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THE USE OF A SAND ENVELOPE FOR SUBSURFACE DRAINAGE WITHIN THE SOUTH AFRICAN SUGAR INDUSTRY

By F. J. DEWEY and J. A. GEORGE

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

Abstract

Sand envelopes have often been used in conjunction with conventional subsurface pipes to improve the drainage of soils in the sugar industry. The expense and effort required to implement these are only justified if this practice results in significantly improved drainage, and it was therefore important to establish whether a sand envelope is effective in all soils. Four observation trials were established on soils with widely differing textures and were used to compare cane yield, drain outflow, and hydraulic conductivity, where subsurface drains were installed with and without sand envelopes. The sand envelopes were found to result in more effective drainage irrespective of soil type although it is clear that in some soils a sand envelope is not needed to lower the watertable.

Introduction

Effective drainage is necessary on many of the poorly structured soils found in the sugar industry. Waterlogging, due to topography or soil characteristics, is detrimental to cane growth. In order to use available land profitably in the sugar industry, consideration of drainage has become essential.

However, many of the soils requiring drainage lack structural stability and this can lead to sedimentation within pipe drains, resulting in failure of the system. This fault may only become apparent after installation, and it is likely that many systems already installed are functioning below their design capability. For this reason, it is important to be able to predict whether a given soil is likely to cause sedimentation and to provide guidelines for a suitable envelope material. Of the materials available, sand was considered to be the most practical and efficient.

The main reasons for using an envelope material are to prevent sealing-off, root blockage, silting-up, and to prevent the accumulation of ferrous oxides within subsurface pipes. All these factors lead to inadequate functioning of the drain, and thus the removal of excess water from the soil profile is hindered. In addition, the high cost of installing drains is wasted if drainage is not effective.

Theoretical background

The most important functions of a porous envelope material such as sand are:

- the **connector** function
- the **hydraulic** function
- the **filter** function.

The connector function (more applicable to conditions in the United Kingdom) refers to deep sand envelopes above pipe drains connected to a mole drainage system. This type of installation is not widely used in South Africa due to the limitations placed on mole drainage by the dry climate and, in some areas, the high cost of clean sand (Johnston[2]). In soils with a shallow permeable topsoil and a deep impermeable subsoil, the envelope material is necessary to connect the topsoil to the drain and thus prevent the pipe becoming sealed-off within the subsoil (Steinhardt *et al.*[9]).

The hydraulic function is fulfilled if the envelope material improves water movement from the soil to the perforations or slots in the pipe. Flow lines within the soil gradually converge on the perforation, causing a bottleneck effect and creating resistance to flow. By improving the hydraulic gradient in the vicinity of the pipe, the inflow resistance is reduced, and effective drainage increased (Trafford[11]).

The filter function is perhaps the most important function of a sand envelope. The envelope material is required to prevent the movement of soil particles into the pipe, yet maintain a permeable layer about it so as not to impede the movement of water through it. Under saturated conditions, a soil particle achieves a buoyancy which enables it to be transported. The speed at which soil particles are transported increases nearer to a perforation, but decreases after entry. This loss in flow velocity to below a critical value results in a decrease in the carrying capacity of water (Morisawa[6]) and the particle is deposited. It is this action which the envelope material helps to prevent.

Sedimentation is a function of particle size distribution, and therefore an analysis of particle size distribution is considered the best indicator of the need for filtration. Soils with a high proportion of fine sand particles, between 0,05 and 0,12 mm diameter, present the greatest difficulty (Trafford;[11] Stuyt[10]). This is particularly so if more than 80% of particles fall into this size range (McAuliffe[5]). One would expect smaller sized particles such as clay particles to be those most easily moved. However, their colloidal nature causes these particles to join to form stable aggregates, and thus follow the behaviour of large particles, requiring a greater water velocity for entrainment (Nelson[7]). Soils with a high risk of sedimentation are those that are weakly structured, sandy textured, and in which a high watertable is likely to occur.

There are characteristics other than particle size distribution which affect sedimentation. Particle shape appears to affect the stability of the soil, in that rounded particles such as those of wind-blown sands are less stable than angular sand particles. Particle density influences how easily they are flushed from the pipe once deposited, ie those of low density are more easily removed. Hydraulic conductivity and gradient determine the velocity of water flow and thus the tendency to cause soil erosion. The uniformity of particle size distribution is also important because a soil of uniform particle size throughout, such as the Fernwood sand, needs a filter more than a heavier soil, particularly if the majority of particles fall into the fine sand range (McAuliffe[5]). It has been stated that a filter is not required in soils with a clay content above 30%, due to the development of structure and the stability of colloidal peds (Nelson[7]). However, it is possible that these soils will require an envelope for the hydraulic function, ie where hydraulic conductivities around the pipe are very low, causing resistance to flow.

The criteria for filter material have been researched by many workers (Bertram;[1] Karpoff;[3] Pillsbury[8]) in order to select those materials which provide good filtration and high permeability. The upper and lower limits of grading curves, based on the proportions of various particle sizes, were used to assess the suitability of local river sands.

Experimental procedure

Four observation trials were conducted between 1978 and 1987 to monitor the efficacy of sand envelopes in different soil types. A description of representative soil profiles at the various sites is given in Appendix I. All sites had severe drainage problems and a history of poor crop growth. For example, during the period 1978 to 1981, increasingly poor growth occurred at the Nevann Ridge and Clifton sites, with valley bottom areas becoming completely waterlogged and no cane being harvested from them. Conservation works and drains were installed in 1982. None of the sites had a salinity or sodicity problem.

The trials were located on widely differing soil forms and details of locality and soil characteristics are shown in Table 1. The designs of the trials were similar in that drain spacing (20 m) and depth (1,1 m) were uniform. They were made of slotted PVC pipes, 50 mm in diameter, and with slots 1 mm wide. The treatments were lateral drains without sand envelopes and lateral drains with sand envelopes. (Where a sand envelope was installed, a 150 mm thick layer surrounded the pipes, following standard Experiment Station specifications. Where a sand envelope was not used, the same specifications regarding grading and levelling were used, without a sand fill. The trench was backfilled with disturbed soil). An example of the drain design used is given in Appendix II.

Table 1

Details of trials

Site	Soil form	No of drains	Hydraulic conductivity (mean of 4 cores) ($m\ d^{-1}$) at 600 mm
Clifton	Cartref	4 with sand 4 no sand	0,114
Nevann Ridge	Rensburg	9 with sand 6 no sand	0,022
Windy Ridge	Cartref	10 with sand 6 no sand	0,110
La Mercy	Kroonstad	3 with sand 3 no sand	0,073

The sites for the trials provided an opportunity to compare soils with different particle sizes as well as different hydraulic conductivities. Apart from yield and sample harvests, various measurements were carried out at each site. These included soil particle size analysis, flow readings from inspection boxes and drain outlets, and hydraulic conductivity measurements, determined in the laboratory on undisturbed soil cores. Drain rodding and inspections were made to assess the degree of blockage, root development, and the general functioning of the drains.

Results and discussion

Yield results

The effects of drainage at Nevann Ridge were shown by considerably improved yields with an average increase of about 70% after drainage had been installed and when rainfall was either normal or well above average. At Clifton, the trend was similar and yield approximately doubled after drain installation. These marked improvements in yield indicated that the drains had created better growing conditions for cane.

An effect of the sand envelope around individual drains is shown by differences in yield at Clifton, the only site at which sample harvesting was possible. The results of the sample harvesting indicated that the yields from rows of cane harvested from plots with drains and a sand envelope were approximately 30% higher than those from plots with drains but no sand envelope. This suggests that the profile was being drained more efficiently with a sand envelope than without one, thus reducing the period over which cane roots were subjected to high watertable levels.

Discharge measurements

On the occasions when flow was observed at 3 of the trial sites (Table 2), it was interesting to note that the rates of water outflow from drains with sand envelopes was generally higher than from those without envelopes (twice as fast for the Rensburg soil form and almost 5 times as fast for the Kroonstad). This was so in the case of a soil which required the hydraulic function to be fulfilled, ie the heavy Rensburg form soil, and also when the filter function was needed, ie the Kroonstad form soil in which the drains were highly susceptible to blockage due to the high fine sand fraction. Both these soil forms have hydraulic conductivities below the critical value of 0,1 $m\ d^{-1}$ regarded by many workers as the value below which a drain spacing of less than 10 m would be necessary. However, the drain spacing of 20 m at these sites appeared to result in relatively good cane growth. It is thus possible that the critical threshold value could be reduced for the South African sugar industry, particularly since we usually have an annual soil moisture deficit, compared with a soil moisture surplus in other parts of the world.

Table 2

Comparison of flow measurements (ml sec^{-1}) at 3 sites

Site	With sand envelope	No sand envelope
Nevann Ridge	90 (mean of 10)	42 (mean of 6)
La Mercy	29 (mean of 3)	6 (mean of 3)
Clifton	46 (mean of 5)	49 (mean of 8)

At the Cartref soil form sites, neither the hydraulic nor filter functions appeared to be important, presumably because there was an evenly distributed soil particle size. The hydraulic conductivity of these soils is relatively high (Table 1), and thus the movement of water through the soil and into the pipe was probably fast enough to entrain and remove any particles previously deposited.

Sand envelope characteristics

Particle size analyses were conducted on samples of material taken adjacent to excavated pipes in pits that were opened to permit inspections to be made (Table 3). At all sites, the envelope material (with sand) had a more balanced particle size distribution than did the indigenous soil (no sand). The fine sand fraction was always lower, and the medium and coarse sand fractions were greater in the envelope materials thus reducing the likelihood of drain blockage. This was particularly true for the Kroonstad form soil at La Mercy, where the fine sand fraction formed the major proportion of the particles. At all the sites the sand envelopes appeared to reduce blockages because they improved hydraulic conductivity in the vicinity of the drains.

Table 3

Analyses of particle sizes within drain vicinity

Site	Trial	Clay (%)	Silt (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)	Tendency of soil to cause blockages
La Mercy	With sand No sand	1 7	2 4	10 66	36 22	51 1	Moderate to high
Windy Ridge	With sand No sand	9 6	6 1	21 32	53 58	11 10	Low to moderate
Clifton Sugar Co	With sand No sand	9 14	6 9	17 31	40 37	28 9	Low to moderate
Nevann Ridge	With sand No sand	31 48	5 8	12 24	22 17	30 3	Low

The grading curves of 3 local, commonly used sands from the Umgeni, Umdloti and Pongola rivers were compared to assess their suitability as envelope materials according to the criteria outlined by the USDA Soil Conservation Service.[12] Figure 1 shows that these sands had similar grading curves, the Pongola sand being slightly coarser than the others and its particle size distribution closest to the USDA lower limit. Since slots in plastic pipes are currently 1 mm wide, these sands would satisfy the criteria for suitable envelope material. However, if slots were larger than 1 mm, the Umgeni and Umdloti sands would be too fine and would not satisfy USDA requirements. It is possible that the limits applicable in other countries may be too severe since considerably improved drainage was obtained using local sands.

Grading curves for the 3 soil forms represented in the project are shown in Figures 2 to 4.

The grading curve for the Rensburg form soil (Figure 2) indicated that it had a high clay content and an even distribution of the sand fractions. With such a particle size distribution, the colloidal nature of the clay would result in little threat of blockage in such a soil. It would appear that the benefit from the filter function of a sand envelope would be small, and greater benefit would be derived from improved hydraulic conductivity in the vicinity of the pipe.

The grading curves for the Cartref form soils (Figure 3) at the two sites were similar. The A and E horizons consisted of fairly high fine sand fractions and less than 20% clay. There was a distinct lack of structure in these horizons, increasing the likelihood of drain blockage. The lower limits of particle size distribution determined by the USDA Soil Conservation Service and that of the Pongola sand are included in Figure 3. The Umgeni and Umdloti sands (Figure 1) appeared to be too fine to be suitable filters.

The Kroonstad form soil appeared to have the greatest need for a filter envelope. The grading curve (Figure 4) showed a very uneven distribution of the sand fractions, with the majority (about 70%) of particles being in the fine sand fraction, the size most likely to cause blockages. With drains installed in the heavy subsoil, the hydraulic function is most important. Some filtering occurred because the fine sand fraction in one drain envelope increased from 10% (original sand material) to 14% within 6 years of installation. Clay and silt fractions increased by only 1,5%, indicating that these particles were not easily entrained. A possible reason for the limited filtering function within the envelope could be that the Umdloti sand (Figure 4) was too fine to filter the Kroonstad form soil lying below the USDA limit, but could still be satisfactory in improving hydraulic conductivity.

While inspecting and rodding the drains at each site it was observed that drains with a sand envelope were less susceptible to ferrous oxide development, although some accumulations were still found at the pipe outlets. There was less root penetration into the envelope zone, and into the pipes for reasons which are still unclear. Where an envelope was employed, silting-up also appeared to be delayed, possibly due to the more rapid movement of drainage water which was therefore able to remove particles from the pipe.

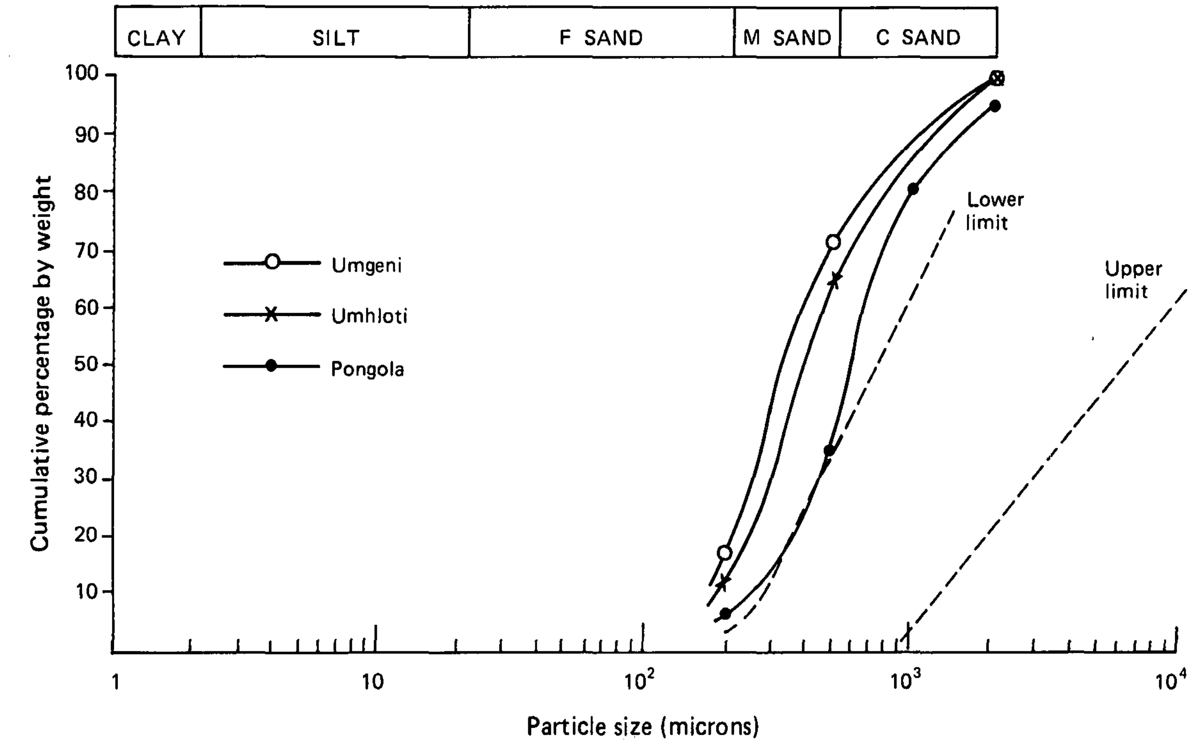

FIGURE 1 Grading curves for 3 river sands.

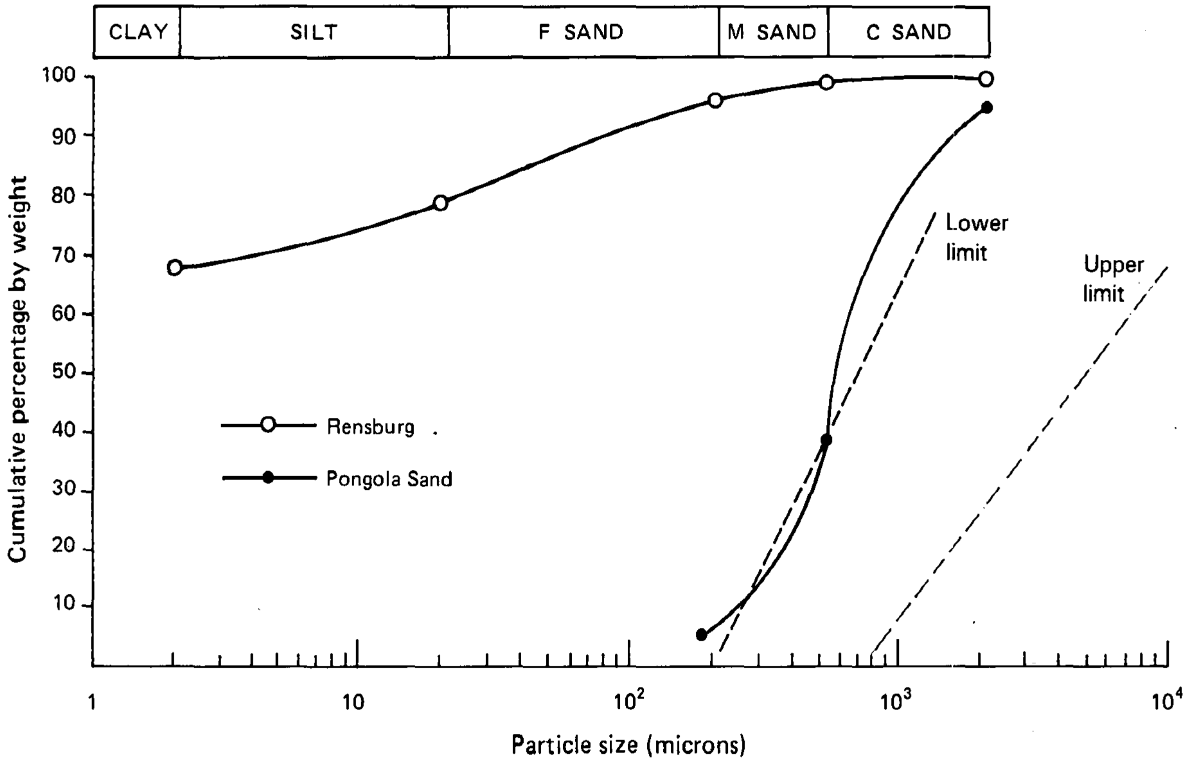

FIGURE 2 Grading curve for the Rensburg form soil.

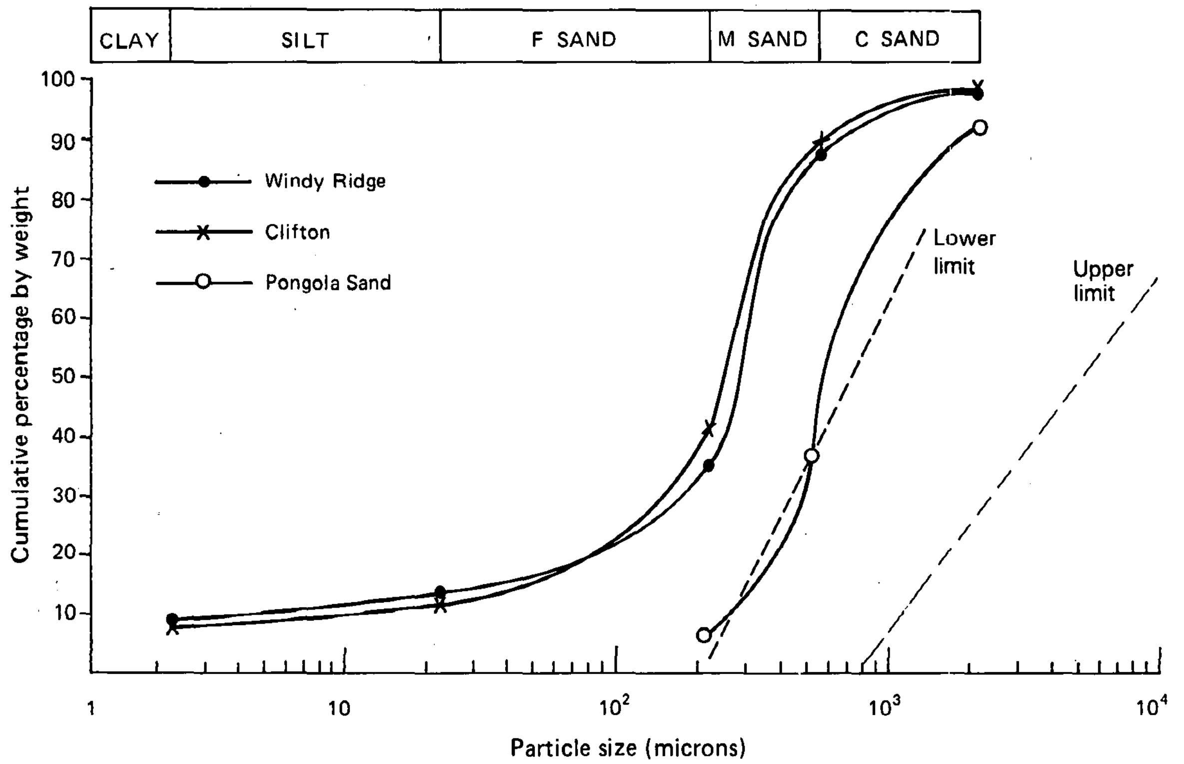

FIGURE 3 Grading curves for the Cartref form soils with boundaries indicated for suitable filter material.

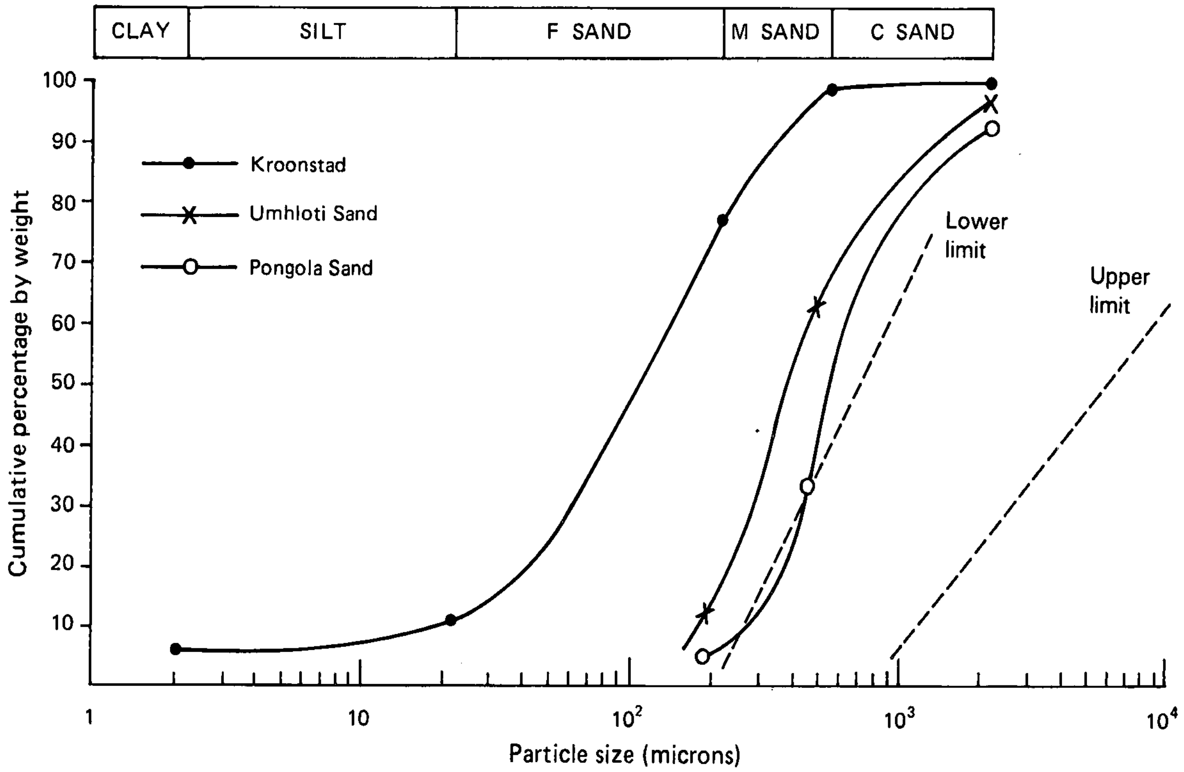

FIGURE 4 Grading curves for the Kroonstad form soil with boundaries indicated for suitable filter material.

Summary and recommendations

In all cases, drains surrounded by a sand envelope appeared to be more efficient and the envelope appeared to prolong drain life. Although a sand envelope would improve drainage in most cases, the expense is considerable and a significant average increase in yield would be required to cover the costs, ie although an envelope is never detrimental, there are some soils in which the installation of an envelope may not be economically warranted. This is a distinction which needs to be made before recommending a sand envelope. It is thus necessary to specify the soils in which the envelope is most likely to be cost-effective.

It has been suggested that soils with a clay content of less than 30% require a sand envelope (Knops and Zuidema[4]). This appears to be an acceptable criterion if the filter function alone is considered. However, where a higher clay content results in moderate to strong blocky structure, eg at Nevann Ridge, the envelope appears to improve drainage due to the hydraulic and connector functions. This is shown by improved flow measurements from drains with a sand envelope. Thus, soils with clay contents higher than 30%, particularly in the subsoil, require an envelope to ensure higher hydraulic conductivity within the vicinity of the drain, and to connect an impermeable subsoil to the topsoil and prevent sealing-off.

In the South African context, it is those soils with a high fine sand fraction which appear to be the most likely to require a filter. Of the soils examined, the Kroonstad form soil at La Mercy appeared to be the one in which drain blockages were most likely to occur, due to the high fine sand fraction (more than 65%). The E horizon of this soil form directly overlies a heavy subsoil which is prone to waterlogging. As the E horizon has less than 15% clay and the dominant fraction is fine sand, this soil is very prone to cause blockages in drains. Fine sand particles migrate into the drain vicinity, particularly after backfilling with disturbed soil. In this soil root development and ferrous oxide formation in the pipe appeared to be greater where a sand envelope was not employed. The Cartref form soils at Clifton and Windy Ridge caused only a moderate degree of blockage in the drain pipes, due to the lower fine sand content and an increase in the medium and coarse sand fractions.

Medium and coarse sand particles tend to lodge across pipe slots and are too large to enter the pipe. Other soils likely to respond to a sand envelope are the swelling black clays with vertic or melanic A horizons, and gleyed subsoils, such as those found in the Willowbrook and Bonheim form soils. A tentative guide to the response of various soil forms based on particle size, to the use of a sand envelope is given in Table 4.

Table 4

Tentative guide to the response of various soil forms to a sand envelope

<table>
<tr><td rowspan="3">Soil form</td><td colspan="3">Predominantly filter function</td></tr>
<tr><td colspan="3">Fine sand fraction</td></tr>
<tr><td>>50%</td><td>20–50%</td><td><20%</td></tr>
<tr><td>Fernwood
Kroonstad
Longlands
Westleigh
Katspruit
Estcourt
Cartref</td><td>Good</td><td>Moderate</td><td>Poor</td></tr>
<tr><td rowspan="3"></td><td colspan="3">Predominantly hydraulic and connector function</td></tr>
<tr><td colspan="3">Clay content</td></tr>
<tr><td>>35%</td><td colspan="2"><35%</td></tr>
<tr><td>Rensburg
Willowbrook
Bonheim
Tambamkulu</td><td>Good</td><td colspan="2">Moderate</td></tr>
</table>

Conclusion

Subsurface drainage is expensive. If river sand is readily available at a low cost, it is recommended that sand envelopes be used for all soils.

Where availability of sand or cost is a limiting factor, soil form and more particularly particle size distribution should be used as the criterion. If sand is not required and is installed, it constitutes an unnecessary expense. If the sand is required and is not installed, it could result in the even greater expense of having to lift and re-lay the drains.

Acknowledgements

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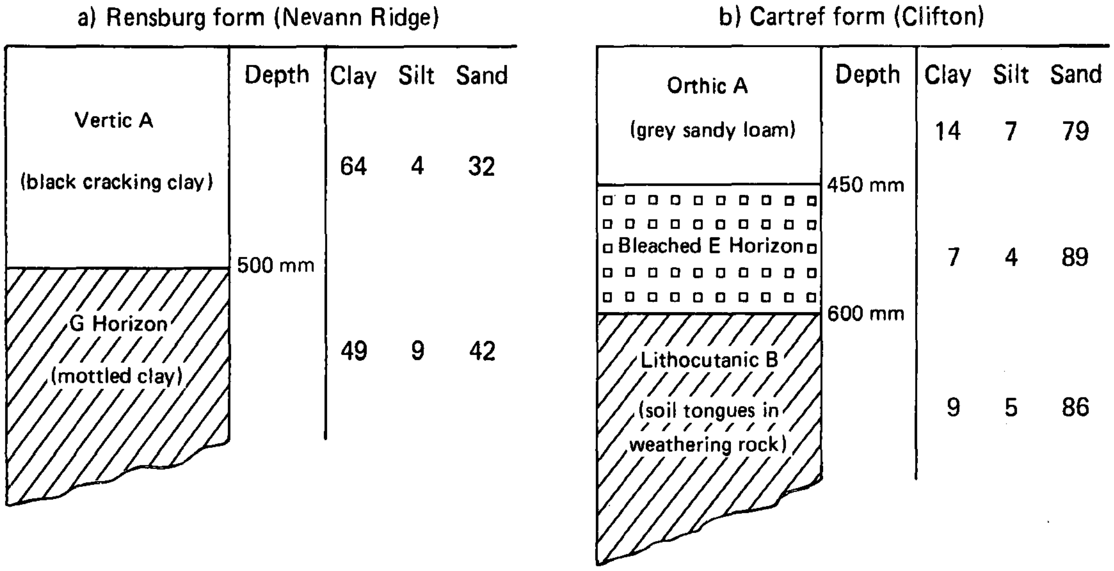
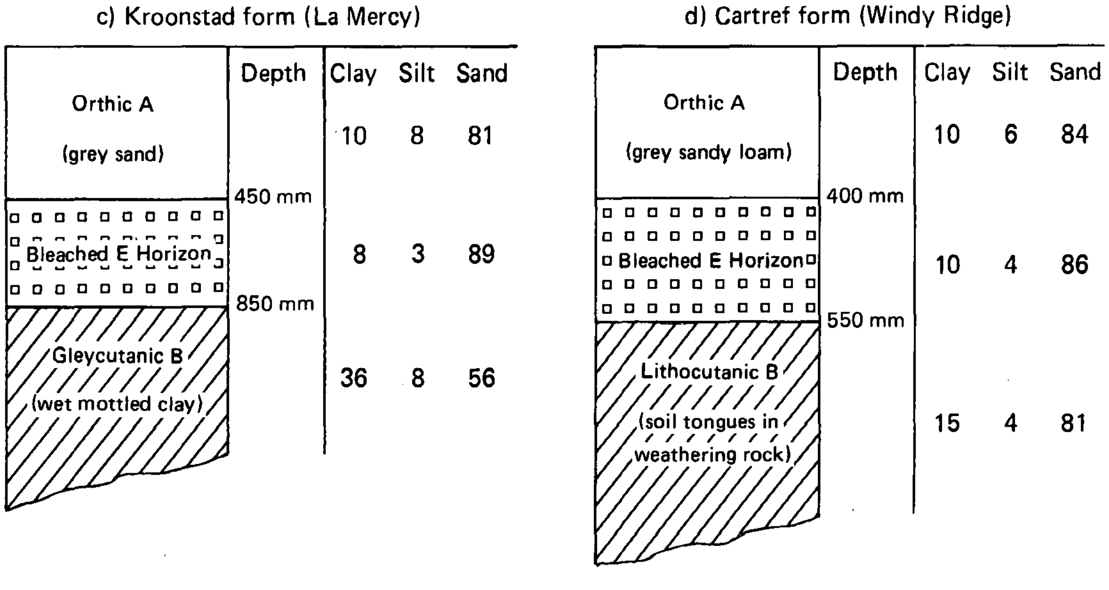
APPENDIX I

Representative soil profiles and textural analyses at the four sites



a) Rensburg form (Nevann Ridge)

b) Cartref form (Clifton)

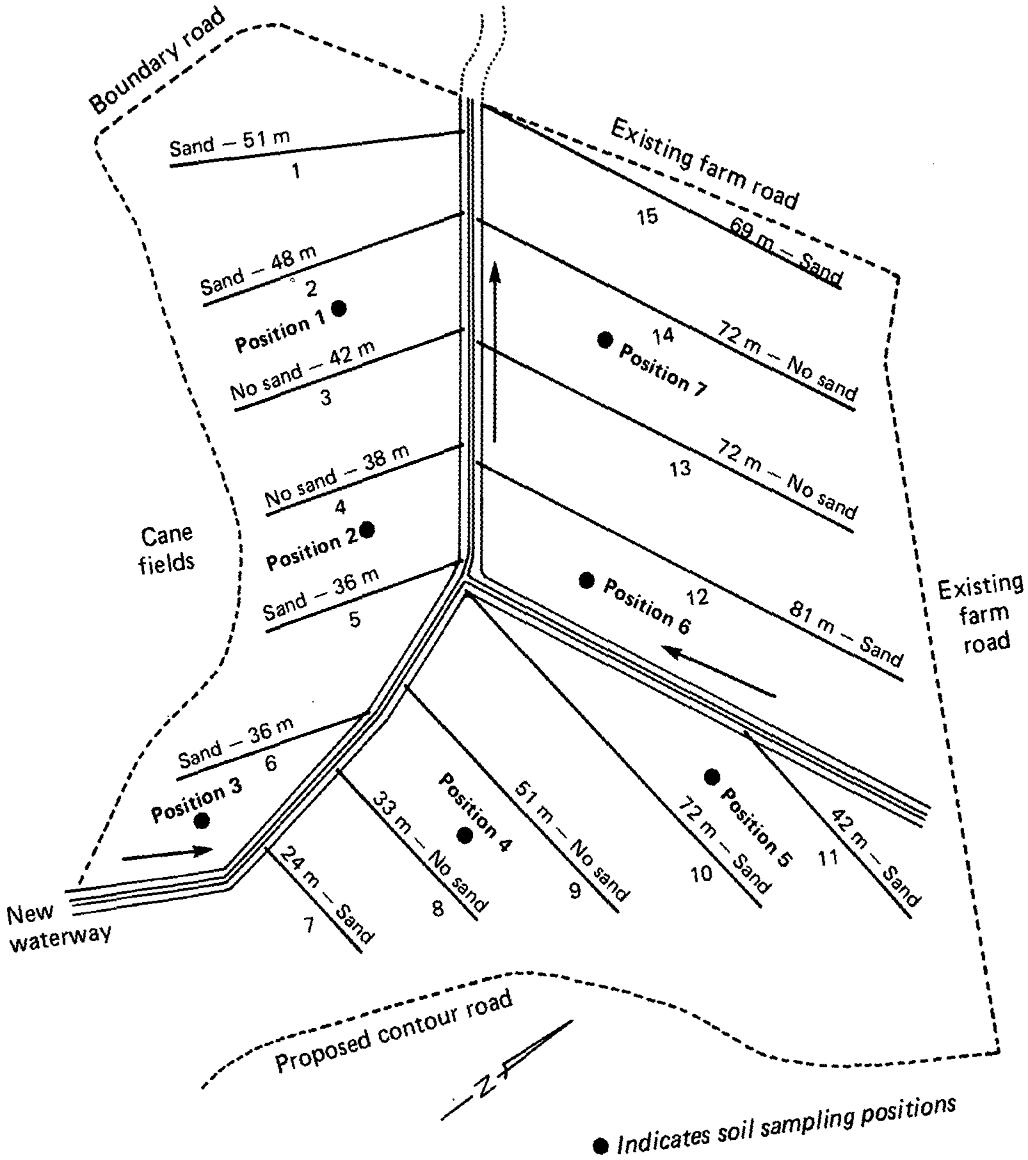


c) Kroonstad form (La Mercy)

d) Cartref form (Windy Ridge)

APPENDIX II

Trial layout at Nevann Ridge



● *Indicates soil sampling positions*