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ATTEMPTS AT IMPROVING IRRIGATION WATER QUALITY IN NORTHERN ZULULAND

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Abstract

The problem of poor water quality in all the major river systems between the Umfolozi and Mkuze rivers, and the attempts to improve the water quality with gypsum and sulphur dioxide are discussed in this paper. Gypsum was dissolved in water to a predetermined concentration and sulphur dioxide was bubbled through the water until a pH value between 6,0 and 6,4 was attained. After treatment, water was analysed to determine the effect on water quality. Irrigation water that had been treated with gypsum was no more effective than the conventional treatment of the soil with gypsum. Sulphur dioxide reduced sodium adsorption ration (SAR) values in all waters but the response may be inadequate for commercial application. The solution to the problem seems to be correctly scheduled irrigation methods and an understanding of the soils which are to be irrigated, so that the application of saline/sodic water is balanced by the natural leaching by rainfall.

Introduction

In a previous survey of river water quality (Johnston),[2] the problem of using poor quality water for irrigation from the Mkuze river was highlighted. The seriousness of this problem only became apparent during the 1980's when a large decline in the yield of sugarcane occurred along some of the rivers in northern Zululand.

The uncontrolled or excessive application of sodic irrigation water causes a breakdown of the soil structure due to the swelling and dispersion of the clay fraction, which results in closed pore spaces and a low permeability of air and water. Consequently, runoff and ponding occur, water tables are easily induced, and the crop suffers from inadequate soil aeration. Physiological damage may also be caused by sodic conditions or sodium toxicity.

Two examples on the lower reaches of the Hluhluwe river illustrate this problem. Water of a quality that varied from a poor Class 'B' to mainly poorer Class 'D' was used to irrigate Rensburg and Bonheim form soils in one irrigation scheme. This resulted in a large decline in yield within ten years. Extensive and costly surface and subterranean drains and de-watering pumps did not resolve the problem and the affected areas have been abandoned. Another irrigation scheme was recently abandoned because of the decline in the yields of sugarcane, despite the fact that 39 % of the soils were free-draining. The yield decline, water quality and total water applied to the crop from 1977 to 1984 for the above scheme are shown in Table 1.

These case histories, together with the fact that a significant percentage of the sugarcane processed at the Umfolozi mill is produced from 6 330 ha which receive supplementary irrigation, led to a water quality survey of the area being conducted to determine the extent of the problem. Laboratory studies were also carried out to find a method which could be used to overcome the effect of poor water quality on sugarcane growth and on soil physical and chemical properties.

TABLE 1

The decline in yield over seven years on a 150 hectare irrigation scheme on the Hluhluwe River

Year	Tons ha^{-1} a^{-1}		Water quality		Water ha^{-1} (mm)	
	Cane	Sucrose	ASAR	Class	Total	Av mth^{-1}
1977	96	12,5	10,1	'D'	1 618	144
1978	96	12,5	-	-	1 556	125
1979	84	10,4	-	-	1 194	104
1980	70	8,8	-	-	1 104	99
1981	66	8,2	16,9	'D'	1 572	125
1982	49	6,2	13,9	'D'	1 035	89
1983	37	4,4	12,2	'D'	1 117	81
1984	35	4,1	10,2	'D'	1 549	98

Notes: (a) Water ha^{-1} (mm) = rainfall and irrigation on that crop.
(b) ASAR = average of all samples taken.
(c) 1978 to 1980 no water analysis, but probably 'D' class.
(d) Long term mean annual rainfall = approximately 825 mm.

Some of the water sources from this area were previously classified as 'saline' but the samples that were analysed during 1985 indicated that sodicity was the major problem.

Water quality assessment in the South African sugar industry is based on the United States Department of Agriculture (USDA) system (US Salinity Lab Staff)[5] but it has been modified at the South African Sugar Association Experiment Station for local conditions and soil types (Johnston).[3,4]

Water quality is classified by taking both the salinity and sodicity levels into account, and these are determined by measuring the electrical conductivity (EC) and the sodium adsorption ratio (SAR) of the water. Rainfall has a diluting effect and the EC must therefore be modified according to the local annual rainfall to obtain the effective electrical conductivity (EEC). The precipitation or dissolution of calcium carbonate ($CaCO_3$) in the soil can also substantially influence the SAR of the irrigation water after application so the potential for the occurrence of the precipitation or dissolution process must be assessed to obtain the adjusted SAR (ASAR) value.

After a water sample has been analysed in the laboratory, the EEC and ASAR values are calculated. These values are then used to classify the quality of the water as 'A' class (suitable for use on all soils), 'B' class (suitable for use only on free-draining soils), 'C' class (suitable for use on free-draining soils if there is no alternative), and 'D' class (unsuitable for irrigation under normal practices) (Figure 1).

Methods

Water quality survey

Water samples were collected monthly from a number of rivers and from the major water sources in the areas where the quality of the water was suspected to be poor. These samples were analysed for salinity/sodicity status and then classified using the system described above.

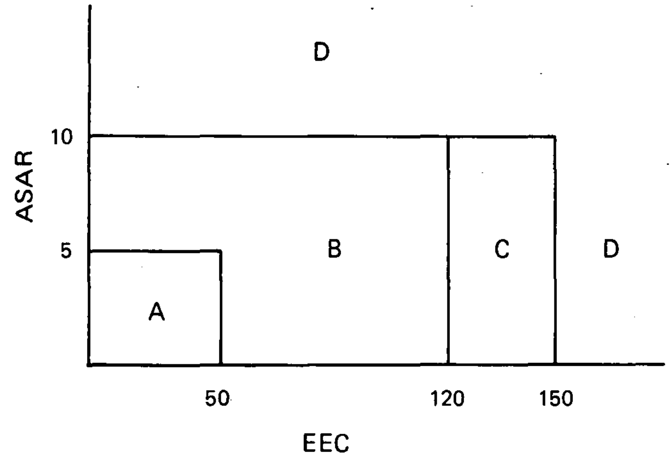

FIGURE 1 Chart for classifying irrigation water quality for sugarcane.

Water amelioration

Since the poor quality water problem in Zululand is related to sodicity rather than salinity, a form of amelioration that would reduce the hazardous effects of sodium had to be considered.

Studies with gypsum

In a previous report (de Bruyn and Grobler)[1] on the dissolution of gypsum in irrigation water it was stated that the amount of gypsum required to ameliorate a soil could be reduced sixfold if it was applied through irrigation water rather than by direct incorporation into the soil. It appeared that the water quality in the areas of limited rainfall could be improved by dissolving gypsum in the irrigation water because, in theory, this would reduce the effect of high concentrations of sodium ions. To test the practical aspects of this theory, a laboratory experiment was carried out.

Water and soil samples were collected from three different sites and the following treatments were applied. (Note that water and soil samples from each site were used together to simulate the farm situation).

- Control - untreated soil leached with untreated 'D' quality water.
- Soil plus gypsum (equivalent to 10 t ha^{-1}) leached with untreated 'D' quality water.
- Soil (untreated) leached with gypsum-treated 'D' quality water (equivalent to 10 t gypsum ha^{-1}).

Six 500 g topsoil sub-samples from each site were weighed into permeameters of 1,1 litre capacity. The equivalent of 1 000 mm of irrigation water (abour 8,1 litres per permeameter) from each site was measured into six separate plastic containers. Gypsum was applied to the soil and water samples, and the water was allowed to percolate through the soil obtained from the same site. This procedure was carried out for all the soil and water samples from each farm.

Studies with sulphur dioxide

As the dissolution of gypsum in the irrigation water was not satisfactory, sulphur dioxide (SO_2) was used as an alternative.

Water samples received in the laboratory were analysed for salinity/sodicity and then SO_2 was bubbled through the water until the pH declined to between 6,0 and 6,4 (this was the requirement specified by the manufacturers of the SO_2 generator). After the water was treated with SO_2, the samples were analysed again to see if any changes had occurred due to the SO_2 treatment.

A laboratory leaching study was also carried out using permeameters. A bulk soil sample, from which 500 g subsamples were taken for each permeameter, was obtained from the topsoil of a non-saline/non-sodic (EC = 78 mS m^{-1}, SAR = 7,1) Bonheim form soil. In this study two leaching treatments were used. In one the soil was leached with untreated 'D' quality water and in the other it was leached with the same water after it had been treated with SO_2. During the leaching study, hydraulic conductivity measurements were also taken.

Results

Water quality survey

The area served by each water source, as well as the water quality classes, are given in Table 2, which shows the percentage of the total area irrigated that was subjected to applications of poor to unsuitable quality water during a one-year period. Of the area irrigated from three water sources (Nyalazi, Msunduze/Lake Eteza and Collins Lake), 25 % received 'D' quality water for 300 days or more during 1985 while water from the Umfolozi north bank drain, which supplies 12 % of the total area was of 'A' quality for more than 300 days during 1985 and was never worse than 'B' quality.

TABLE 2

The area irrigated from each water source as a percentage of the total area with a breakdown of all 1985 water analyses into irrigation water quality classes

* % of total area	Water sources	Percent of samples x water class			Actual samples
		Class 'D'	Class 'B'	Class 'A'	
34	Hluhluwe	41	53	6	32
27	Mkuze	21	69	10	38
18	Nyalazi	87	4	9	22
12	Umfolozi	–	10	90	11
	North bank drain	10	72	18	11
4	Msunduze and Lake Eteza	82	14	4	22
3	Collins Lake	90	10	–	11
2	Umzinene	57	29	14	7

* Total area = 6 330 ha

Notes: (a) From December 1984 to November 1985 water samples were taken every month except July.
(b) 1985 annual rainfall was above long term mean.

Water amelioration using gypsum

The soil and water samples were analysed for salinity and sodicity before any treatments commenced. A summary of these results, together with the results of analyses after treatment, are given in Tables 3 and 4.

Results in Table 3 show that in all soils the sodicity values were higher after leaching with poor quality water, but where gypsum was applied directly to the soil, the increase in sodicity was not as marked. When soil with a low salinity level was used, as in Sources B and C, the EC values increased with leaching while, where soil of a high salinity level was used (Source A), leaching resulted in a reduction of EC.

From Table 4 it is evident that although the sodicity level in each case was reduced slightly due to the addition of gypsum, the water quality remained as Class 'D'. Salinity levels were marginally affected by the dissolved gypsum.

TABLE 3

Results of soil analysis leaching experiment

Source of soil	Treatment	pH	EC mS m⁻¹	SAR	Soil form	Salinity/ sodicity status
A	Before treatment	7,0	329	13,9	Inhoek	Saline/sodic
	Control	7,4	250	16,6		Saline/sodic
	Gypsum in water	7,4	250	16,6		Saline/sodic
	Gypsum in soil	7,4	239	14,7		Saline/sodic
B	Before treatment	7,8	88	7,0	Kroonstad	Non-saline/ sodic
	Control	8,5	330	11,3		Saline/sodic
	Gypsum in water	8,3	306	10,8		Saline/sodic
	Gypsum in soil	8,4	284	9,4		Saline/sodic
C	Before treatment	6,3	55	1,6	Hutton	Non-saline/ non-sodic
	Control	7,2	174	7,9		Non-saline/ non-sodic
	Gypsum in water	7,2	185	7,3		Non-saline/ non-sodic
	Gypsum in soil	7,4	182	8,4		Non-saline/ non-sodic

TABLE 4

Changes in EEC and ASAR due to dissolved gypsum in the water

Source of water	Treatment	EEC mS m⁻¹	SAR	Water quality class
A	No gypsum	125	15,0	'D'
	Gypsum	128	12,6	'D'
B	No gypsum	182	22,2	'D'
	Gypsum	–	–	–
C	No gypsum	115	17,0	'D'
	Gypsum	122	16,5	'D'

Water amelioration using sulphur dioxide

- **Salinity/sodicity analyses**

Results of the water sample analyses before and after treatment with SO_2 are shown in Table 5. They show that, as with the gypsum treatment, SO_2 reduced sodicity slightly but not sufficiently. The poorer the quality of the water the less likely it appeared that treatment with SO_2 would improve the quality rating. This is illustrated in Figures 2 and 3 which show the changes in the class of water quality following treatment with SO_2 from Sources 1 and 4, which represent the worst and best quality water of all the sources sampled.

TABLE 5

Some water quality changes due to treatment with SO_2 gas in the laboratory

Source of water	Before SO_2 treatment			After SO_2 treatment		
	EEC mS m⁻¹	ASAR	Quality	EEC mS m⁻¹	ASAR	Quality
1	82	12,9	'D'	72	10,4	'D'
4	58	8,8	'B'	51	8,4	'B'
6	50	10,2	'D'	46	5,9	'B'
11	107	9,3	'B'	52	7,2	'B'
13	47	5,6	'B'	48	3,5	'A'

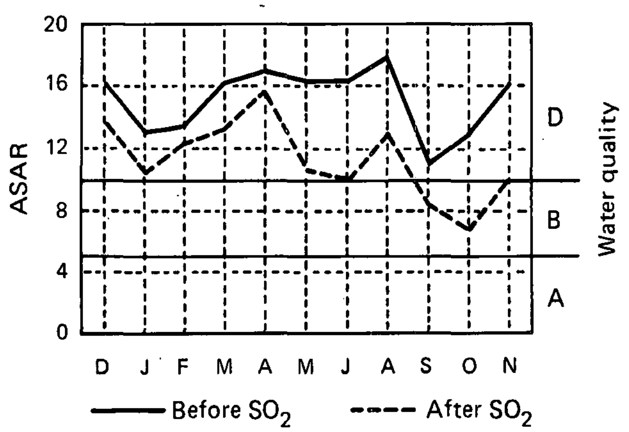

FIGURE 2 The effect of SO_2 treatment on water quality (December 1984 to November 1985, excluding July). Source 1 (worst quality water).

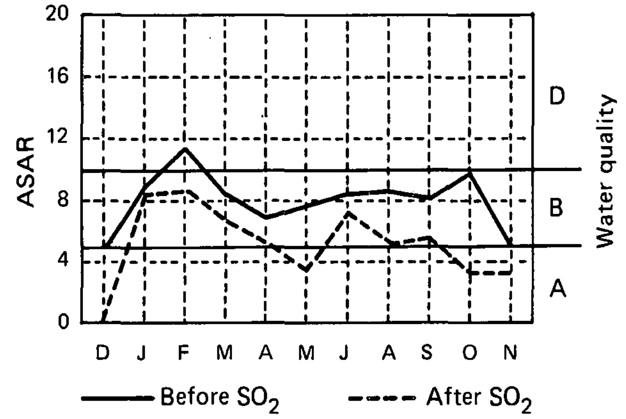

FIGURE 3 The effect of SO_2 treatment on water quality (December 1984 to November 1985, excluding July). Source 4 (best quality water).

The results of the soil analyses (Table 6) showed that there was an increase in EC when both SO_2 treated and untreated water was leached through the soil. Although soil SAR values increased after leaching with untreated water, leaching with treated water resulted in a decline in SAR values.

TABLE 6

A summary of the permeameter soil analysis results before and after the leaching treatments (mean of three replicates)

Leaching treatment	SO_2 treatment	pH	EC mS m⁻¹	SAR
Pre-leaching	–	8,2	78	7,1
After leaching	Untreated water	8,3	131	7,7
After leaching	Treated water	8,2	134	5,8

Water analysis results (Table 7) showed a large decline in ASAR from 13,6 to 3,4 while EEC values were not changed. The large decline in the ASAR value did not occur in any other analyses and it is thought that the observed decline may have been artificial as the pH value was reduced to below 6,0 and was then increased to 6,3 by dilution with untreated water.

TABLE 7

A summary of the water sample analyses before and after SO_2 treatment (mean of three replicates)

SO_2	pH	EEC mS m⁻¹	ASAR	Water quality
Untreated	8,5	110	13,6	'D'
Treated	6,3	110	3,4	'B'

- **Hydraulic conductivity measurements**

The curves in Figure 4 show clearly that the treatment of poor quality water with SO_2 resulted in a substantial increase in soil hydraulic conductivity from about 4 to 8 mm h^{-1} in eight days, while leaching with untreated water resulted in a decline in hydraulic conductivity.

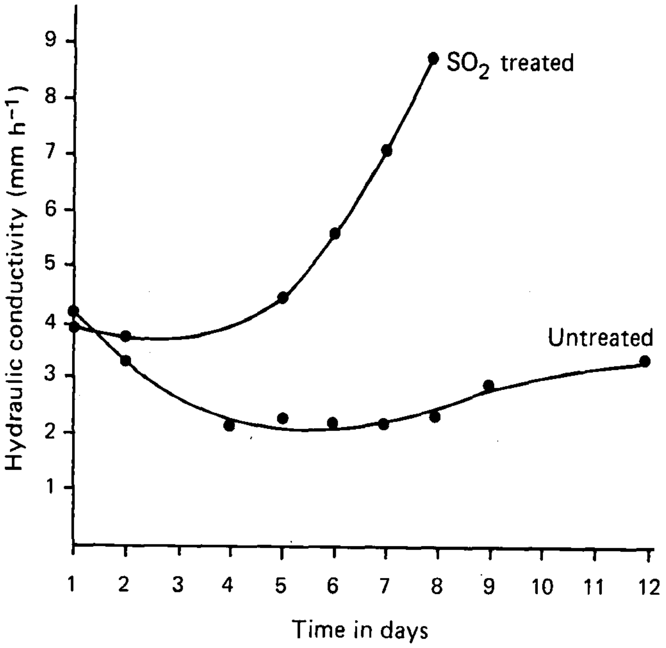

FIGURE 4 Changes in hydraulic conductivity

Discussion

Treatment of poor quality irrigation water with either gypsum or SO_2 gas reduced the sodicity status slightly, but the improvement was not sufficient to indicate that this practice would be worthwhile in commercial practice. When gypsum was dissolved in water in the laboratory it was found that it was less effective than when it was applied directly to the soil as an ameliorant.

When soils were leached with poor quality water that had been treated with SO_2, the hydraulic properties of the soil improved due to enhanced aggregation. This aggregation was caused by the more favourable calcium and magnesium to sodium ratio which resulted in an improvement in both the infiltration rate and the hydraulic conductivity.

There was no advantage in applying poor quality water treated either with gypsum or SO_2 to soils that were not free-draining. This limitation could be overcome if a good subsurface drainage system were to be installed, enabling any build-up of salts that might occur during irrigation to be flushed out by rain water.

From the results it is apparent that under most circumstances the two methods of ameliorating poor quality water that were used in this project are neither practical nor economical at this stage.

Conclusions

There is a serious water quality problem in the irrigated areas of the Umfolozi mill group. At present, it is not practical to ameliorate water of poor quality by using gypsum or SO_2, but the concept should be investigated further as the cost of soil amelioration in the form of subterranean drainage and gypsum incorporation is expensive. The solution would be to obtain a balance in the use of poor quality water for irrigation together with the leaching of salts by rainfall.

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REFERENCES

1. De Bruyn, J. G. and Grobler, B. J. (1978). Application of gypsum by means of irrigated water. *Ag Eng in SA* 12: 77–83.
2. Johnston, M. A. (1976). River water quality in the northern sugar areas. *Proc S Afr Sug Tech Ass* 50: 90–97.
3. Johnston, M.A. (1978). *Soil salinity and sodicity problems in the South African sugar industry.* MSc thesis, University of Natal.
4. Johnston, M. A. (1979). Evaluation of the quality of water for irrigation of sugarcane in South Africa. SASA Experiment Station unpublished report.
5. US Salinity Lab Staff (1954). The diagnosis and improvement of saline and alkaline soils. *USDA Handbook* No 60.