A REVIEW OF THE EFFECTIVENESS OF GYPSUM, FILTERCAKE AND DEEP PLOUGHING FOR AMELIORATING IRRIGATED DUPLEX SOILS IN SWAZILAND

PC HENRY AND W RHEBERGEN

Inyoni Yami Swaziland Irrigation Scheme, Tshaneni, Swaziland

Abstract

At Inyoni Yami Swaziland Irrigation Scheme (IYSIS) duplex soils dominate Ricelands estate. When the estate was redeveloped in the late 1970s, the conversion from rice to sugarcane was accompanied by the adoption of ameliorative practices, including surface and subsurface drainage and the incorporation of gypsum into the topsoil. More recently, high rates of filtercake were incorporated when replanting. Data were collected from field trials on the effectiveness of gypsum and filtercake in improving soil properties and yields of sugarcane. The results showed that commercial rates of gypsum (5 or 10 t/ha) were beneficial only when excess sodium occurred in the topsoil. Filtercake improved yields by reducing sodicity (sodic soils) as well as improving water holding capacity and structural stability (sodic and non-sodic soils). Root studies showed that effective rooting depth associated with gypsum and filtercake remained shallow, indicating that these treatments were ineffective in dealing with subsoil limitations. Gypsum at higher rates than used commercially, although improving subsoil sodicity, failed to improve yields, thus demonstrating that excess sodium is not the only unfavourable factor in the subsoil. By contrast, good yield responses to deep ploughing were obtained in recent trials, suggesting that in the duplex soils loosening the hard consistency of the subsoil is at least as important as reducing sodicity.

Introduction

Ricelands estate, with 2 300 ha of irrigated sugarcane, accounts for more than half the sucrose production of Inyoni Yami Swaziland Irrigation Scheme (IYSIS) in the northern lowveld of Swaziland. The soils, which are predominantly duplex in nature, were mostly planted to rice during the first 21 years of the project's existence (1956-1977). Generally they are the saline/sodic, grey, structureless, sandstone-derived H and Z set soils (Murdoch, 1972), which approximate to the Katspruit and Estcourt forms respectively of the South African taxonomic system of soil classification (Anon., 1991). They consist of a sandy loam or sandy clay loam topsoil, overlying a poorly draining sandy clay subsoil.

Duplex soils are notorious for their limitations, including salinity/sodicity hazards (Johnston, 1977), crusting and poor infiltration rate (Dewey and Meyer, 1989; Ndlovu, 1993), high soil strength and mechanical impedance to root growth (Dracup *et al.*, 1992), low total available moisture content (Johnston, 1973) and slow internal drainage, waterlogging and poor aeration at depth (McFarlane and Cox, 1992). Hardsetting behaviour (Mullins *et al.*, 1990) is commonly diplayed by these soils, as is often the case in soils which are low in organic matter and sesquioxides and high in dispersive clay. Upon drying, duplex soils tend to become hard, structureless and difficult to cultivate, whereas irrigation or rainfall leads to slumping.

In the mid-1960s, the yield of rice began to decline because of uncontrollable weeds and chemical and physical deterioration of the soil. At higher elevations, the irrigation of rice with good quality water together with lateral seepage resulted in a decrease of the electrolyte concentration of the soil solution while sodium, an inherent constituent of the duplex soils, accumulated to a greater extent than calcium or magnesium. The development of sodicity led to clay swelling and dispersion, contributing to the degradation in both top and subsoil of an inherently weak structure. Along natural drainage lines and in flat areas, the accumulation of salts induced the development of saline/sodic conditions, resulting in the abandonment of arable lands in the low lying areas as early as 1962. In the mid-1970s, alternative crops were investigated in exploratory trials, and it became apparent that sugarcane was the most attractive substitute for rice. It was further apparent that the successful conversion of Ricelands to sugarcane production depended on the soil deterioration processes being checked and, in the most seriously affected areas, reversed.

When the results of permeability experiments and drainage trials showed that the duplex soils responded to gypsum and were drainable, the redevelopment of the estate was undertaken. Attention was paid to both surface and subsurface drainage and the gypsum amelioration policy was expanded to include the application of filtercake at plough-out, after the benefits of organic matter (inherently low in duplex soils) was recognised (Workman *et al.*, 1986). In addition, deep ploughing as a soil amelioration practice was investigated after the benefits of deep ploughing of sodic soils (Rasmussen *et al.*, 1972; McAndrew and Malhi, 1990) and the successes obtained from vertical mulching of duplex soils (Jayawardane and Blackwell, 1986; Meyer *et al.*, 1992) were noted.

In this paper, the results of gypsum, filtercake and deep ploughing trials are presented and the effectiveness of the ameliorative practices adopted at IYSIS are evaluated.

Materials and Methods

Data were collected from replicated trials, which are referred to by the code of the commercial blocks (fields) in which they were established (Table 1). Two contrasting periods are covered. Two trials (S9-9 and S2-1) were established in the early 1980s. Soil conditions essentially reflected those found at the end of the rice period. The other trials were initiated in the period 1989-91, a decade after the estate redevelopment had been completed. Soil conditions then reflected the effects of drainage and gypsum application. The topographical positions of the blocks used for the trials span the range found at Ricelands (Table 1). All the blocks where trials were located are drained by networks of parallel subsurface interceptor drains (1,2 to 1,5 m deep) with various spacing distances (Table 1).

Table 1

Details of experiment sites, treatments and trial designs

Pre-trial history						Trial dates			
Trial code location	Rice cultivation	Topographical feature	First drainage installation (spacing)	Gypsum application (5-10 t/ha)	Sugarcane cycles (PI = planting date, R = Ratoon at plough-out date)	Trial subject	Dates Start	End	No of crops
S9-9	P	Low-lying	1980 (20 m)	None	None	Gyp rate	Apr 81	May 88	Pl + R1-6
S2-1	U	Gentle slope	1976 (40-120 m)	None	1976 (PI)-1982 (R5)	Gyp rate	May 83	Jul 88	Pl + R1-4
S6-23	P	Flat	1976 (20 m)	1977, 1985	1979 (PI)-1985 (R5) 1985 (PI)-1989 (R3)	Gyp rate	Sept 89		Pl + R1-3
S2-6	U	Gentle slope	1977 (40 m)	1983	1977 (Pl)-1982 (R4) 1983 (Pl)-1991 (R7)	FC rate	Jul 91		Pl + Rl
S6-25	P	Flat	1975 (20 m)	1975, 1985	1979 (Pl)-1985 (R5) 1985 (Pl)-1989 (R3)	Gyp + FC	Sept 89		Pl + R1-3
S3-1	U	Gentle slope	1978 (20-40 m)	1978, 1984	1978 (Pl)-1983 (R4) 1984 (Pl)-1990 (R5)	Gyp + FC/Incp	Sept 90		Pl + R1-2
S6-9	P	Flat	1978 (20 m)	1979, 1986, 1991	1979 (Pl)-1986 (R6) 1986 (Pl)-1991 (R4)	Deep plough	March 92		Pl

Gyp = gypsum, FC = filtercake, Incp = incorporation
U = upland rice, P = paddy rice

Table 2

Mean salinity and sodicity levels in amelioration trials prior to the application of treatments

Trial subject	Gypsum						FC		Gypsum + FC		Gypsum + FC/Incp		Deep ploughing			
Trial code	S9-9 (1981)		S2-1 (1983)		S6-23 (1989)		S2-6 (1990)		S6-25 (1989)		S3-1 (1990)		S6-9 (1991) Good area		Poor area	
Parameter tested	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR	EC	SAR
Depth (cm)																
0-30	3,81	15,0	0,70	5,0	0,61	3,4	0,32	2,0	0,91	5,2	0,63	2,8	0,40	2,2	0,72	4,8
30-60	6,93	22,8	0,94	7,9	0,95	5,9	0,45	3,6	1,49	9,8	0,85	5,2	0,86	4,9	1,35	9,9
60-90	8,28	25,8	1,14	10,7	1,05	7,8			1,57	10,5	0,97	7,2	0,71	4,9	0,95	8,4

EC = electrical conductivity (mS/cm) SAR = sodium adsorption ration

Gypsum trials (S9-9, S2-1, S6-23)

Salinity and sodicity in the trial areas before the application of the treatments are summarised in Table 2. Examination of the data shows that the trials allowed the effect of gypsum on soil properties and yield to be evaluated under three different sets of initial conditions, namely whole profile saline/sodic (S9-9), whole profile non-saline/topsoil marginally sodic/subsoil sodic (S2-1, S6-25) and whole profile non-saline/topsoil non-sodic/subsoil sodic (S6-23). The salinity/sodicity status of the soil profile in block S9-9 was typical of the conditions which had developed under rice paddies in low lying areas.

Although one sugarcane cropping cycle had been completed before the trial started, the initial salinity/sodicity status of the soil in block S2-1 was typical of that encountered in upland fields at the end of the rice period. This is because the first salinity/sodicity survey was limited to the topsoil and the results suggested the soil to be non-saline and non-sodic. Hence drains were laid wide apart and gypsum application was omitted from the amelioration programme of the first crop cycle. The salinity/sodicity status of block S6-23 in 1989, before the trial, is typical of that revealed by recent pre-replant commercial surveys of poor draining areas, and broadly summarises the soil status on the estate.

Despite reference to the ameliorant as gypsum in this paper, the product used is phosphogypsum and typically consists of $CaSO_4$ (72%), H_2O (23%), P_2O_5 (2,5%) and trace elements (2,5%). This distinction is important because the solubility of phosphogypsum has been shown to be higher than mined gypsum (Frenkel and Fey, 1989). In all the trials, gypsum was incorporated by ripping to a depth of 25-30 cm followed by discing.

Filtercake trial (S2-6)

Trial S2-6 was aimed at determining the optimum level of filtercake for plant cane, as well as its residual value for subsequent ratoons. The soil was non-saline with a tendency for sodicity to occur in the subsoil (Table 2). In the 1991 replant, gypsum was purposely omitted from the trial area.

Filtercake was applied after the completion of land levelling, spread manually with rakes and incorporated to a depth of 30 cm by ripping and discing. Varying rates of inorganic fertiliser were applied in an attempt to bring the status of phosphorus and potassium in all plots to a standard level.

Gypsum/filtercake trials (S6-25, S3-1)

In 1991 a gypsum/filtercake trial was initiated in block S6-25 to test whether there was any merit in combining filtercake and gypsum. Despite application of gypsum in 1975 and 1985, sodicity in S6-25 before the trial remained marginal in the topsoil and was a problem in the subsoil (Table 2). Filtercake was applied at a rate of 250 t/ha followed by gypsum at the rate of 20 t/ha. Incorporation of the ameliorants was by the standard practice of ripping and discing. In the trial in block S3-1, the standard practice of incorporating filtercake and gypsum was compared with ploughing in the ameliorants to a depth of approximately 40 cm with a mouldboard plough. Although Meyer *et al.* (1992) showed that sucrose yield in duplex soils could be improved by slotting filtercake in the upper subsoil with an alubuster, it was considered important to test whether similar responses could be obtained using more conventional methods of incorporation. The rates of filtercake and gypsum were 150 t/ha and 5 t/ha respectively.

Deep ploughing trial (S6-9)

The objective was to establish the value of inverting the soil profile in areas of poor cane growth. Inversion to a depth of 1 m was achieved by excavating the soil with a mechanical digger and refilling with the topsoil first. Gypsum at the rate of 10 t/ha was applied to the whole trial area and incorporated by standard practice after the inversion of the soil profile.

Determination of soil properties

Electrical conductivity (EC) and sodium adsorption ratio (SAR) values were determined to depth. The EC threshold value for sugarcane is 2 mS/cm, while for duplex soils hydraulic conductivity is affected when SAR exceeds a value of 6 (Johnston, 1975).

Soil bulk density was determined on undisturbed soil cores taken 24 hours after irrigation to ensure comparable moisture status (field capacity) in all plots. This step was taken as a precautionary measure as in swelling clay soils, bulk density depends on the soil moisture content (Fox, 1964). Infiltration rate measurements were carried out in two trials (S2-6 and S6-23). Soil moisture content at two depths was determined gravimetrically in trial S6-25, 24 h before and after irrigation.

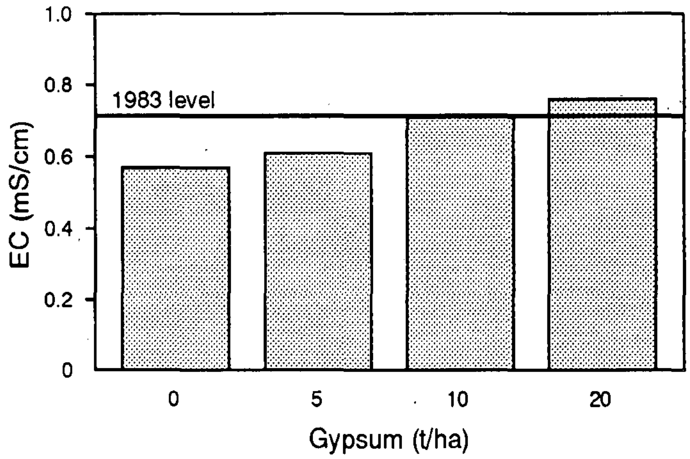
Results

General

Examination of the data in Table 2, which spans a decade of the soil amelioration programme, allows some broad generalisations regarding its effectiveness. Block S6-23 and S6-25, with their almost flat topography were under paddy rice. The salinity/sodicity status of these blocks at the end of the rice period was similar to that of block S9-9 which is also located in an area of poor drainage. A comparison of the data of block S9-9 to those collected in S6-23 and S6-25 in 1989 shows that subsurface drainage brought salinity under control. Sodicity although reduced in intensity still remained a problem in the subsoil ten years after the inception of reclamation. On gentle slopes the salinity/sodicity status of blocks S2-6 and S3-1 at the end of the rice period was similar to that of block S2-1. The data collected in 1990 show that sodicity in blocks S2-6 and S3-1 had improved in the topsoil but remained a problem in the subsoil.

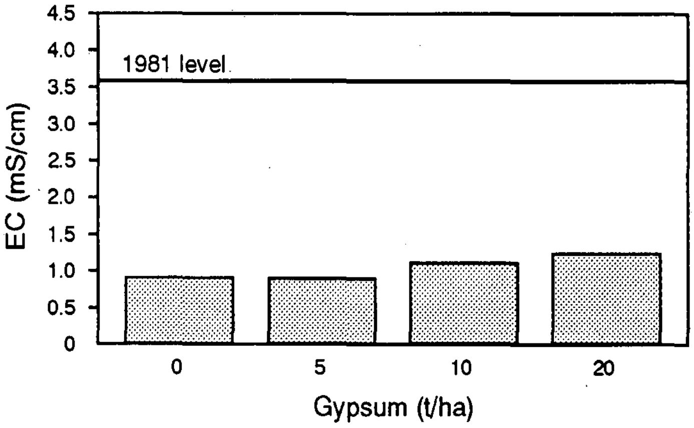
Effect of treatments on salinity

The application of gypsum to non-saline soils with a subsurface drainage history (S2-1, S6-23, S6-25) increased salinity (Figure 1). In trial S9-9 (a saline soil without previous drainage history), salinity decreased swiftly within the first year of drainage despite the application of gypsum. The decrease in salinity, however, was slightly more pronounced in the control than in the gypsum-treated plots (Figure 2).



Sampling period used for computing mean = 1986-88

FIGURE 1 Effect of gypsum application to non-saline soil (Trial S2-1).



Sampling period used for computing mean = 1986-88

FIGURE 2 Effect of gypsum application to saline soil (Trial S9-9).

Effect of treatments on sodicity

SAR values in Table 3 (after the treatments) are lower than in Table 2 (before the treatments), including those in the control plots (drainage only). The data from trial S9-9 confirm that drainage alone removed appreciable amounts of sodium, but that it was not as effective as the combination of drainage and gypsum and/or filtercake.

The extent of reclamation and the depth reclaimed increased with the rate of gypsum. At Ricelands, as was shown earlier, sodicity problems are no longer often found in the topsoil. One consequence of this improvement is that the computed gypsum requirement for reclaiming the subsoil now rarely exceeds 5 t/ha. However, the data of trial S2-1 (Table 3)

Table 3

Post Treatment mean SAR value

Trial subject	Gypsum								Gypsum + FC			Gypsum + FC/Incp				Deep ploughing (DP)		
Trial code	S9-9 (1986-1988)			S2-1 (1985-1988)		S6-23 (1991-1993)			S6-25 (1993)			S3-1 (1993)				S6-9 (1992)		
Depth (cm)	0-30	30-60	60-90	0-30	30-60	0-30	30-60	60-90		0-30	30-60		0-30	30-60	60-90		0-30	30-60
Treatment	SAR	SAR	SAR	SAR	SAR	SAR	SAR	SAR		SAR	SAR		SAR	SAR	SAR		SAR	SAR
0 t/ha Gyp	6,9	10,9	11,3	4,4	8,4	2,8	4,2	5,7	Go FCo	4,2	7,0	Std	2,2	4,4	6,6	Good area	2,1	3,4
5 t/ha Gyp	6,5	11,2	12,2	4,3	8,6				Go FCl	1,9	5,1	Plough	1,3	2,7	4,6	Poor area	3,9	5,9
10 t/ha Gyp	6.4	10,9	12,3	3,4	7,8	2,5	4,5	5,9	Gl FCo	1,4	4,1					Poor area + DP	6,2	6,1
20 t/ha Gyp	5.7	9,7	9,7	3,0	6,3	1,5	3,1	4,6	Gl FCl	1,2	4,1							
30 t/ha Gyp						1,6	3,2	4,9										

show that gypsum at a rate of 5 t/ha was ineffective in lowering subsoil sodicity, which brings the relevance of the current commercial practice into question.

From the data of trial S6-25 (Table 3), it is apparent that filtercake alone was less effective than the high rate of gypsum in reclaiming sodicity, especially in the subsoil. The combination of filtercake and gypsum, however, tended to be better than gypsum alone suggesting that the effects of the treatments was additive.

Deep ploughing, by inverting the profile, brings subsoil salts to the surface. Although six months after the operation, SAR in the topsoil of trial S6-9 was higher than in the control, the results of trial S3-1 suggest that in the longer term deep ploughing reduces sodicity. In trial S6-9, the increase in SAR following deep ploughing was not a problem, because the level remained below the adjusted critical threshold following concurrent rise in salinity.

Effect of treatments on soil physical properties

These are summarised in Table 4. It can be seen that gypsum had no apparent effect on soil bulk density, whereas filtercake significantly lowered bulk density in the topsoil, and deep ploughing benefited the whole profile. Soil bulk densities of the levels found at Ricelands are expected to be associated with mechanical root growth and low porosity and are likely to be yield-limiting. Any improvement in this factor, even slight, is therefore expected to improve yield.

Final infiltration rate (FIR) was improved by filtercake but not by gypsum. There was a considerable difference between FIR in the control of the gypsum experiment and that of the filtercake trial. Factors accounting for this difference include differences in site (S2-6 versus S6-23), method of infiltration determination (double rings versus ponding) and location of measurements (furrow versus ridge).

Gravimetric moisture determination showed that water content after irrigation was higher where filtercake was applied, suggesting that filtercake improved the soil water holding capacity. The difference between water content before and after irrigation was greater in the filtercake plots, suggesting that cane water use was increased by the application of filtercake. Water content also appeared to be less depleted before irrigation, indicating that cane growing where filtercake was applied had a larger reserve of water. The onset of water stress in sugarcane is likely to occur later in the filtercake treatments than in the gypsum or control plots.

Effect of treatments on yield

In the gypsum trials sucrose yield tended to reflect cane yield and therefore only results of the latter are presented. In the first two trials (S9-9 and S2-1) growth was highly variable, and no significant differences in cane yield between treatments were ever detected. In the other two trials (S6-23 and S6-25) variability was less of a problem, but differences in yield were also statistically non-significant.

Cane yields for these trials are shown in Table 5. Although not statistically significant, it can be seen that yield tended

Table 4

Effect of treatments on some selected soil physical properties

Bulk density g/cc

Trial code	S6-25 (1994)				S6-9 (1994)		
Depth (cm)	Control	FC	Gyp	Gyp + FC	Good	Poor	Poor + DP
15-30	1,81	1,69	1,81	1,74	1,70	1,71	1,65
35-40	1,76	1,73	1,77	1,76			
45-50					1,65	1,76	1,52
Significance							
Treatment	**				*		
Depth	NS				NS		
LSD 0,05	0,058				0.16		
0,01	0,077				0.22		

Final infiltration rate mm/h

Trial Code	S6-23 (1993)		S2-6 (1992)	
Treatment	Control	30 t/ha Gyp	Control	200 t/ha FC
Range	10,3-12,1	8,7-10,4	8,1-38,5	19,2-43,4
Mean	11,0	9,2	22,5	29,8
Significance	NS		*	
LSD 0,05	2,0		6,2	
0,01	3,4		8,8	

Gravimetric moisture content (% w/w) in trial S6-25

Treatment	Control		FC		Gyp		Gyp + FC	
Depth (cm)	AF	BF	AF	BF	AF	BF	AF	BF
0-25	13,5	11,6	17,1	12,9	12,8	11,3	16,6	11,9
35-60	14,7	11,8	17,6	13,0	15,4	11,8	16,6	14,3
Significance								
Gypsum	NS							
FC	**							
Inter Gyp × FC	NS							
Timing (Af-BF)	**							
Depth	NS							
LSD 0,05	1,51							
0,01	1,99							

AF = After irrigation, BF = before irrigation

Table 5

Effect of treatments on cane and sucrose yield (values are mean over the crop cycle)

Trial subject	Gypsum			FC		Gyp + FC		Gyp + FC/Incp		Deep ploughing	
Trial code	S9-9	S2-1	S6-23	S2-6		S6-25		S3-1		S6-9	
Crops	Pl + R1-6	Pl + R1-4	Pl + R1-3		Pl + R1		Pl + R1-3		Pl + R1-2		Pl
Treatment	tc/ha	tc/ha	tc/ha		ts/ha		ts/ha		tc/ha		ts/ha
0 t/ha Gyp	73,0	136,7	85,0	0 t/ha FC	14,03	Control	14,26	Std	98,8	Good	25,06
5 t/ha Gyp	75,9	122,9		50 t/ha FC	13,86	FC	16,61	Plough	113,5	Poor	21,26
10 t/ha Gyp	77,9	145,0	75,6	100 t/ha FC	14,63	Gyp	15,38			Poor + DP	23,17
20 t/ha Gyp	86,1	160,1	83,2	150 t/ha FC	16,29	Gyp + FC	17,27				
30 t/ha Gyp			81,7	200 t/ha FC	15,56						
				250 t/ha FC	14,90						
Significance	NS	NS	NS		NS/*	FC	*/**		NS/*		NS
						Gyp	NS				
						Interaction	NS				

to respond to gypsum application in some of the trials. This was especially so at high rates of applied gypsum. It is interesting to note that trial S6-23, where no response could be found, was the only one where sodicity in the topsoil was not a problem. This suggests that gypsum improved yield only when sodicity occurred in the topsoil.

Root studies showed that, despite improvement in subsoil sodicity, effective rooting depth in the plots associated with high rates of gypsum was no better than in the control plots, indicating that sodium was not the only unfavourable factor in the subsoil.

Filtercake was found to improve cane yield but to depress cane quality. Sucrose yield was therefore used to assess the response of yield to treatments. The results in Table 5 show that statistically significant responses were obtained in every trial. However, the means mask the fact that the responses were seasonally variable. Sustained yield reponses were obtained in trial S6-25. It is of interest that the response to filtercake was sustained in the trial where the soil conditions were the least favourable. Root studies in the filtercake trials showed that effective rooting depth was not increased by the application of filtercake, suggesting that the benefit obtained was exclusively due to amelioration of the topsoil.

Deep ploughing tended to improve cane yield, whereas its effect on quality was found to differ between trials S3-1 and S6-9. The results of S3-1 showed that, although already apparent in the plant crop, the benefit of the treatment became significant in the ratoon crops. Rooting studies in trial S6-9 showed that deep ploughing increased effective rooting depth from 50 cm in the control to 70 cm in the treatment. This result indicates that deep ploughing effectively ameliorates the subsoil.

Discussion

The decision whether to apply gypsum at Ricelands is made solely on the need to rectify conditions which lead to hydraulic conductivity failure. This is because the value of 6 used as the baseline SAR threshold for duplex soils is that derived by Johnston (1975) in his study on the effect of sodium on hydraulic conductivity. In this work the experimental design was such that the soil surface was left undisturbed, whereas in measuring the effect of sodium on infiltration rate, surface disturbance needs to be considered.

At Ricelands, more than a decade of combined drainage and gypsum application have reduced salinity in the soil profile and sodicity in the topsoil to levels which, while safe for cane growth and compatible with the maintenance of hydraulic conductivity, are apparently inadequate for maintaining original infiltration rates. This is suggested by the fact that surface crusts are observed. In order to address the problem of declining infiltration rate the critical SAR for the duplex topsoil might have to be amended to include crusting hazards.

Other aspects of soil amelioration which might need modification are the method used to estimate the gypsum requirement and the placement of gypsum in soil. At present the requirment is based on the amount of calcium needed to exchange the excess sodium. Considerable effort is expended on ensuring that the gypsum is well incorporated into the soil. While valid in situations where sodium content is high (SAR >6), this approach can be wasteful at low sodium contents, because calcium tends to exchange for magnesium rather than sodium (Chaudhry and Warkenten, 1968) and potassium. At low sodium contents the detrimental effect of sodicity on crusting is best counteracted by ensuring that water entering the soil has a sufficiently high concentration of electrolyte to prevent dispersion (Agassi *et al.*, 1981). This can be best achieved by spreading (phospho)gypsum at the surface of the soil (Shainberg *et al.*, 1982).

Although sodium content in the topsoil at Ricelands tends to be low, the occurrence of sodicity in the subsoil remains widespread. Reclamation, using the commercial rate of 5t gypsum /ha will at best be slow. Although higher rates can successfully improve subsoil sodicity, the evidence suggests that removal of sodium alone is insufficient to stimulate root development. Also, removing sodium alone, although a necessary condition for flocculating dispersed clay, is in itself not sufficient to cause aggregation. The latter process requires biological, mechanical and weathering (drying cycle) actions which, while possible in the plough layer, are lacking in the subsoil. To address the problem of sub-soil sodicity, a combination of gypsum application and deep ploughing may be necessary. The result of the experiment conducted at S6-9 indicates that the increase of salts and sodium content in the plough layer was not detrimental to the yield of the plant cane, while the results of trial S3-1 confirmed that, with time, the sodicity status of the profile improved overall. Besides indirectly promoting improvement in sodicity, deep ploughing enhances the aggregating process by bringing the subsoil to the surface. It also benefits yield, in the short term at least, by stimulating root development in the subsoil.

Filtercake as a source of calcium can be used as a substitute for gypsum to alleviate topsoil sodicity. It is apparent, however, that filtercake also acts on some of the other limitations of the duplex soils and can be used advantageously in a non-sodic situation where soil strength and porosity, for instance, are limiting. The residual effect of filtercake suggests that the improvement in bulk density, infiltration rate and water holding capacity observed is not the result of the increase in organic matter *per se*, but rather that of its indirect effect in stabilising structure.

Conclusion

These results raise questions about certain aspects of IYSIS's current gypsum policy and proposed changes have been submitted for consideration. Some of the more pressing aspects requiring further scrutiny include the establishment of the sodium content thresholds and electrolyte concentrations at which crusting occurs, and the investigation of the residual effect of deep ploughing and of its practice on a commercial field scale.

Acknowledgements

The authors would like to acknowledge the contributions of Messrs Nick Burns, Jon Peet and Bruce Lankford, Agronomists at IYSIS, for initiating, collecting and processing data during the 1980-1991 period of the soil amelioration research programme, the assistance of Cable Dlamini, Supervisor at IYSIS, and his team of Agronomy Recorders in carrying out the trial operations and the helpful advice given by Mr Rod Ellis, Field Manager at IYSIS, during the preparation of this paper.

REFERENCES

Anon (1991). Soil Classification Working Group. *Soil classification. A taxonomic system for South Africa.* Dept Agricultural Development, Pretoria.

Agassi, M, Shainberg, I and Morin, J (1981). Effect of electrolyte concentration and soil sodicity on infiltration rate and crust formation. *Soil Sci Am J* 45: 848-851.

Chaudhry, GH and Warkenten, BP (1968). Studies on exchange of sodium from soils by leaching with calcium sulfate. *Soil Sci* 105: 190-197.

Dewey, FJ and Meyer, JH. (1989). The use of phosphogypsum as an ameliorant for poorly structured crust-forming soils. *Proc S Afr Sug Technol Ass* 63: 147-152.

Dracup, M, Belford, RK and Gregory, PJ (1992). Constraints to root growth of wheat and lupin crops in duplex soils. *Aust J Exp Agric* 32: 947-61.

Fox, WE (1964). A study of bulk density and water in a swelling soil. *Soil Sci* 98: 307-316.

Frenkel, H and Fey, MV (1989). Rate of dissolution of gypsum from different sources and its effect on water infiltration rate. *S Afr J Plant Soil* 6 (3): 191-196.

Jayawardane, NS and Blackwell, J (1986). Effects of gypsum-slotting on infiltration rates and moisture storage in a swelling clay soil. *Soil use and mangement*, Vol. 2(3): 114-118.

Johnston, MA (1973). Physical properties of sugar belt soils with particular reference to moisture release characteristics. *Proc S Afr Sug Technol Ass* 47: 115-119.

Johnston, MA (1975). The effects of different levels of exchangeable sodium on soil hydraulic conductivity. *Proc S Afr Sug Technol Ass* 49: 142-147.

Johnston, MA (1977). Reclamation of a saline sodic soil in the Nkwalini valley. *Proc S Afr Sug Technol Ass* 51: 42-46.

McAndrew, DW and Malhi, SS (1990). Long-term effect of deep plowing solonetzic soil on chemical characteristics and crop yield. *Can J Soil Sci* 70: 565-570.

McFarlane, DJ and Cox, JW (1992). Management of excess water on duplex soil. *Aust J Exp Agric* 32: 857-864.

Meyer, JH, van Antwerpen, R, Henry, PC and Leibbrandt, N (1992). Improved cane yield from vertical mulching under rainfed and irrigated conditions. *Proc S Afr Sug Technol Ass* 66: 89-94.

Murdoch, G (1972). *Soils and land capability in Swaziland.* Swaziland Ministry of Agiculture.

Mullins, CE, MacLeod, DA, Northcote, KH, Tisdall, JM and Young, IM (1990). Hardsetting soils: behaviour, occurence and management. *Adv Soil Sci* 11: 37-108.

Ndlovu, DJ (1993). Effects of furrow irrigation methods on water application and the growth of sugarcane on unstable soils in Swaziland. Unpub MSc thesis, Univ Natal, Pietermaritzburg.

Rasmussen, WW, Moore, DP and Alban, LA (1972). Improvement of a solonetzic (slick spot) soil by deep plowing, subsoiling and amendments. *Proc Soil Sci Soc Am* 36: 137-142.

Shainberg, I, Keren, R and Frenkel, H (1982). Response of sodic soils to gypsum and calcium chloride. *Soil Sci Soc Am J* 46: 113-117.

Workman, M, Scott, PM and Nixon, DJ (1986). A review of the management and amelioration of saline/sodic soils at Mhlume (Swaziland) Sugar Company. *Proc S Afr Sug Technol Ass* 60: 162-167.