AN EVALUATION OF THE SUITABILITY OF SOILS FOR MOLE DRAINAGE IN THE SOUTH AFRICAN SUGAR INDUSTRY

By F. J. DEWEY, J. H. MEYER and J. A. GEORGE

South African Sugar Association Experiment Station, Private Bag X02, Mount Edgecombe 4300

Abstract

In the South African sugar industry it is important that relatively inexpensive but viable drainage systems are developed for those soils which have a low hydraulic conductivity. From the results of field and laboratory investigations conducted during the past five years it appears that the use of unlined mole channels as an alternative for, or a supplement to conventional subsurface drainage, could be considered. Mole drainage is more successful in the heavy Rensburg and Willowbrook soil forms than in the variable duplex soils such as those of the Kroonstad and Longlands forms. The factors of slope, antecedent and current soil moisture content, soil bulk density, and soil type are important in determining the success of the installation and performance of a mole drainage system. Various guidelines are outlined for the use of mole drainage in the sugar industry.

Introduction

Poor sugarcane yields can result from a combination of adverse conditions of which moisture stress during drought, and poor drainage during wet periods, are among the most serious. In South Africa, Gosnell[3] showed how yield was affected when cane was grown in containers in which the watertables were maintained at depths of 250, 500, 750, 1 000 and 1 250 mm. In comparison with the yields obtained when the watertables were maintained at 750, 1 000 and 1 250 mm below the soil surface, yields were reduced by about 35 % when the watertable was maintained at 500 mm, and 63 % where the watertable was at 250 mm. This indicated that high watertables were detrimental to cane yields.

During the past two decades there has been a growing awareness of the need to improve cane yield and quality and growers have requested advice from the Experiment Station on the drainage of areas prone to waterlogging. Significant success has been achieved by growers in controlling wet conditions with efficient surface water management and conventional slotted plastic pipes as subsurface drains. However, in soils such as those of the Rensburg, Willowbrook, Longlands and Katspruit forms, low hydraulic conductivities result in slow internal drainage of the subsoil horizons. Under these conditions, the required drain spacing of less than 20 m cannot be economically justified. Mole drainage has been extensively used in the United Kingdom and Europe to control perched watertables in heavy soils and these successes stimulated research into its potential use in the South African sugar industry.

The successful application of mole drainage depends on the creation of a stable unlined cavity or channel at depths as great as 700 mm. Many attempts have been made to identify the soil characteristics required for successful mole drainage (Rycroft and Alcock;[7] Spoor;[9] Trafford and Massey[11]). Important properties that were assessed included texture, aggregate stability on wetting (Child[2]), clay mineralogy, and antecedent soil moisture. How applicable these findings are to vertic and duplex soils in South Africa is not known. A co-ordinated programme of field and laboratory research was therefore initiated at the Experiment Station in 1980. This paper is an interim report on some of the results obtained and outlines the soil conditions required for successful mole drainage in the sugar industry.

Experimental Procedure

Description of trial sites

Five field trials are being conducted to study the effectiveness and longevity of mole drainage in two different soil groups: the grey hydromorphic soils and the heavy black cracking clays. The characteristics and soil properties of the selected sites are given in Table 1. Details of trials are presented in Table 2. Descriptions of the representative soil profiles are given in Appendix I.

Grey hydromorphic soils: these soils are represented by the Katspruit, Longlands, Westleigh and Kroonstad forms and are derived mainly from Dwyka tillite, Middle Ecca sandstone, and Table Mountain sandstone (TMS) (ordinary) parent materials. Collectively these soil forms comprise about 15 % of the area under cane in South Africa and they are frequently associated with poor and uneven cane growth due to the poor soil physical properties such as low water intake rate, slow internal drainage, and the development of brak conditions in the subsoil.

Two observational trials were established on the Experiment Station farm at Mtunzini on sites on which cane production had been abandoned due to a history of poor and

Table 1

Properties of the soil forms at the various field sites

Site no	Location	Dominant soil form	Depth of impervious horizon (mm)	Physical analysis			Chemical analysis			
				Clay (%)	Fine sand (%)	Medium + coarse sand (%)	CEC of soil (me 100 g^{-1})	pH	EC (mS m^{-1})	SAR
1	Mtunzini	Katspruit	300	22	69	9	10	7,1	187	7,4
2	Mtunzini	Longlands	450–700	26	38	36	9	5,8	49	3,4
3	La Mercy	Rensburg	450	63	30	7	28	6,7	87	7,9
4	La Mercy	Willowbrook	450	47	45	8	22	6,3	101	6,2
5	Umhlali	Willowbrook	450	48	47	5	20	6,1	72	4,7

Table 2

Details of trial design

Site no	Trial started	Treatments	Cane varieties	Trial design	Plot size (m²)	Mole spacing (m)	Mole density (No 100 m⁻²)	Mole depth (mm)
1	1981	Subsurface	NCo 376	Non-randomised	224,0	-	-	-
		Moles* + gypsum	N11, N8	(2 replicates)	216,0	1,5	9,3	350
		Moles* (M)		(2 replicates)	216,0	1,5	9,3	350
2	1981	Control	NCo 376	Non-randomised	98,4	-	-	-
		Moles*	N7, N8	(7 replicates)	98,4	2,0	5,0	450
		M* + filtercake	N11, N12		98,4	2,0	5,0	450
		M* + gypsum	N13, N14		98,4	2,0	5,0	450
3	1981	Control	NCo 376	Randomised	270,0	-	-	-
		Moles*		(4 replicates)	270,0	1,5	2,0	600
	1985	Control	NCo 376	(4 replicates)	270,0	-	-	-
		Moles#			270,0	1,5	2,0	600
4	1981	Control	NCo 376	Non-randomised	2 100,0	-	-	-
		Moles*		(5 replicates)	2 100,0	3,0	1,2	300
	1986	Control	NCo 376	(5 replicates)	2 100,0	-	-	-
		Moles#			2 100,0	3,0	1,2	300
5	1986	Control	N12	Randomised	156,0	-	-	-
		Moles#		(9 replicates)	156,0	2,6	2,0	400

* Mounted mole plough
\# Trailed mole plough

uneven cane growth. Site 1 was located on a sodic Katspruit form soil, with a moderate clay content of 22 % and a high percentage of fine sand (69 %). The combined percentage of medium and coarse sand was fairly low (9%), and the 300 mm depth of the impervious gleyed horizon was within the range of the mole plough.

The cation exchange capacity (CEC) of 10 me 100 g^{-1} soil suggested that the clay complex was dominated by kaolinitic clay with secondary illitic clays also present. These 1 : 1 lattice clays have a moderate to low adsorptive capacity, and are resistant to shrinking and swelling under changing moisture conditions (Buckman and Brady[1]). Mole drains, with and without gypsum (3 t ha^{-1}) applied to the topsoil, were compared with an adjacent subsurface drainage treatment. The mole drains were installed at a spacing of 1,5 m, and a depth of 500 mm which was about 100 mm into the gleyed subsoil. The subsurface pipe drains were installed at a spacing of 20 m and at a depth of 1,2 m, which was within the gleyed layer. As a precaution to prevent surface water collecting on the trial site, a cut-off drain was installed before the trial was started.

In the second trial at Mtunzini, the soils comprised mainly the Longlands and Westleigh forms, with a slightly higher percentage of clay (26 %) and less fine sand (38 %) than the Katspruit form. However, the combined medium and coarse sand fraction (36 %) was much higher, reducing the possible success of a mole drainage operation. The depth of the heavier subsoil layer was variable being between 450 and 700 mm and this resulted in many of the mole drains being pulled through the eluviated sandy E horizon. The probability of the moles collapsing prematurely on this site was therefore high. The CEC value of 9 me 100 g^{-1} soil and the pH value of 5,8 also indicated a clay complex dominated by kaolinitic 1 : 1 lattice clay minerals. Mole drains were tested with and without ameliorants (gypsum broadcast at 3 t ha^{-1} and filtercake in the furrow at 50 t ha^{-1}) in conjuction with 7 cane varieties which were superimposed on split plots of the main treatments. Because the mole channels subsided repeatedly, the trial was discontinued after two crops had been harvested.

Heavy black clays: this category is represented by the Rensburg, Willowbrook and Bonheim form soils which are derived mainly from dolerite and Lower and Middle Ecca shales. Unlike the grey hydromorphic soils these soils, which represent about 8 % of the area under cane in the sugarbelt, are strongly structured with more than 50 % clay. Initially, trials on a Rensburg form soil were established at two sites on the Experiment Station's La Mercy farm. The impervious subsoil horizons were within 450 mm of the surface, which was within reach of the mole plough and, due to a perched watertable, were moist enough to ensure a smooth strong channel. The CEC values, for the soil from Sites 3, 4 and 5 were 28, 22, 20 me 100 g^{-1} soil respectively, and the pH values were also similar. This indicated that montmorillonitic clays dominated in these soils, the 2 : 1 lattice clay type being highly plastic, susceptible to shrinking and swelling, highly dispersive in the presence of sodium, and having a high adsorptive capacity.

In all trials, plots with and without (control) mole drains were compared in terms of changes in the heights of the watertable and the salinity/sodicity levels to a depth of 900 mm. The trials differed slightly in that the trial at Site 3 had mole drains installed 1,5 m apart, 400 mm deep, with cane rows at right-angles to mole direction, while in the trial at Site 4, the mole drains were drawn at 2 m spacings, 400 mm deep, but parallel to the cane rows. The area was very wet at the time of installation, and water flowed rapidly from most of the mole drains, drying the profile in a short time. The trial at Site 3 was discontinued after the first ratoon crop due to the installation of a water supply pipeline. However, this trial has been recently re-established using a wider mole spacing of 3 m and a deeper moling depth of 600 mm. The fifth trial has been established on a soil of the Willowbrook form in a poorly drained valley bottom on a farm in the Umhlali area. Mole drains were drawn at a depth of about 450 mm, with a spacing of 2,6 m (every alternate interrow). In all of the trials, the outlets of the mole channels into the open drain were sleeved with lengths of metal or PVC piping for protection against bank erosion.

Description and operation of the mole plough

With the exception of Site 5, the mole channels were initially formed using a mounted plough. This required a graded soil surface before the channels could be drawn to minimise any undulations in the mole channels. The implement used more recently for making the channels is a mole plough (Figure 1) which is trailed rather than mounted behind the tractor. This has the advantage of less vertical movement due to an ungraded surface and results in a more uniform and constant grade of the mole channel. The trailed mole plough consists of a boom mounted on wheels which are hydraulically controlled. An adjustable shank with three or four depth positions is attached to the end of the boom, the bottom being torpedo-like in shape. This section creates the initial shape of the drain. Attached to the 'torpedo' by means of a short chain is the expander plug, which has a slightly larger diameter giving the mole channel a diameter of about 90 mm. The expander compresses and smooths the wall of the mole channel and removes any lumps of soil falling into the channel. This minimises the chances of premature silting up or collapse. Mole drains are more successful if pulled up the slope away from the main drain, and mole drains which are pulled at a greater depth appear to last longer, providing the gradient, length of pull, soil moisture content, and soil type are satisfactory.

Field and laboratory measurements: several field and laboratory measurements were conducted in all trials to assess the performance of mole drains and to see whether there were any correlations between the life of a mole channel and various soil characteristics with time. The various analyses and measurements are given in Table 3.

Table 3

Summary of field and laboratory measurements

Field	Laboratory
1. Yield and height measurement	1. Particle size analysis
2. Watertable height readings	2. Sodicity/salinity analysis
3. Hydraulic conductivity using piezometers	3. Clay mineralogical identification using CEC values
4. Mole channel inspections & visual ratings	4. Soil stability tests: (a) Child's (b) Dispersion index (c) Linear shrinkage (d) Air-water permeability ratio
	5. Permeameter measurements for hydraulic conductivity
	6. Drainage water analyses

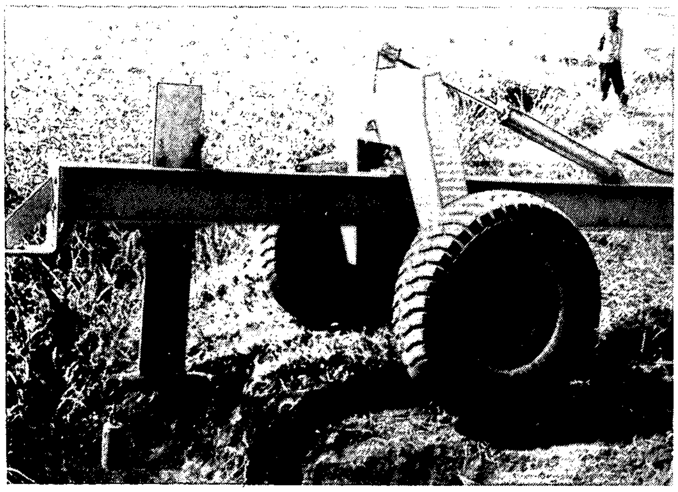


FIGURE 1 Trailed mole plough.

Standard salinity and sodicity measurements were conducted on soil samples from three depths (0 to 300 mm, 300 to 600 mm, and 600 to 900 mm) to determine how effective mole drains were in removing salts from the soil profile. Dipwells were installed at several of the trial sites to monitor the effects of mole drains in lowering perched watertables and also to estimate hydraulic conductivity. Observations of the mole channel in the field were made to determine the amount of drain collapse, to assess the longevity of mole channels and to ascertain the mechanisms which contributed to their failure, such as the collapse of the walls and silting up. The amount of channel collapse was rated according to a six-point scale using the following:

Rating	Description
1	Mole channel intact - no signs of collapse
2	Mole channel intact - first signs of collapse evident
3	First stage of collapse - silt and clay deposits in channel bottom
4	Partial collapse - bottom of channel largely blocked
5	Almost complete collapse - mole channel blocked, unable to function
6	Complete collapse - channel totally collapsed or silted up, remoling necessary

Mole channel ratings were carried out 2, 6 and 9 months after the mole drains were installed at Sites 2, 3 and 4. These ratings were correlated where possible with laboratory results where particle size analysis, dispersion indices, electrical conductivity (EC) and sodium adsorption ratio (SAR) values, CEC and various stability measurements were compared.

Results and Discussion

Field observations

Effect of mole drains on yield: yield data obtained from the various trials have in general shown no large responses to mole drains. A comparison of yield data from the plots with mole drainage versus plots with conventional drainage at Mtunzini (Site 1, Table 4) showed that, on average over five crops, the conventionally drained treatment was slightly better (73 tc ha^{-1} a^{-1}) than the mole drainage treatment (64 tc ha^{-1} a^{-1}). This suggests that mole drains were comparatively effective in coping with a soil moisture build-up. However, where gypsum was incorporated into the topsoil, yields from the plots with mole drains tended to be slightly better than from those plots under conventional drainage in the third and fourth ratoon crops.

Table 4

A summary of yield data for plant and four ratoon crops at Site 1, Mtunzini

Crop	Subsurface drains		Mole drains			
			No gypsum		Gypsum	
	tc ha^{-1}	ts ha^{-1}	tc ha^{-1}	ts ha^{-1}	tc ha^{-1}	ts ha^{-1}
Plant	79,0	9,9	69,0	8,6	79,0	10,8
1R	72,0	7,4	45,0	3,4	67,0	6,1
2R	82,0	10,0	78,0	9,2	67,0	10,9
3R	59,0	7,6	57,0	7,4	72,0	9,8
4R	74,0	9,2	71,0	9,3	88,0	11,6
Average	73,0	8,8	64,0	7,6	76,0	10,0

At site 2, Mtunzini, treatment with mole drains in the plant crop yielded on average 6 tc ha^{-1} (1,2 ts ha^{-1}) more than the control plots despite the collapsing of the mole drains and silt blockages in most plots. Re-drawing the mole drains produced no beneficial effects on yield in the first and second ratoon crops. Pit inspections showed that the mole drains had collapsed within 6 months of being drawn. In many of the plots, the mole drains had been drawn through a sandy eluviated horizon which was very unstable, and had a low clay content. The subsurface gley layer was deeper than the effective mole channel depth of 450 mm.

At both trials on the Rensburg and Willowbrook form soils at La Mercy, mole drainage showed no beneficial effect on cane yield even during the relatively wet 1983/84 season. The trial at Umhlali has only recently been established, and has not yet been harvested.

Measurements of watertable height: the regular monitoring of watertable heights in 30 dipwells located throughout Site 4 at La Mercy, showed that there were no consistent differences in height between the plots with mole drainage and the control plots from February 1983 to July 1984. For most of this period, the watertable remained below 600 mm indicating that the soil profile was adequately drained. Although there were fluctuations with rainfall, no dramatic rise or fall in the height of the watertable was noticed, probably due to the very low intake rate and hydraulic conductivity of this heavy soil. The lowest watertable height measurements occurred after the hot dry months when it reached a depth of 1 200 mm. However, after good rains in November 1983 and February 1984, the plots with mole drainage showed slightly lower watertable levels than the control plots. This can probably be attributed to the mole drains removing drainage water from the profile before it reached the watertable. For the period October to December 1983 and between February and July 1984, the watertable levels of the mole drainage plots were 100 mm lower than those in the control plots.

Internal drainage in this soil is very slow, hydraulic conductivities between 0,04 and 2,5 m d^{-1} being recorded in six different plots. With such low hydraulic conductivities, it was felt that mole drains with a spacing of 2 m should be tested. An open drain was also found to be effective in improving the internal drainage up to a distance of about 10 m from the drain.

Ratings of mole drainage in relation to soil properties: inspection pits were used to monitor mole channels and they have shown a complete collapse of mole drains in soil forms with an E horizon or soft plinthite layer within 500 mm of the surface (Table 5). Mole drains tend to have a greater longevity in the Rensburg form soil on Site 4 at La Mercy as indicated by ratings between 1 and 3. However, at Site 3 on the same soil form mole channels were less stable, probably due to the dispersive effect of a higher sodium concentration. Samples taken in the vicinity of the collapsed mole drains were generally associated with soils having a clay content less than 30 %. Regression analysis based on 34 mole channel observations and on a range of soil forms, confirmed that mole channel longevity was significantly correlated with clay content ($r^2 = 0,432$). However, this correlation did not apply to clays where the SAR values were greater than 6 for the grey soil group and 10 for the black soil group. Mole channel life also appeared to be limited in clays with more than 20 % coarse sand. Regression analysis has also indicated that mole channel life is inversely related to SAR values and the dispersion index. Premature collapse in soils with a disperion index below 20 did not occur. This observation was supported by the old mole channels at La Mercy, Site 4, which were drawn 3 years before inspection, and were still functioning although the diameter of the drains was much smaller than the original size.

Child's test appeared to be the most acceptable method for measuring mole channel life. This test involves different wetting rates on sieved soil fractions. An index of soil stability on wetting may be obtained by comparing the moisture characteristic curves of the crumbs after two wetting cycles. Soils that are structurally very stable, are associated with index values that tend towards one, whereas unstable soils tend towards zero. A disadvantage of the test is that it is time-consuming. Neither the Emerson nor the air-water permeability tests appeared to show any correlation with mole channel stability.

Laboratory observations

Effect of mole drains in removing salts from the soil profile: in the Katspruit form soil at Site 1, EC values for both mole drainage (without gypsum) and subsurface drainage plots showed a similar trend (Figure 2).

Table 5

Comparison of mole channel ratings from selected trial sites

Locality	Site no	Soil form	Mole channel		Texture			Stability measurements				
			Observation time (mths)	Rating	Coarse sand %	Fine sand %	Clay %	EC (mS m^{-1})	SAR	CEC	Dispersion index	Child's test
Mtunzini	1	Katspruit	2	6	9	73	18	140	8,8	12	42	0,67
	2	Longlands	2	6	14	40	12	30	2,5	8	34	0,57
La Mercy	3	Rensburg	2	4	7	46	47	282	10,4	24	25	0,67
			6	4	7	42	51	327	10,8	32	19	0,72
			9	5	9	41	50	297	9,5	27	25	0,71
La Mercy	4	Rensburg	2	1	18	39	43	66	4,8	23	14	0,76
			6	1	15	46	39	79	5,5	24	12	0,73
			9	3	18	45	37	87	6,2	21	17	0,78
		Willowbrook	2	5	26	50	24	100	5,2	17	18	–
			6	6	29	54	17	105	7,5	15	21	0,82
			9	6	30	53	17	95	5,7	14	24	–

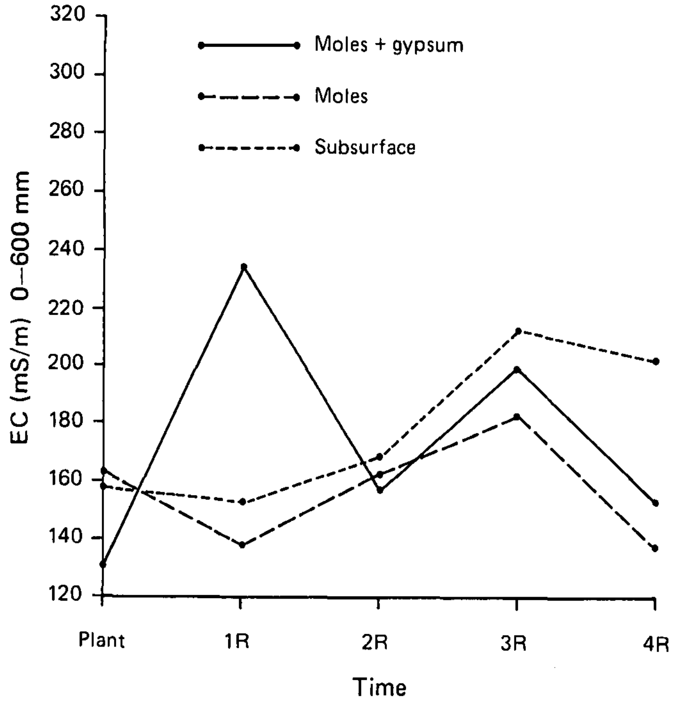


FIGURE 2 Changes in soil EC values with time at Mtunzini Site 1.

In all crops, the plots with mole drainage had EC values below the threshold value of 200 mS m^{-1}, while the plots with subsurface drainage had EC values slightly above this in both the third and fourth ratoon (211 and 201 mS m^{-1} respectively). This build-up in salinity could be attributed to blockages within the subsurface pipes due to silting up within the inspection boxes. On plots where gypsum had been applied, EC values initially peaked due to the dissolution of the gypsum during the first year of application (235 mS m^{-1}) but once the gypsum had leached into the subsoil layers, the EC values dropped to below 200 mS m^{-1}, a condition which continued into the fourth ratoon. The analysis of water flowing from mole drain outlets also confirmed that salts had been flushed from the soil profile. Sodicity (SAR) values for Site 1 indicated that the areas served by mole drains coped as well as those areas with subsurface drains in removing sodium ions from the soil profile and in preventing further increases in sodicity. SAR values were on average 1,1 units lower for plots with mole drains (Figure 3).

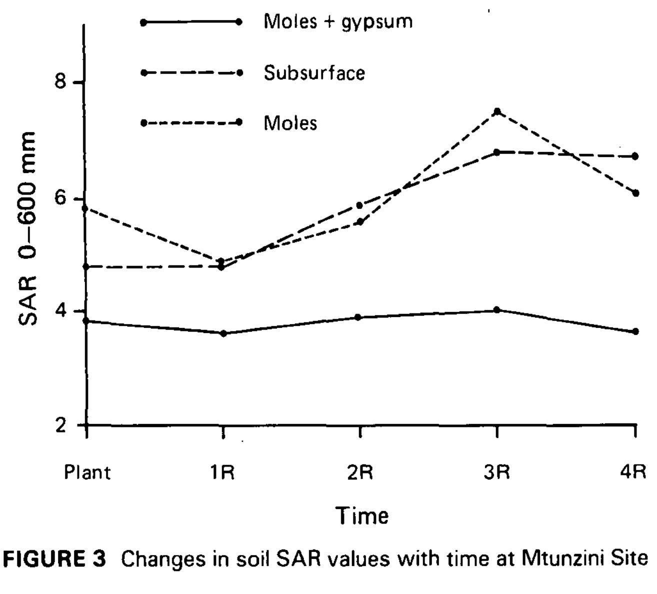


FIGURE 3 Changes in soil SAR values with time at Mtunzini Site 1.

Both treatments on Site 1 showed an increase in SAR values above the threshold value of 6 during the third and fourth ratoons. After the fourth ratoon was harvested it was found that all the mole drains had collapsed which resulted in a gradual build-up of sodicity. This also occurred in three of the inspection boxes in the subsurface drained area, and there was a build-up of moisture within the profile. The plots where both mole drains and gypsum were used showed the lowest SAR values (average of 4) which were below the critical value. These values may have been due to the ameliorating effect of the gypsum. These plots also showed the greatest increases in yield, which indicated that better growing conditions had been achieved in these plots. In the Longlands form soil at Site 2, there were no marked differences between EC and SAR values for all the crops, which indicated that the mole drains were not functioning, thus neither the salinity nor the sodicity status was lowered in these plots.

Heavy black soils: for Sites 3, 4 and 5 the SAR values of the mole drainage plots were generally lower than those of the control plots, although with increasing deterioration at Site 3 during 1984, values tended to become similar to those of the control plots. Sites 3 and 5 had EC and SAR values well below the threshold values, but Site 4 exhibited a slight sodicity hazard which would enhance the dispersiveness of this Willowbrook soil form.

Interim guidelines for recommending mole drains

Moisture: both antecedent soil moisture as well as the soil moisture content at the depth of the mole drain are important (Nicholson[5]). The current working figure is about 50 mm soil moisture deficit in the topsoil at the time of moling in order to promote shattering and fissuring. This condition also ensures that the soil at the depth of the mole drain is within the plastic range or just below field capacity. This condition can be estimated in the field by taking a soil sample at the depth of the mole drain and attempting to roll it into a thread about 2 mm in diameter. If this is possible, the soil is within the plastic range.

Depth of mole drains: the soil should be compressed at depth while shattering the soil in the upper layers (Hudson and Hopewell;[4] Nicholson[5]). The mole foot must be well within the heavier clay layer. With duplex soils, the mole channel must be pulled through the heavier subsoil layer, and be well below any sandy eluviated or impervious plinthic layer. These two conditions can cause problems in any attempted mole drain operation, and such soils should be individually assessed. Mole drains are usually drawn at a depth between 450 and 600 mm, penetrating the plastic illuviated horizon.

Structural stability and clay content: soils in which mole drains are established should have a clay content between 30 % (lower limit) (Rycroft and Alcock[7]) and 55 % (upper limit) and the clay fraction should be mainly of the 2 : 1 lattice clay type (Spoor[8]). Mole drains in soils with less than 30 % clay will tend to collapse, due to the high sand fraction, and particularly if the sand fraction is mostly medium to coarse grained. Above 60 % clay, swelling and shrinking may cause the drain to collapse because in the dry periods, cracks up to 25 mm wide may result in sediment inwash to the mole channel and subsequent blockage, or the channel wall may collapse completely on swelling (Nicholson[5]). Soils should be structurally stable, non-dispersive, non-sodic, and with a moderate degree of swelling.

Slope: a slope of about 1 % is considered ideal. If the gradient is less than 1 %, mole drains are considered to be unreliable, and a gradient greater than 5 % will result in a high velocity of drainage water, erosion of the walls, and therefore premature collapse (Hudson and Hopewell;[4] Szabo and

Szekrenyi[10]). Mole drains must always be drawn uphill because the smeared and compacted clay walls are more stable as water flowing down will tend to flatten the dried flakes rather than causing a peeling effect.

Mole drain spacing and length: more difficult soils will require and benefit from spacings as close as 1,5 m while wider spacings can be used in less difficult soils. A maximum spacing is about 3 m because beyond this, the mole channel is not likely to drain the whole profile adequately. Closer spacing of the drains gives quicker 'drawdown' and will result in a more effective control of the watertable. The length of a mole drain depends mainly on the stability of the soil, 80 m being the recommended length on stable soils, and 40 m on the poorer soils (Rycroft[6]).

Cost and frequency: the cost of mole drainage will depend on the draught of the implement and the type of tractor used for installation, but it is less than 10 % of the cost of subsurface pipe drainage, and it is considered to be the cheapest form of drainage available. It is important to redraw mole drains before the existing system breaks down completely, and it is suggested that the operation be carried out after each crop if moisture requirements are satisfactory. The expected life of mole drains can only be determined in each individual case, but redrawing the mole drains is more important, in terms of cost and time, for maintaining their effectiveness than is adding new drains. It is thus common practice to redraw mole drains on a portion of the land for each crop if conditions are suitable, even though they may last 4 or 5 years (Spoor[6]).

Outlets: the mole channel outlets into main drains should be protected from blockage and erosion of the drain bank by the use of short plastic or asbestos sleeving (about 0,5 m long). The outlets should be covered with wire mesh to prevent animals venturing into the channels.

Mole channel ratings: recommendations with regard to the various criteria defining the stages of mole channel collapse have been revised to suit local conditions, and to eliminate confusion between stages which may be difficult to assess in the field. The modified ratings are given as follows and some of the stages are illustrated in Figure 4:

(i) Mole channel intact – no signs of collapse
(ii) Mole channel intact – root penetration within the channel
(iii) Mole channel intact – signs of cracking within the channel walls
(iv) First stage of collapse – particles of clay, sand or silt on channel bottom, mole channel begins to move up the profile
(v) Second stage of collapse – the mole channel has moved above the original position of the tube and remoling is necessary
(vi) Channel completely collapsed

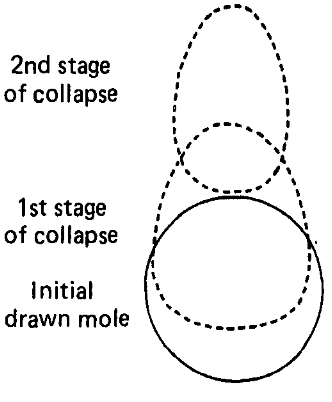


FIGURE 4 Changes in mole drain deterioration.

Conclusions

Mole drainage is an inexpensive, viable system which can be successfully used for lowering perched watertables in black and some of the grey problem soils. Mole drains can also be used as a supplement to increase the efficiency of traditional drainage systems. The criteria used for rating mole channels in the field are useful as a comparative tool and for assessing the longevity of channels in various soils, but they need to be adjusted to suit local conditions. Various laboratory measurements are valuable as a means of establishing the merits of using mole drains on different soils and to indicate their suitability for the operation. Particle size distribution, particularly clay and sand content, and timing of the operation, are critical both for soil stability and for the success of mole drain installation.

Mole drainage is satisfactory in heavy soils, particularly the Rensburg and Willowbrook form soils with SAR values below 10. For Katspruit form soils, mole drainage appears to be useful if the clay content is above 30 % and SAR values are below 6. Results for grey hydromorphic soils are, as yet, inconclusive but there appears to be little benefit from mole drains in Longlands/Kroonstad form soils. Further work within the grey soil group is necessary, particularly as it is this category which is the most problematic in the South African sugar industry. Furthermore, the economic advantages of this type of drainage system cannot be overlooked at a time when costs of drainage installations are rising and demands for increased productivity in the industry are high.

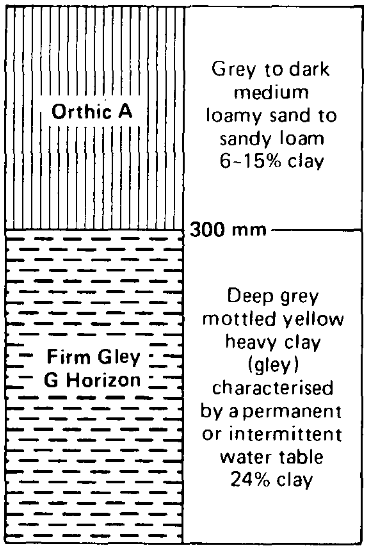
Acknowledgements

The authors gratefully acknowledge the contribution of Mr V Dorasamy both in the field and the laboratory; of Mr J Swinford who compiled much of the background information: and of Messrs I Macfadyen and B Worlock for their assistance with the field trials.

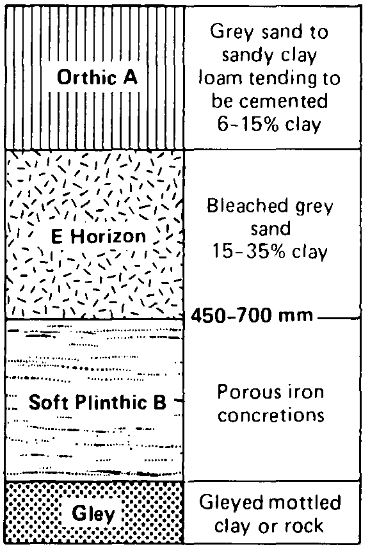
REFERENCES

1. Buckman, HO and Brady, NC (1969). *The nature and properties of soils.* Macmillan Co, Canada.
2. Child, EC (1942). Stability of clay soils. *Soil Science* 53: 79–92.
3. Gosnell, JM (1971). Some effects of watertable level on the growth of sugarcane. *Proc int Soc Sug Cane Technol* 14: 841–849.
4. Hudson, AW and Hopewell, HG (1940). *Mole drainage in New Zealand.* Massey Agric Coll, New Zealand. Bulletin No 11.
5. Nicholson, HH (1934). The durability of mole drains. *J Agric Sci* 24, Part 2: 185–191.
6. Rycroft, DW (1972). Review of the literature on mole drainage. *FDEU Tech Bull* 72/10 MAFF.
7. Rycroft, DW and Alcock, M (1974). The assessment of suitability of soils for moling. *FDEU Tech Bull* 74/1.
8. Spoor, G (1974). Improving heavy subsoils – making the most of present knowledge and techniques. MAFF Conference on improving Heavy Subsoils. NAC Stoneleigh.
9. Spoor, G, Leeds-Harrison, PB and Godwin, RJ (1982). Some fundamental aspects of the formation, stability and failure of mole drainage channels. *J Soil Sci* 33: 427–441.
10. Szabo, L and Szekrenyi, B (1971). Problems arising from the draining of heavy soils and the introduction of measures to improve the functioning of drainage systems. *FAD Drainage and Irrigation Paper* No 6 : 23.
11. Trafford, BD and Massey, W (1975). A design philosophy for heavy soils. Tech Bull 75/5. Field drainage Exp Unit, Cambridge.

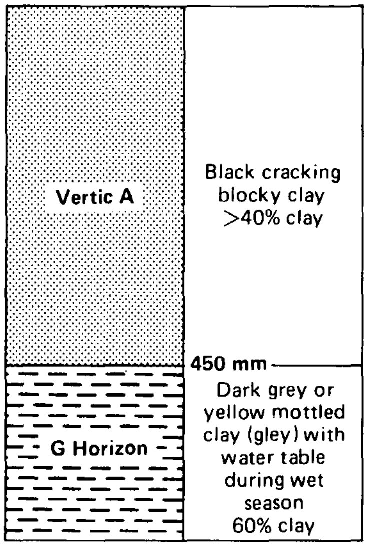
SITE 1
KATSPRUIT FORM – Ka



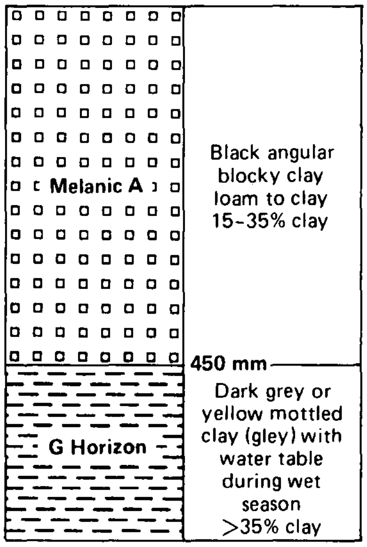
SITE 2
LONGLANDS FORM – Lo



SITE 3
RENSBURG FORM – Rg



SITE 4
WILLOWBROOK FORM – Wo



SITE 5
WILLOWBROOK FORM – Wo