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A REVIEW OF THE MANAGEMENT AND AMELIORATION OF SALINE/SODIC SOILS AT MHLUME (SWAZILAND) SUGAR COMPANY

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Abstract

Mhlume's main estate (4 000 ha) is a variable mosaic of saline/sodic, weakly structured soils with sandy topsoils and heavy clay subsoils, interspersed with doleritic clays. Surface irrigation, without drainage, reduced average yields from 7,0 tc ha^{-1} mth^{-1} in the early 1960's to 5,5 tc ha^{-1} mth^{-1} in the early seventies. Improved land management practices were adopted, including trenchless drainage with 50 mm flexible slotted pipe; land levelling; the use of gypsum; and better controlled water flow from in-field step canals. Mean yields have increased to 6,3 tc ha^{-1} mth^{-1} largely through improved drainage of the topsoil. Plant and first ratoon yields are higher than previously obtained, but the rate of ratoon yield decline is still increasing as the soils degrade. The subsoils have not been reclaimed. Largest yield increases have been obtained by incorporation of filtercake and green manure. It is suggested that a cane: green manure rotation be adopted to prevent total degradation of the soils.

Introduction

Mhlume's estates cover 4 800 hectares in Swaziland's Northern Lowveld. The main estate (4 000 ha) is part of the Nkomane Land System (Murdoch *et al*)[1] of Ecca sandstones and shales with dolerite intrustions. These have given rise to mainly Z, H, E, D and T set soils (which are the Sterkspruit, Katspruit, Kroonstad, Tambankulu and Westleigh forms of the binomial classification). The T and D sets, which are gravelly doleritic clays, constitute 34 % of the estate. The Z's, H's and E's have weakly structured or structureless shallow topsoils over saline/sodic clay subsoils, and make up 54 % of the estate. Pockets of cracking clays (K and C sets) also occur. The soils are a variable mosaic; homogeneous areas of any one soil type may be as small as 1 hectare, or as large as 60 hectares.

In 1959, a furrow irrigation system was superimposed on the area, with no regard for the distribution of the soils, nor for the physical and chemical problems that would arise from heavily irrigating the poorer soils. Average annual yields dropped from 84 tc ha^{-1} in the first 2 years, to 65 tc ha^{-1} in the early 1970's, largely due to waterlogging and the appearance of large saline and sodic areas. Up to 700 hectares were considered for abandonment. From 1971, the estate has been extensively drained, levelled, and the sodicity ameliorated with gypsum. Surface water management has also been improved. These measures have restored the mean annual yields to 76 tc ha^{-1} (Figure 1). If abandoned land is disregarded, the currently cultivated 3 400 hectares are yielding 86 tc ha^{-1} annually, about the same yield as was obtained from the virgin soils. Of the 350 hectares abandoned, 50 hectares have been brought back into production.

This paper describes some of the measures that have contributed to the increased yields, and considers how the soils must be further protected.

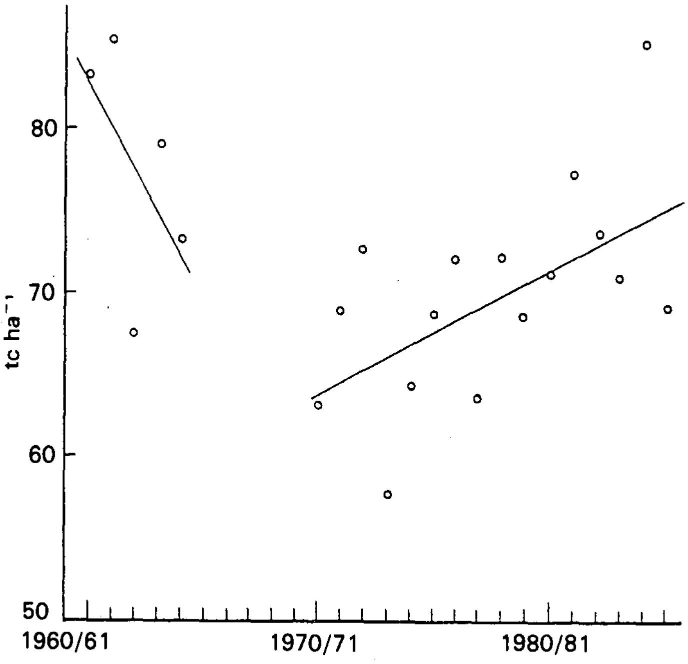

FIGURE 1 Annual yield per hectare of the main estate of Mhlume (Swaziland) Sugar Company, from 1960/61 to 1985/86 Yield records incomplete 1965–1969

Drainage

Criteria for Drainage

The first drains were open ditches, followed by *ad hoc* salt-glazed tile layouts. These were laid too far apart to have a significant effect. Because of the variability of the soils, calculation of exact drainage requirements was impossible. For a drain at a depth of 1,3 m in the poorer soils, there was no downward curvature of the water table until 5 m from the drain. Where the water-table was close to the surface, the initial drawdown was rapid, (through the upper, sandy, horizon), whereafter the drawdown exhibited a very slow logarithmic decline through the subsoil. A spacing of 40 m between drains was finally chosen; a compromise between what was needful, and what could be afforded. It would give scope for supplementary drainage later at 20 m or 10 m spacings. Areas to be drained were identified by observations of waterlogging and poor growth; by repeated salinity surveys at 3 depths on a 50 m grid; and by water-table measurements. No drains were installed if salinity was below 1 mSm^{-1} in the top 600 mm. Observations on the ground were enhanced by the use of aerial infra-red, and colour, photographs. The aims were to reduce salinity to below 2 mSm^{-1} in the top 600 mm, and to eliminate waterlogging.

Methods

Trenched smooth slotted PVC pipe was used at first. However, this method proved too slow for the 100 km of drain required annually in ploughout fields, so a Bruff TG3 trenchless drainlayer, using 50 mm flexible corrugated pipe, was imported. The Bruff is an adaptation of a 4-wheel drive Ford tractor, developing 87 kW. It pulls itself against a tractor-mounted anchor by means of a low speed hydraulic winch. At the rear of the Bruff, a hard-faced steel blade is pulled through the ground, opening a slot up to 1,3 m deep for the drain pipe. The drain can be back-filled with sand from a hopper above the blade. Traction developed is up to 3 700 Newtons and depth control power 9 700 Newtons. Accuracy of drain gradient is achieved with hydraulic pitch and depth settings operated by the driver in response to changes in sight lines. In addition to the Bruff and its anchor tractor, the drainage team consisted of two diggers/front end loaders, 4 drivers and 3 labourers. Up to 136 km of drains were laid annually, and to date, 1 100 km have been laid. Current costs are shown in Table 1.

Table 1

Current cost of drainage using 50 mm corrugated slotted PVC pipe

Pipe	R1,25/m
Laying by Bruff	R1,25/m
Bruff + sand back filling	R3,25/m
Trenching and handlay	R2,20/m

Cost/ha including manholes and collector drains (Rand):

Drain spacing (m)	Standard Bruff	Bruff + sand backfill	Trench + hand laying
40	900	1300	1100
20	1600	2500	2000
10	3000	4900	3700

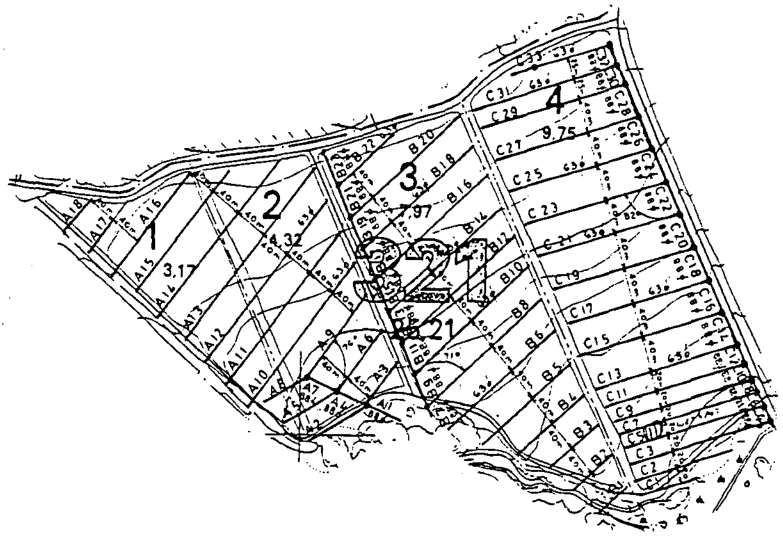

FIGURE 3 Map showing typical drainage layout of laterals, at 40 and 20 m spacing, flowing into collectors along field edges.

Drainage Design

The drains were laid across fields at a gradient of 1 : 100, flowing into 80 and 110 mm collectors along field edges. The relatively steep gradient was chosen to permit removal of water even where depth control had been poor. Cement block manholes were constructed where laterals and collectors joined.

A typical drainage design is shown in Figure 3. Sand was not often backfilled, because of the high cost of transporting it, except where there was a perched water-table.

Problems of Installation and Maintenance

The subsoil was occasionally so hard and abrasive that the Bruff blade could not penetrate it. At these points the drain was trenched and laid by hand. Underground rock intrusions were encountered; these were removed with explosives. Where the Bruff could easily move through the subsoil the slot was first opened without any pipe, to make the subsequent pipe laying as uniform as possible. The greatest problem was with blockages of drains by silt, trapped behind cane roots. The evidence of this would be a wet patch along the line of a drain, or a blocked manhole. A drain-cleaner was designed, in which a pulsating backward jet of water pulls a hose, from the manhole, along the drainpipe, flushing the whole length of the drain (Figure 4). One drain-cleaning team can clean 1 500 m of drain per day; 800 km are cleaned annually, with two machines, at a cost of 8 to 10 cents per metre.

Monitoring of Drains

Unfortunately there has been no long term monitoring of drain flow. Recent measurements from drains installed in Habelo series soils in 1975, (Figure 5), showed good removal of water after heavy rain, though the base level is extremely low, around 0,1 mm per day, or less. Some leaching must be taking place, (the conductivity of drainage water can be up to 10 mSm^{-1}, in contrast to the 0,18 mSm^{-1} of irrigation water), but at such low flow rates it must overall be negligible.

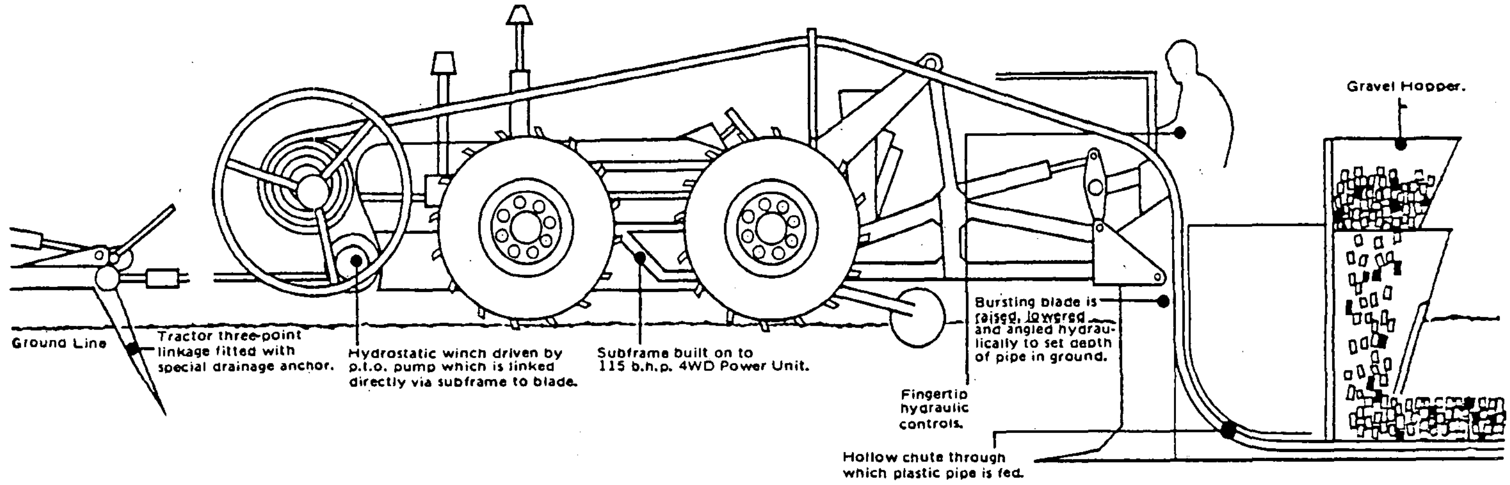

FIGURE 2 The Bruff TG3 Trenchless Drainlayer

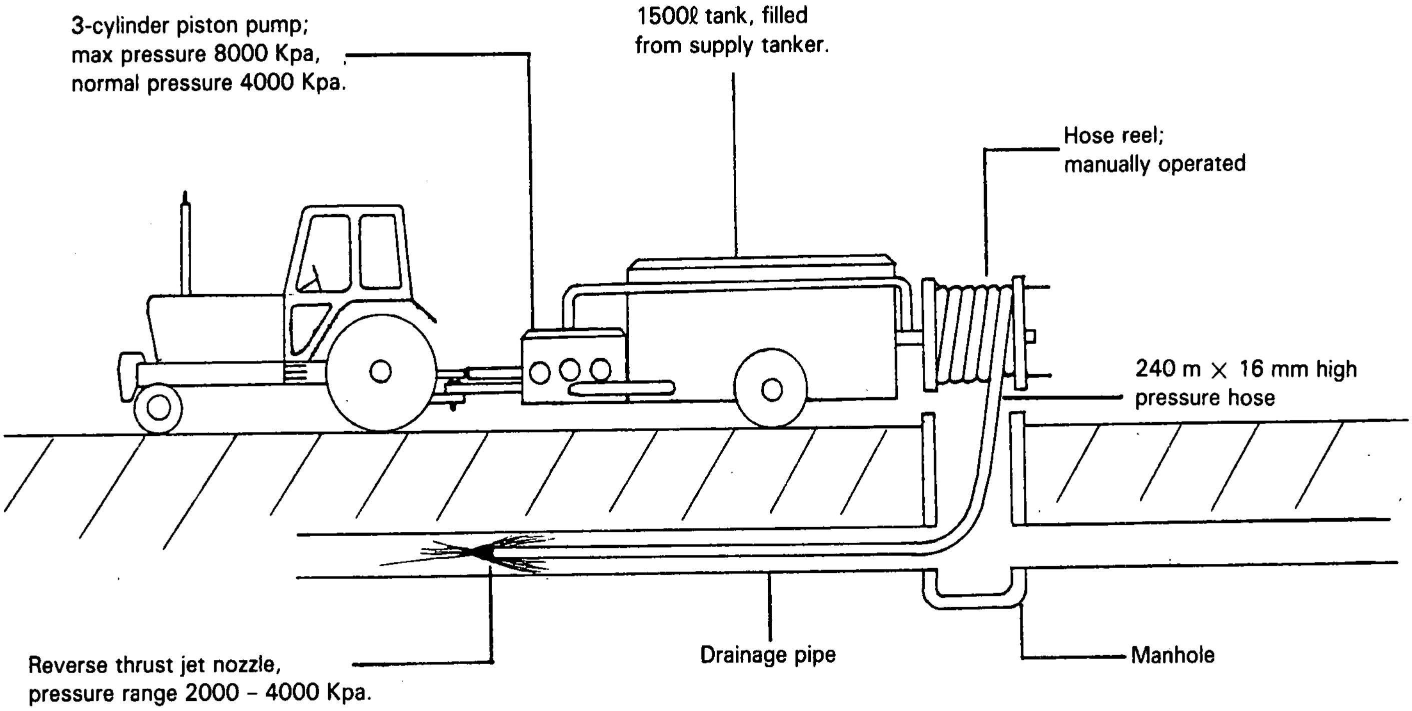

FIGURE 4 Detail of draincleaner

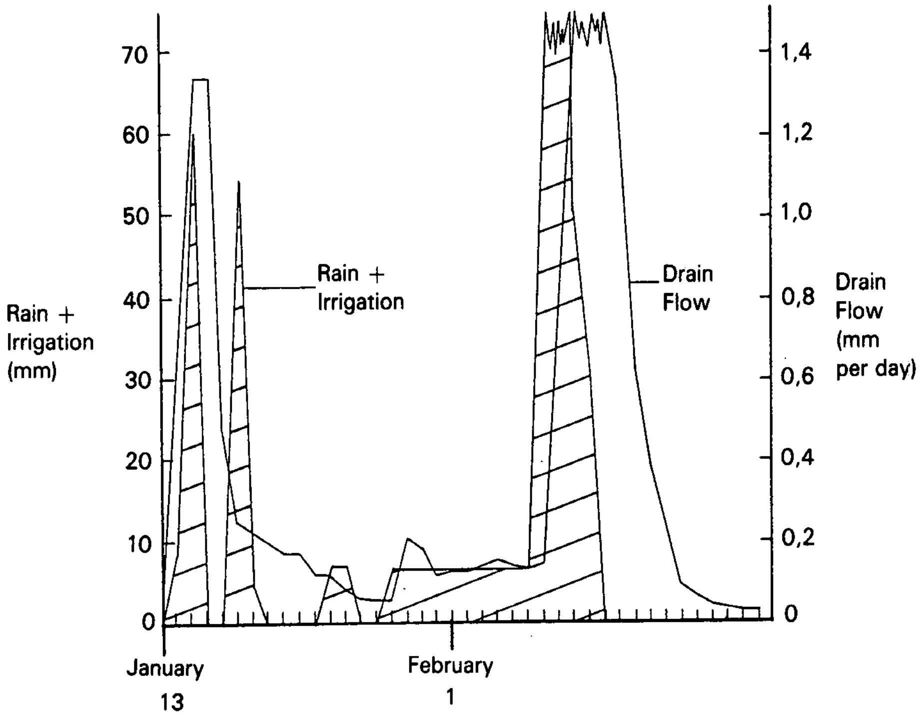

FIGURE 5 Rain plus irrigation water, and drainage from Mhlume's block 207/3, between 13 January and 20 February 1985. Trenchless drains were installed at 40 m spacing in 1975. Soils are mostly H set

Irrigation Water Management

Apart from the removal of termite mounds, Mhlume's fields were originally not levelled. Therefore steep furrows, at 1 : 100 or 1 : 150, were required to get the water from one side of a field to the other. There was much erosion, and variations in the gradients of furrows, plus impeded drainage, led to waterlogging of the topsoils. Land levelling was adopted in the early seventies using Gurries (70 foot) and Eversman (45 foot) land planes. Water was originally supplied, at the field edge, from earth or ashcrete canals, giving no control of application rate, so excessive amounts of water were applied. Control was made possible by the building of sand/cement step canals giving a constant head of water through siphons or spiles. Subsequent trials have showed that siphons should deliver no more than 3.5 ℓ sec^{-1}, to avoid erosion in the furrow, and the longer the furrow, the better the wetting. A shallower gradient of 1 : 250 has been adopted, also to give better wetting. (Lesser gradients lead to local ponding where soils collapse from being too weakly structured).

Unfortunately, these measures cannot increase the amount of water held by the poorer soils, nor its movement through the soil, away from the irrigation furrow. Total available moisture (T.A.M.) of these soils may be as low as 30 mm, and may vary considerably within a field. In the summer, irrigation cycles must be as short as 4 to 5 days. Cane is planted in the centre of an M-shaped furrow to allow in-row irrigation for the plant-crop, as well as deeper rooting and improved drainage. However, because of a commitment to mechanical harvesting, ratoon cane is ridged up, and has to be irrigated in the interrow, from where the water hardly moves into the cane row. In-row irrigation, with hand harvesting, is currently being considered for selected areas.

Gypsum

The problem of sodicity was first detected in 1972. It occurs where poor drainage causes the accumulation of sodium-rich salts, particularly in flat, poorly drained areas, and at the bottoms of slopes. Soil samples from the salinity surveys were bulked for determination of Exchangeable Sodium Percentage (ESP), and sufficient gypsum applied to displace the excess sodium in the 0 to 600 mm horizon. Either 3,5 or 10 tons per hectare are spread with a Breadall gypsum applicator, and then incorporated to 200 mm. The effectiveness of this treatment, in combination with drainage, has been shown by Swinford *et al.*[2] About 2 000 t of gypsum have been used annually since 1975. There is no sign of this requirement diminishing, presumably because surface drainage is still relatively poor. The gypsum costs about R60-00 per ton applied, of which haulage to the field edge accounts for R40-00. Gypsum requirement is now monitored on a point by point basis on a 50 m grid, for the 0 to 300, 300 to 600, and 600 to 1 000 mm horizons. This permits trends in sodicity to be followed, and makes the use of gypsum more efficient, by pinpointing where it is required within a field.

Discussion

The increase in cane yields from 1971 cannot be attributed solely to drainage, water control and gypsum, since a number of other improvements have also been made. Smut and RSD infections contributed to the yield decline during the 1960's and were subsequently reduced by changing to NCo 376 with hot water treatment. Weed control has been improved by the use of herbicides, and the mean age of cane at cutting has been reduced from 14 to 12 months. Nevertheless, the qualitative effects of the soil and water measures are clear. Only half of the land considered for abandoning was actually abandoned, and of the abandoned area, 50 hectares have been reclaimed. Surface waterlogging is no longer a widespread problem; brak areas are not increasing in size, and erosion due to irrigation has been reduced.

However, for Mhlume to refine its amelioration policies, it is necessary to know how the ameliorative practices are working. The increase in yields, estate-wide, may be masking continued degradation of some soils. Therefore, the histories of four fairly homogeneous cane blocks on H and Z set soils have been investigated, and are contrasted with two blocks on T and D set soils (Table 2 and Figure 6).

The yields from the T set block, 343, rose markedly after drainage in 1976, but, in this case, the early tile drains had been damaged, and were causing waterlogging. The yields from block 212, a better field, have remained consistent. Of the poorer blocks, yields from 333 have improved by 13 %. Yields from 401 have deteriorated slightly, and though the total tonnage taken from 409 increased 6 % between 1975–1978 and 1980–1983, yields per unit of cultivated land declined, because 7,8 hectares were reclaimed for the second cycle. The salinity distributions for successive surveys (Figure 6) show no leaching of salts from any profile in any of these blocks. Rather, salinity in 401 increased between 1976 and 1984. This block was not levelled until 1979 when the

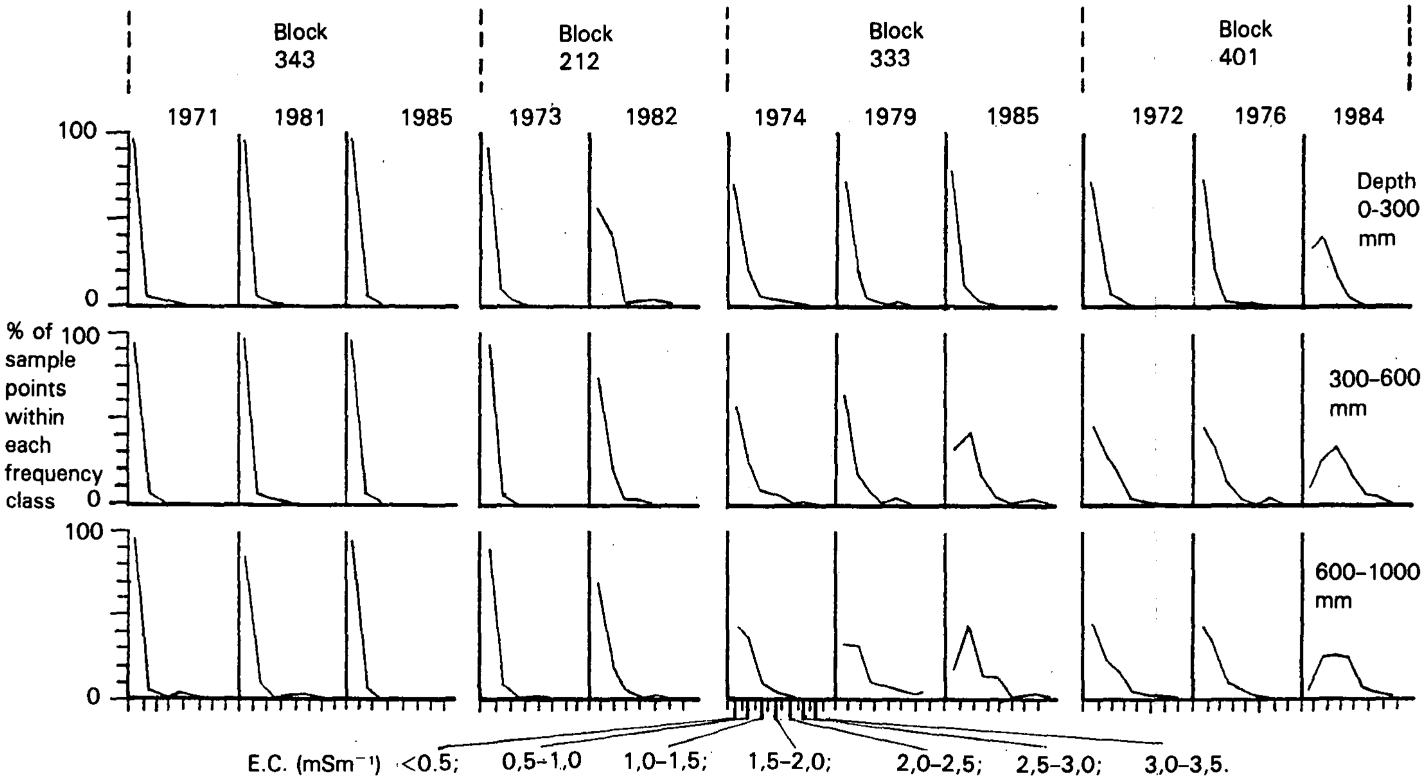

FIGURE 6 Frequency distributions of salinity sampled in 4 cane blocks, at 3 depths, in various years

Table 2

Summary histories of six relatively homogeneous blocks of cane on the main estate of Mhlume Sugar Company

Block	Soil/Area		1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
343	T & D sets 70%	Cycle and variety				P NCo 376	R1	R2	R3		P N52/219	R1	R2	R3	R4	P NCo 376	R1	R2	R3
		Tons cane				3066	3802	4121	4097		4121	4658	3976	4605	4218	4582	3671	5707	4288
		tc ha^{-1}				74.1	91.8	99.5	99.0		99.5	112.5	96.0	111.2	101.9	110.7	88.7	137.9	103.6
		Average tc ha^{-1} mth^{-1}				7.1					8.7					8.8			
	41.4 ha	Drainage, Gypsum etc.			S					D (4.7)					S				S
212	T & D sets 100%	Cycle and variety	R3 NCo 376	R4	R5	R6	R7	R8		P NCo 376	R1	R2	R3	R4	R5	R6	R7	P N14 Nursery N/A	R1
		Tons cane	3071	2484	3697	2127	2343	2160		3784	3182	3373	2978	2850	3237	2620	2471		2408
		tc ha^{-1}	119.5	96.7	143.8	82.8	91.2	84.0		147.2	123.8	131.2	115.9	110.9	126.0	101.9	96.1		93.7
		Average tc ha^{-1} mth^{-1}	9.8										9.2						
	25.7 ha	Drainage, Gypsum etc.					S		D (3.9)							S			
333	Z, H & E sets 95%	Cycle and variety	Key: S Salinity survey D Drainage (km) SD Supplementary drainage G Gypsum (tonnes) F Filtercake (150 t/ha) M Green manure							P NCo 376	R1	R2	R3		P NCo 376	R1	R2	R3	NCo 376 Nursery N/A
		Tons cane								2407	2300	2590	1837		3773	2566	2498	2299	
		tc ha^{-1}								76.2	72.8	82.0	58.1		119.4	81.2	79.1	72.8	
		Average tc ha^{-1} mth^{-1}								6.1					6.9				
	31.6 ha	Drainage, Gypsum etc.											S	D (11.0) G (150)				S G (86)	
401	Z & H sets 100%	Cycle and variety		P NCo 334	R1	R2	R3		P NCo 376	R1	R2	R3		P NCo 376	R1	R2	R3	R4	P N14
		Tons cane		3996	4856	2657	3180		6526	5574	4680	4810		6288	5814	4167	3636	3787	3348
		tc ha^{-1}		69.1	84.0	46.0	55.0		112.9	96.4	81.0	83.2		108.8	100.6	72.1	62.9	65.5	57.9
		Average tc ha^{-1} mth^{-1}		5.3					7.5					7.0					
	57.8 ha	Drainage, Gypsum etc.				S				S			D (12.7) G (348)					S G, D	
409	Z & H sets 95%	Cycle and variety					1974: 18.7 ha abandoned		P 376/334	R1	R2	R3		P NCo 376	R1	R2	R3	P NCo 376	R1
		Ha growing cane							41.0	41.0	41.0	41.0		48.8	48.8	48.8	48.8	53.0	53.0
		Tons cane							4867	4343	3230	3691		5588	4511	3924	3132	4050	3009
		tc ha^{-1}							118.7	105.9	78.8	70.0		114.5	92.4	80.4	64.2	76.4	56.8
		Average tc ha^{-1} mth^{1} over original area							5.4					5.7					
	59.7 ha	Drainage, Gypsum etc.				S				S			D (9.8) G (205)				S	D (3.6) G (200)	
206	Z, H & E sets	Cycle and variety						Attempted leaching under rice failed because of inadequate drainage.				P NCo 376	R1	R2		P NCo 376	R1	R2	R3
		Tons cane										5904	4376	3252		7026	5441	5225	4152
		tc ha^{-1}										116.2	86.1	64.0		138.3	107.1	102.8	81.7
		Average tc ha^{-1} mth^{-1}										7.0				9.4			
	50.8 ha	Drainage, Gypsum etc.									D (16.0) G (365)				S, F, M, G				

Data for early years is omitted either because cane was "carried over", or because records are incomplete. Calculation of tc ha^{-1} mth^{-1} assumes the average age of ratoon cane was 12 months, but allows for an older plant crop where appropriate. The first cycles of blocks 212, 333 and 401 were late cut, so their average tc ha^{-1} mth^{-1} have been corrected to the early season equivalent, appropriate to their soil type.

thin topsoil was moved to fill up the hollows. Thus the subsoils were nearer to the surface, and they were then ripped to create some "tilth". Now 10% of the 300 to 600 mm horizon has salinity greater than 2 mSm^{-1}.

If salt is not being leached in these poor fields, and the subsoils are not being drained (Figure 5), it is likely that the main benefit of drainage has been to reduce waterlogging in the topsoil. Rain and irrigation water are removed presumably by flowing across the top of the heavy subsoil, and then down the drain slot. Thus blocks having a greater depth of topsoil show a response to drainage (e g 333), while blocks with little topsoil show no response (e g 409). Leaching of the subsoil does not generally seem possible, though it may take place where the subsoils have more structure, for example in the Zwide series. Such soils would benefit from supplementary drainage, while no more is required in soils with structureless clay subsoils, provided surface drainage is sufficient.

In contrast to the other blocks with poor soil, the yields from block 206 increased by 34% between the 1978–1980 and 1982–1984 crop cycles, with the latter continuing for an additional two ratoons (Table 2). This block received 150 t filtercake per hectare, as well as a summer crop of sunnhemp (*Crotalaria juncea*) during the 1981 fallow. Putting more organic matter into the topsoils appears to be the major requirement for improvement of the soils, at least for fields that cannot be further improved by drainage. Field observations substantiate this; where cane is planted in areas that were previously loading zones, or in a headland alongside a step canal, where weeds have grown for many seasons, yields are perhaps 40% greater than in the adjacent field. Topsoils must have been degraded by the 25 years of cane monoculture, and most probably in all the weak soils, not only in those where drainage has had little effect. This is borne out in Figure 7. For all the poorer soils, i e soils which cannot be taken beyond a fourth ratoon, the average rate of ratoon yield decline has increased considerably between the mid-1970's and early 1980's. Yields have improved in plant and first ratoon crops, (through the better surface drainage), but then they collapse faster, confirming that these poorer soils are indeed in a worse condition than previously, in spite of the overall improvement in yields. The solution must be a system of rotation, with ameliorative crops such as sunnhemp. If three crops of sunnhemp in a fallow year could increase subsequent cane yields by 25%, then it might be possible to maintain Mhlume's cane production at its present level, (assuming a plant crop and three ratoons). If a rotation system is not adopted, it appears that the weaker areas will be lost to crop production altogether.

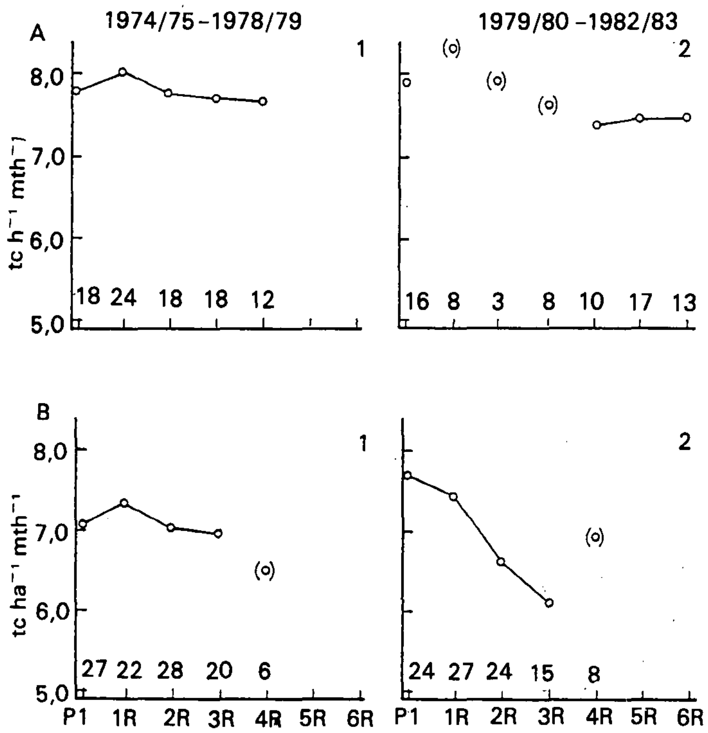

FIGURE 7 Mean yields (tc ha^{-1} mth^{-1}) by crop cycle of
A: Cane blocks on soils which allow 6 ratoons or more
B: Cane blocks on soils which allow no more than 4 ratoons, in
1: the late 1970's, and
2: the early 1980's
The numbers along the x axes show how many blocks have been used to calculate each mean yield. Points in brackets may be unreliable as few blocks of cane contributed to the calculated means.

Minimum tillage, using Roundup, is not a solution, because, by the third ratoon, soils are already so degraded that it is impossible to plant cane in them.

Improvements might also take place if sprinkler or drip irrigation were adopted. They would do less physical damage to the soils than the heavy wetting of furrow irrigation, and would circumvent the problem of low and variable moisture holding capacity of the soils. Sprinkler irrigation was tried in the 1960's, but it showed no benefit over furrow irrigation, perhaps because surface water drainage was limiting. Drip irrigation would be expected to be most beneficial as there is no impact of droplets on the soil surface. Neither of these methods, however, will reverse the degraded structure of the soils. A current trial in which drip irrigation is compared with furrow irrigation, shows a 25% growth increment under drip in the first ratoon, while there has been no response, in a similar trial, under sprinklers. Perhaps the water regime under sprinklers is ineffective because the degraded structure of the soil, rather than water availability, is already the limiting factor for cane growth.

Conclusion

The amelioration of Mhlume's poor H, Z, and E set soils has occurred largely through reduced waterlogging of the topsoil. Reclamation of the subsoils will be impossible except, perhaps, where they have some structure. The improved water conditions in the surface 300 mm of soil have permitted higher plant and first ratoon yields on the poor soils, but the soils continue to be degraded, so that a high and regular input of organic matter is required to prevent their total loss.

Acknowledgements

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