RECLAMATION OF A SALINE SODIC SOIL IN THE NKWALINI VALLEY

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Abstract

An area of saline sodic soil was intensively drained and treatments of gypsum (31 t/ha) or sulphur (6 t/ha) were applied, while control plots received no ameliorants. Physical and chemical soil analyses showed gypsum to have an ameliorative effect slightly superior to that of sulphur. Both treatments were more beneficial than the control but differences were not always as great as expected. For the plant and first ratoon sugarcane crops grown on the experiment, average yields were 100, 99 and 82 tc/ha for the gypsum, sulphur and control, respectively.

Introduction

Excessive salt levels in the soil have for some years been recognised as a problem in the dry, irrigated regions of the South African sugar industry (Maud[3], von der Meden[7]). The saline sodic (saline alkali) condition is by far the most common, but saline non-sodic and non-saline sodic soils are also found.

Salinisation of soils in the sugarcane areas is generally caused by improper water management, ie inadequate drainage is provided for irrigation excesses and this results in a rise in the level of the water table. Salts dissolved in the groundwater reach the soil surface by capillary movement and then accumulate there. It is usually soils of naturally poor drainage that are affected in this way, and in many instances these are marginally affected by salts in the virgin state.

In reclaiming sodic soils, improvement or maintenance of soil permeability is the prime consideration. This is usually achieved by supplying calcium ions to the soil, either directly by adding gypsum (calcium sulphate) or indirectly by acidifying the soil with sulphur or sulphuric acid to dissolve free calcium carbonate. Techniques of reclamation have been thoroughly discussed in the literature (US Salinity Lab Staff[6]; Szabolcs[5]; Kovda, van den Berg and Hagen[2]) but, because of a general lack of local practical experience, it was decided that it would be worthwhile, as a first step, to test commonly used ameliorants in a small field trial.

Selecting a site for reclamation work presented difficulties since, in such soils, marked variations in salt level frequently occur over very short distances. Nevertheless, a site was selected for an experiment in the Nkwalini Valley (Zululand) which represented a typical example of a saline sodic condition. The climate in this area is described as semi-arid, the mean annual rainfall being approximately 700 mm, so that intensive irrigation is required to achieve satisfactory sugarcane yields.

Experimental procedure

The soil is of the Nyoka series (Swartland form) and consists of a very dark grey brown porous sandy clay loam (± 25% clay) about 36 cm in depth, overlying a B horizon of dark to yellowish brown, slowly permeable sandy clay (±40% clay). The transition between A and B horizons is gradual and the profile depth generally exceeds 0,9 metres. The underlying material consists of water worn gravel and weathering Middle Ecca sediments, the latter being the dominant parent material in this area.

The highly saline sodic condition that exists (see Table 1) is believed to have arisen primarily from a high water table which, in turn, was caused by seepage from an unlined dam up the slope from the area. At the time when the experiment was laid down, much of the soil was in a highly dispersed state, with little plant growth before treatment (Fig. 1).

TABLE 1
Average chemical status of the soil prior to treatment

Sample depth (cm)	pH	EC_{se} (millimhos/cm at 25° C)	Total cations (meq %)			SAR_{se}	Exch. Na (meq %)
			Na	Ca	Mg		
0–15	6,9	7,7	3,0	6,9	7,3	17,2	1,5
15–36	7,5	7,6	4,5	7,8	9,9	19,6	2,8
36–66	8,1	7,7	5,6	12,2	12,6	22,1	3,2
66–90	8,0	9,7	6,1	10,5	12,5	24,2	3,3

FIGURE 1 Appearance of the experiment site prior to application of treatments.

Three replications of the following treatments were tested:

Drainage alone as control (C)
Drainage + gypsum at 31 t/ha (G)
Drainage + sulphur at 6 t/ha (S)

The gypsum ($CaSO_4.2H_2O$) requirement was determined from the exchangeable Na level of the worst affected areas of the site. The aim was to displace the exchangeable Na in excess of 2,0 meq/100 g with Ca. An amount of sulphur that was chemically equivalent to the gypsum was used. The ameliorants were of fine texture, 90% and 100% of the gypsum and sulphur, respectively, passing a 100 mesh sieve, and both were at least 98% pure.

As the salt status of the soil varied quite markedly across the site, it was considered necessary to group together the three worst, the three intermediate and the three least affected plots. One of each of the three treatments was allocated at random to a plot in each group to minimise bias in the results towards any specific treatment.

In December 1970, flexible plastic pipe drains (50 mm diam.) were installed at a spacing of 8,5 metres and an average depth of about 0,85 metres. Ten parallel drains formed the boundaries of the nine plots and these extended down the 36 metre length of each into an open collector drain. The natural slope of the land, at about 5%, provided grade for the drains. An open cut off drain (approximately 1,5 metre deep) above the experiment site served to intercept seepage from higher up the slope. In January 1971 the ameliorants were broadcast by hand and worked into the soil to a depth of 15 cm by two passes of an offset disc harrow to ensure good mixing. The whole of the experiment site, including the control plots, was then ploughed to a depth of 35 cm with a single furrow mouldboard plough. It was intended to sprinkler-irrigate the site at least once every 14 days with 50 mm of water per application, but it was not possible to irrigate to any meaningful extent before September 1973 so that, up to this time, rainfall alone was relied on for leaching of salts. The monthly rainfall and the amount of irrigation water applied are indicated in Figures 2, 3 and 4. It is not possible to estimate what proportion of this water actually entered the soil, but runoff losses were no doubt high. Erosion on the worst affected areas was clearly evident. The source of irrigation water in this region is the Umhlatuzi River and it is considered to be of good quality, with no significant salinity or sodicity hazards (Natal Town and Regional Planning Report[4]).

The whole area was basin-listed soon after applying the treatments, in order to improve water retention on the plots and thus enhance leaching. Seradella, a legume which is reputed to be fairly salt tolerant, was sown over the whole site with the aim of establishing a crop to reduce runoff. Germination was poor, but the growth of natural weeds and grasses gradually improved until fairly good cover was provided after about a year. The site was ploughed again in August 1972 to improve infiltration rates, after which weeds were again allowed to grow. In February 1974 the salt level in the soil had decreased sufficiently to allow reasonable sugarcane growth, and a crop of variety N55/805 was planted. Urea and single superphosphate fertilizers were applied according to Fertilizer Advisory Service recommendations.

Chemical measurements

In order to monitor changes in salt status, the soil was sampled at depths of 0-15 cm, 15-36 cm, 36-66 cm and, where possible, 60-90 cm near each of four marked positions on each plot. Samples were taken before application of treatments and subsequently at two-monthly intervals. During the latter stages of the experiment, sampling was less frequent. The following measurements were made on each sample:

- Electrical conductivity of saturation extract (EC_{se})
- Soluble Na, Ca and Mg concentrations
- Sodium adsorption ratio of saturation extract (SAR_{se})
- Total Na, Ca and Mg (1N NH_4OAc extract)
- Soil pH (1 : 2,5, soil : water).

Physical measurements

In December 1975 measurements of infiltration rate were made using double ring infiltrometers. A falling head method was employed, the head of water being allowed to drop by 100 mm before it was refilled to the zero level. The depth of water infiltration after three hours was recorded at ten points on each plot. To minimise the effect on infiltration rate of differences in soil moisture content with time, measurements of infiltration were taken concurrently on each of the nine plots.

The percentage dispersion measurement was made on soil samples taken in January 1977. This index of dispersion expresses the amount of silt plus clay dispersed on shaking a soil sample in de-ionised water, as a percentage of the total silt plus clay (US Salinity Lab. Staff[6]).

Results

Chemical measurements

EC_{se}

Electrical conductivity measurements showed that chemical amelioration had a relatively small effect on the rate of desalinisation (see Fig. 2). The EC_{se} levels in the gypsum and sulphur treatments were marginally but consistently lower than that of the control. The amount of rainfall and irrigation water clearly had a marked effect on the rate of desalinisation. This is evident from the noticeable decline in EC_{se} in all treatments when relatively large amounts of rainfall plus irrigation water were received towards the end of 1973. Since then resalinisation has taken place to some extent particularly in the sub-soil.

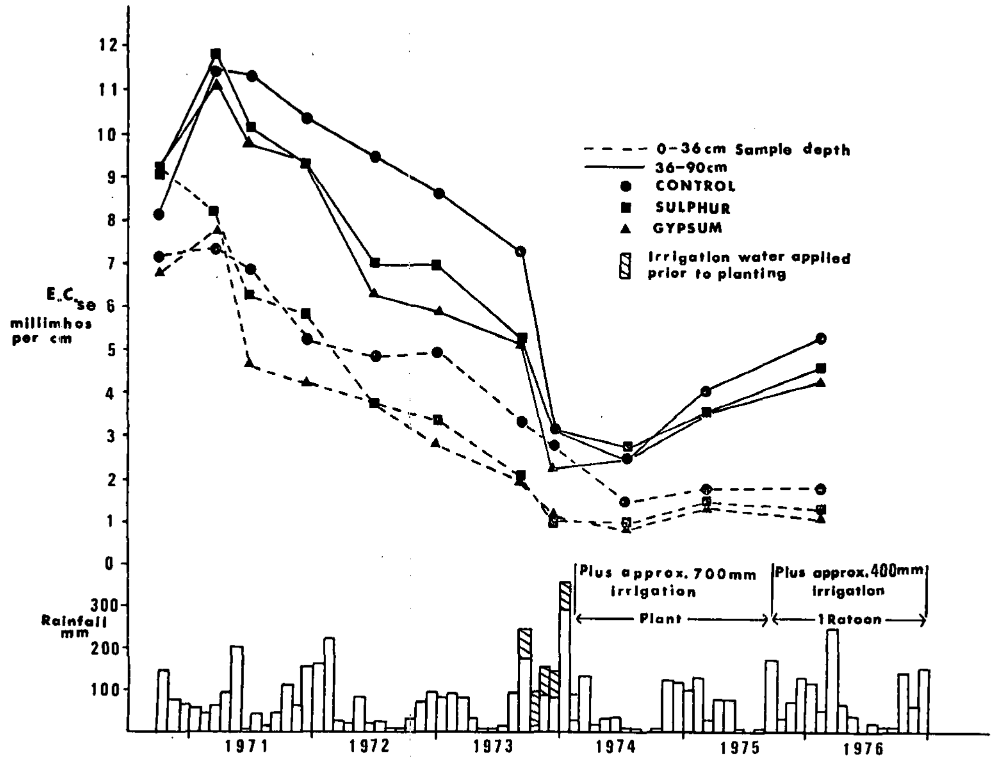

FIGURE 2 Changes with time in electrical conductivity of the saturation extract.

SAR_{se}

The sulphur and gypsum treatments were found to be closely similar in their ability to lower the SAR_{se} (see Fig. 3). In the A horizon the SAR_{se} levels of these two treatments were reduced very rapidly to reach about half their original value in less than a year. Since then they have declined more gradually to the safe SAR level of approximately 4. This relatively rapid decline in SAR_{se} in the A horizon was to be expected, since this corresponds with the soil depth to which ameliorants were physically incorporated.

In the B horizon, gypsum and sulphur have resulted in a gradual decline in the SAR_{se} to the present level of about 10. From the chemical point of view this is considered to be marginal (Johnston[1]).

The slight decline in the SAR_{se} of the control in the A and B horizons is attributed to the decrease in the SAR that results from dilution of a solution (SAR decreases by $\sqrt{\text{dilution factor}}$). The SAR_{se} of 16 in the B horizon is considered to be excessively high while that of 9 in the A horizon is marginal.

pH

Soil pH was markedly affected by the sulphur treatment. The pH of the A horizon showed a fairly sharp decline five to nine months after application of the ameliorants (Fig. 4).

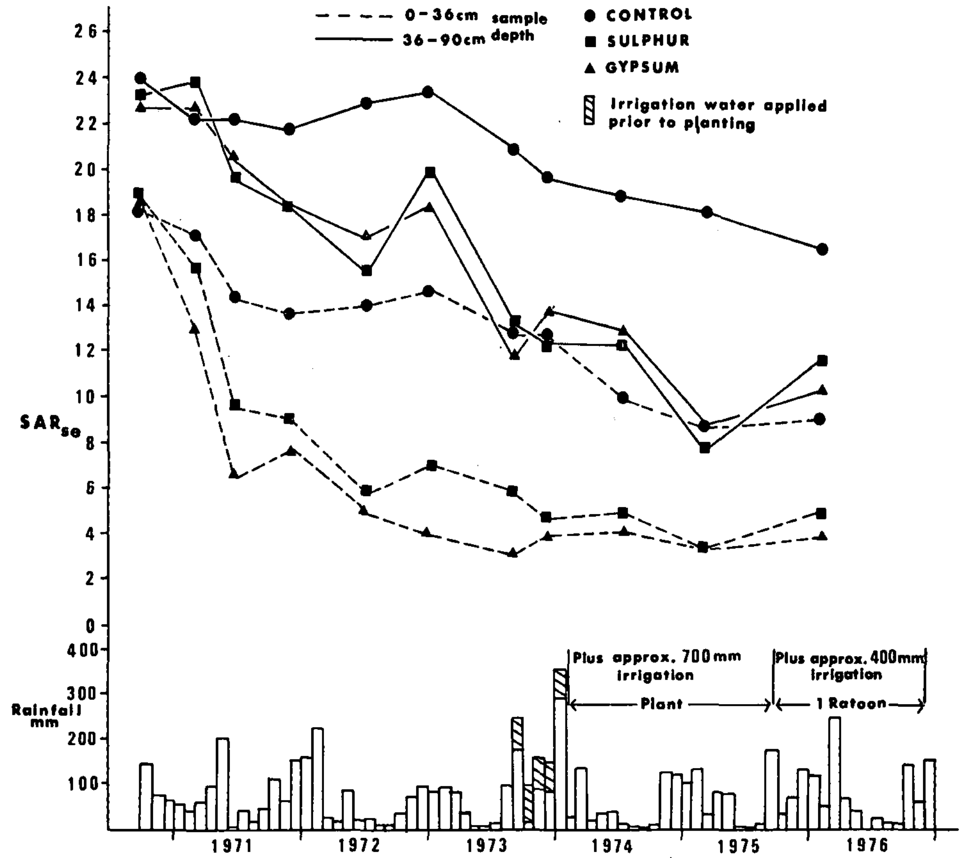

FIGURE 3 Changes with time in sodium adsorption ratio of the saturation extract.

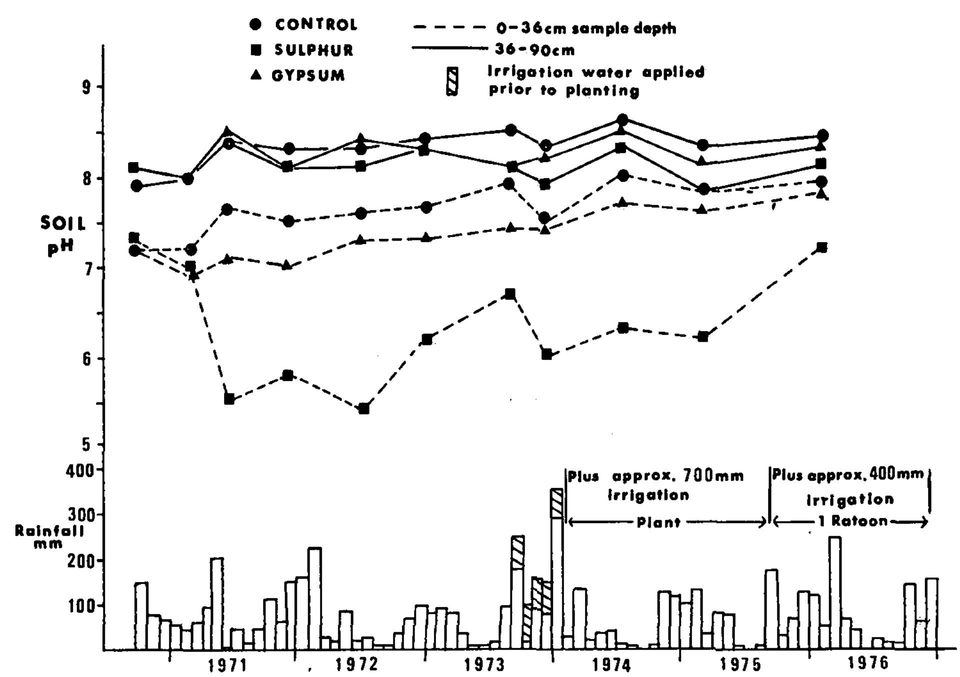

FIGURE 4 Changes with time in soil pH.

From a minimum of about 5,5 units in 1972 the pH has gradually risen to its present level, which is very similar to the original value of 7,2. The subsoil has shown no noticeable change in pH which indicates that, if any acids produced from oxidation of the sulphur did leach into the B horizon, they were rapidly neutralised by free lime occurring in this zone.

The A horizons of the control and gypsum plots showed a gradual increase in pH of about 0,6 units over the duration of the experiment. In the control this could have been caused by the formation of bicarbonates or carbonates resulting from the hydrolysis by dissolved carbonic acid of the sodium clay. In the gypsum treatment the reason for the rise in pH is not clear.

In the B horizon, pH levels have shown some fluctuation due primarily, it is believed, to sampling error. There appears to be a real increase in pH in the control and gypsum plots of approximately 0,5 and 0,2 units respectively.

Physical measurements

As was expected, results from the infiltrometer tests were somewhat variable (see Table 2). Particularly disturbing were the few measurements that exceeded the mean by approximately ten-fold. To eliminate bias in the mean caused by the inclusion of these large values, medians are also given. Higher infiltration rates in the gypsum and sulphur treated plots, when compared with the control, showed that chemical amelioration had a favourable effect on soil physical properties. It is considered that greater reliance should be placed on the median rather than the mean values, and this would lead to a suggestion that gypsum had produced a slightly more beneficial effect than sulphur.

The above results are supported by the measurements of percentage soil dispersion (Table 3). On the three soil depths at which determinations were made, gypsum treated soil showed the least dispersion while unameliorated soil showed the greatest.

Sugarcane yield

From stalk measurements of both plant and first ratoon crops it was clear, from an early age, that growth in the ameliorated plots was superior to that in the control plots. This was borne out in the harvested yields (Table 4). In the plant crop sulphur and gypsum treatments produced average

TABLE 2

Depth of water (mm) infiltrated after three hours given as means and medians of ten measurements per replication

Replication	Control		Sulphur		Gypsum	
	Mean	Median	Mean	Median	Mean	Median
1	19	15	52	16	30	26
2	18	14	60	39	23	15
3	20	21	38	30	79	63
Mean	19	17	50	28	44	35

TABLE 3

Effect of ameliorants on percentage dispersion on the silt plus clay fraction*

Replication	Control			Sulphur			Gypsum		
	0-15 cm	15-36 cm	36-66 cm	0-15 cm	15-36 cm	36-66 cm	0-15 cm	15-36 cm	36-66 cm
1	24	42	57	18	21	40	14	30	50
2	37	72	73	19	18	32	11	13	27
3	15	21	39	18	32	61	15	16	25
Mean	26	45	56	18	23	44	13	20	34

* Each figure in the body of the table represents the mean of 8 determinations.

TABLE 4

Yield data for the plant and first ratoon crops

	Replication	Salinity rating	Control (C)		Sulphur (S)		Gypsum (G)		Treatment responses					
									S − C		G − C		$\frac{S+G}{2} - C$	
			tc/ha	ters/ha	tc/ha	ters/ha	tc/ha	ters/ha	tc/ha	ters/ha	tc/ha	ters/ha	tc/ha	ters/ha
Plant crop (19 months)	1	Worst . . .	97	13,8	104	14,8	119	16,8	7	1,0	22	3,0	15	2,0
	2	Intermediate .	80	10,7	120	16,4	123	17,1	40	5,7	43	6,4	41	6,1
	3	Least . . .	110	15,2	111	14,5	110	14,8	1	0,7	0	− 0,4	0	0,2
	Mean		96	13,2	112	15,2	117	16,2	16	2,0	22	3,0	19	2,5
First ratoon (14 months)	1	Worst . . .	66	8,4	78	9,3	85	10,9	12	0,9	19	2,5	16	1,7
	2	Intermediate .	54	6,1	87	10,7	87	11,2	33	4,6	33	5,1	33	4,9
	3	Least . . .	81	11,2	88	10,9	81	9,6	7	−0,3	0	−1,6	3	−0,9
	Mean		67	8,6	85	10,3	84	10,6	17	1,7	17	2,0	17	1,9

	Plant crop		First ratoon	
	tc/ha	ters/ha	tc/ha	ters/ha
CV%	11,8	13,3	11,6	18,6
LSD (0,05) treatment means	29	4,5	21	4,2
LSD (0,05) $\frac{S+G}{2} - C$	25	3,9	18	3,6

responses of 16 and 22 tc/ha (or 2,0 and 3,0 ters/ha) respectively. Stalk heights and populations at harvest were in agreement with these results.

First ratoon yield results are similar, in that sulphur and gypsum have both given an average response of 17 tc/ha (or 1,7 and 2,0 ters/ha respectively).

In the third replications of each treatment (category of least salt affected soil) it is clear for both crops that the yields show no response to treatment with gypsum and sulphur. Strangely enough, responses are consistently greater in the second replication (intermediate salt affected soil) than in the first (worst salt affected). This apparent anomaly is associated with a very low yield in the control plot, indeed the lowest in the whole experiment. The reason for this appears to be the relatively high exchangeable sodium and EC_{se} levels in the A horizon of this plot. For some reason the levels have not declined to the degree of those in the other plots.

Discussion and conclusions

It is clear that drainage alone has brought about very substantial decreases in EC_{se} and sodium level. Although the chemical and physical condition of the soil in the two ameliorative treatments were shown to be more favourable, sugarcane yields were not statistically greater than that of the control. At the outset it was considered possible that the soil physical condition in the control plots would deteriorate (due to enhanced dispersion following desalinisation) to such an extent that the soil would become quite unsuitable for plant growth. That this did not occur was clearly shown by the satisfactory yield of sugarcane that was obtained from areas which had previously supported only very sparse vegetation (see Figs. 1 and 5). These results suggest that the detrimental effects of poor physical condition are somewhat less important than those of high free salt content, at least in the short term.

FIGURE 5 Appearance of cane in 1976.

From chemical and physical measurements on soil, and from sugarcane yield results, the ameliorative ability of gypsum and sulphur was found to be similar although gypsum was slightly superior. For this and economic reasons, gypsum is favoured in preference to sulphur as an ameliorant for sodic soils, unless sulphur is required to reduce a very high soil pH.

During the early stages of the experiment it was observed that weeds were greener and more prolific directly above the drains than in the area adjacent to them. Enhanced nitrogen mineralisation due to improved aeration of the disturbed soil is believed to be the reason for this. Better cane growth directly over drains has subsequently been observed in commercial fields and this suggests that above average nitrogen fertilizer applications would be an advantage in poorly aerated sodic soils.

Since the critical EC_{se} for sugarcane under South African conditions is approximately 2,0 millimhos/cm (von der Meden[8]) it is clear that, in the A horizon (0-36 cm), the free salt content has been maintained at a safe level since mid-1974 (Fig. 2). Although the subsoil reached a fairly low EC_{se} level of about 2,5 millimhos/cm for all treatments in mid-1974, it has since then risen quite markedly and now exceeds 4 millimhos/cm for all treatments.

Sodicity has been reduced to what is considered to be a marginal level by the gypsum and sulphur treatments. In the control the sodium level, particularly in the subsoil, is considered to be excessive in spite of a slight decline.

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