	4.76
	2	7.19	3.23	1.44	1.10	6.89	4.29	2.70	2.14	5.24	2.84	2.51	1.88
	3	6.91	3.09	1.37	1.21	7.80	4.44	2.85	2.29				

[a] 1—sampled before irrigation started; 2—sampled after irrigating for 6 years; 3—sampled after irrigating for 8 years.

As might be expected, a considerable degree of salination of the soil occurred as a result of irrigation with the highly mineralized effluent. The sodium content of the soil increased considerably, although to a lesser extent with the treated soil than the control. Calcium increased in the topsoil (0 to 30 cm) for all treatments, but decreased progressively with depth (Table VI). No significant changes in salt content of the soil from the years 6 to 8 of irrigation could be found, and it appears that equilibrium conditions had been established.

Despite the high salinity of the soil, its structure is still such that no problems are encountered with infiltration. Except for a crust that forms on the surface when dry, there are no apparent differences in the physical appearance of the control when compared with the treated soils.

Re-establishing alfalfa from seed presented no problems in those lysimeters that received soil amendments. Problems with germination occurred with the control, apparently as a result of the crust that formed on the surface when dry. However, when this condition was alleviated by irrigating more frequently, germination occurred quite readily.

With the large-scale irrigation project that has now been in operation for about 5 years, a well-established and generally healthy-looking vegetal cover has been maintained and no problems with surface runoff are encountered. Analysis of soil samples taken from the two irrigation areas in June 1977 indicates that in the plantation area, which has been irrigated since 1973, the applied sodium had not penetrated down to more than about 5 m (Figure 6). Even on the old black liquor farm, which received very high loads of sodium over a period of many years, the exchangeable sodium in the soil is 10% or less at a depth of 9 m below the surface.

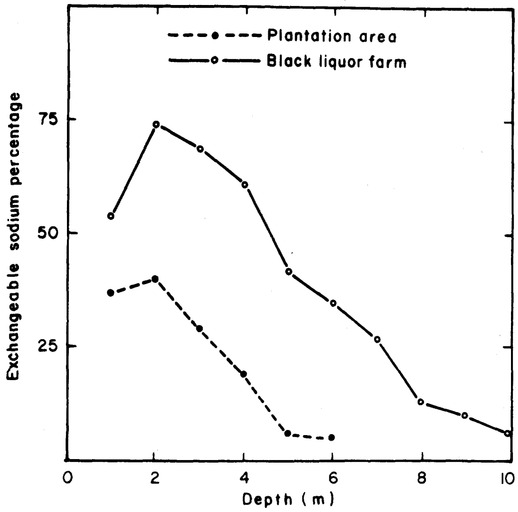

FIGURE 6. Exchangeable sodium percentage (ESP) of soil profile in the large-scale irrigation area. (June 1977)

TABLE VII. Average chemical analysis of effluent disposed of by irrigation on land since 1973.

		Concentration
pH		8.6
Total dissolved solids	(mg/l)	4 080
Sodium as Na	(mg/l)	1 050
Chloride as Cl	(mg/l)	520
Sulfate as SO_4	(mg/l)	990

The results obtained in this study indicate that the soil has a tremendous salt-storage capacity. It is realized, however, that the danger of polluting underground waters does exist and the question arises as to how serious this problem could become. At present this question cannot be answered but the situation is being watched and steps such as the provision of interceptor drains to return seepage for disposal on surface will be taken if necessary. Alternative methods for the treatment and disposal of mineralized factory effluents are also being studied.

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